

EVALUATING BICYCLISTS COMFORT AND SAFETY PERCEPTION

JAIN, Himani, Project Scientist TRIPP and Research Scholar, Civil, Indian Institute of Technology Delhi, India, himani.iit@gmail.com

TIWARI, Geetam, Associate Professor, Civil Department, Indian Institute of Technology Delhi, India, geetamt@gmail.com

ZUIDGEEST, Mark, Assistant Professor, Geo-Information Science and Earth Observation (ITC), University of Twente, The Netherlands, zuidgeest@itc.nl

ABSTRACT

Perception of safety and comfort of bicycle infrastructure is an important factor influencing the use of bicycles. Cyclists can be found all over India. In urban areas presently, mostly captive riders choose to bicycle as no other viable options of travel are available to them. This study discusses perceptions of these captive riders as compared to a group of not yet riding (potential) cyclists. A stated preference survey to estimate the perception of captive users and potential users on cycling was conducted.

The perception of risk among captive riders and potential riders does not show much difference as against popular beliefs. Both the captive users as well as the potential users focus on physical safety and the difficulties in crossing the intersections. Differences arise in perception of comfort / attractiveness and barriers. Pedestrians / bus commuters waiting at the curb side lane are considered as predominant barriers (about 28%) by potential users while captive riders are more tolerant to them. Results indicate that perception of safety and comfort are not related to age, gender, type of zone and distance travelled. However, the presence of informal sector on the street side is social security element and attractive for providing services for captive cyclists. The potential users consider informal sector as a barrier, although, lighting seems to be important to them. Results of SP experiment shows potential users perceive slope as bigger threat to bicycle compatibility as compared to captive riders. Captive riders prefer wider roads against the narrow roads preferred by potential cyclists. Land use mix seems to be not a major concern, while low density areas are preferred. The results can be used for evaluating area bicycle compatibility both for captive and potential users.

Keywords: Safety, Captive bicycle users, Potential users, comfort, barriers, India

BICYCLE IN THE INDIAN CONTEXT

Bicycle is an important commuting mode for poor urban workers and students in Indian cities. It is an important means of mobility particularly for short trips in medium and large Indian cities. Bicycle use varies from 7-15% in very large cities (above 5 million populations). The

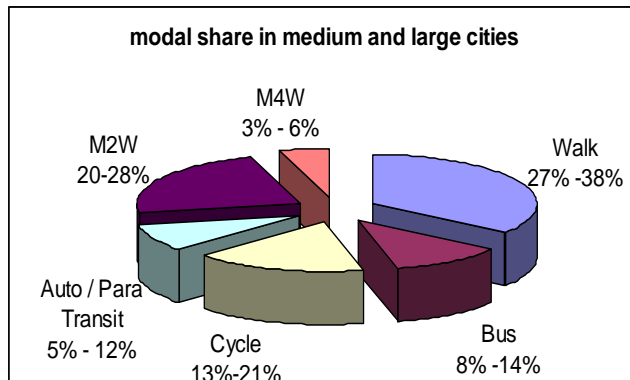


Figure 1 - Approximate modal share in medium and large cities in India (Source: Tiwari and Jain 2008)

medium (1-3 million) and larger (3-5 million) cities have a typical bicycle modal share of 13%-21%. (Figure1) Cycle trips might be as low as 7-10% in mega cities, however the absolute numbers are still large in comparison to many European cities. (TIWARI AND JAIN, 2008). However, contrary to most European cities the majority of them are captive riders i.e they use bicycle

because other modes cannot be used for financial constraints or non availability of preferred mode.

The high ownership levels of bicycles, its low cost and easy use make it a desirable mode of transport for students and low income workers. A large amount of utility cycling is present in Indian cities because the bicycles are the most affordable and only form of transport available to low income households. The subsidized public transport also remains cost prohibitive to them (SINGH 1997; TIWARI 2002).

The time trend analysis in various cities shows a sharp decline in bicycle trip share during the 80's and 90's. During this period all these cities experienced a high growth rate of motorized vehicles, road infrastructure improvements (primarily road widening and construction of grade separated junctions). The dedicated infrastructure for bicycling is not present in any city as a network.

Bicyclists face a high risk of getting involved in fatal traffic crash. It is observed that cyclists are involved in 5% to 10% of total road related fatalities in medium and large cities. About 20% to 32% cyclists are involved in crashes leading to severe injuries to bicycle users. (NCRB, 2001-06).

However despite the lack of safe infrastructure, high risk of fatal crashes and lack of favourable policies for cycling, bicycle trips have not disappeared completely. In Mumbai and Delhi the two largest cities in India, at least 6-12% trips are on bicycles. (WILBER SMITH, 2008; MPD-2021, 2006) Bicycle is the only mode of transport which enables them to access employment; therefore despite unsafe infrastructure and hostile traffic conditions on the road they have to use bicycle. As the household income grows these bicycle riders upgrade themselves to bus or motorized two wheelers.

BICYCLES USERS

The bicycle offers riders speed and flexibility over short distances. It is the fastest mode of transport for short trips because it does not involve access and egress trips. It is also accessible to many people who cannot drive, especially the young. It is observed that college students in many American and European countries cycle at much higher rates than the general population (PUCHER et. al., 2007). Data from Indian cities shows two main groups of bicycle users: the captive users and the potential users.

Captive users

Income plays a significant role in influencing transportation choices people have. Where there is extensive poverty in Indian cities, it is most important to ensure that the modes used by the poor continue to remain available as safe travel options. Although walking costs nothing, it takes a lot of time for all but very short trips. Cycling often offers four or five times greater speed and is cheaper than public transport. Irrespective of city size, the poor continue to be dependent on non-motorized transport modes for mobility in many Asian cities. (REPLOGLE, 1991)

Some people are forced to depend on only a specific vehicle because their choice sets are constrained, i.e. they have no other alternative to choose from or their preferred alternative is out of their acceptable financial means. The limitations on their choice set may arise from their own abilities (e.g. their ability to operate other vehicles or their ability to afford the cost of using another vehicle) or from environmental conditions (e.g. the lack of a public transportation service). Such travellers are regarded as having structural dependences on a vehicle, and they are called “captive riders” of that vehicle. (WALLE AND STEENBERGHEN, 2006) In Indian cities this is true for most cyclists; they are often poor people living in slums, travelling longer than walk-able distances. Hence, in the present study, captivity is defined by financial constraints especially applicable to low income workers and students.

Travel patterns of low income group living in informal housing or slums are very different from residents in formal housing. Generally, cycling and walking account for 50 to 75 percent of the commuter trips for those in the informal sector. Their socio-economic conditions are such, that they do not own any other motorized vehicles. Even the highly subsidized public transport services remain non affordable to them (>12% of their income). They are forced to ride bicycles for long distances in high speed mix traffic. The bicycles are essential for access to their employment. They are means for survival to them and also important for poverty alleviation. This captive group takes high risk, generally takes the shortest path and to them factors of safety and comfort are relatively less important.

Hence it is important to understand the needs of these captive riders. With this understanding it is possible to create better bicycle infrastructure and facilities that cater for the direct and shortest possible routes between their major origins and destinations thus enabling safe access to employment.

Potential Users

There is, also a group of people who would like to cycle and could be persuaded to cycle under the right circumstances. (GATERSLEBEN AND APPLETON, 2007). A large number of students continue to use bicycles in small and medium size cities in India. However in large cities a substantial number of students commute to school by bus or other motorized vehicles even for short distances. Potential bicycle users in the present study are young students and workers owning a bicycle and who travel short distances (less than 6 km) and are currently using motorized modes. These groups might use bicycle if safe and comfortable travelling conditions prevail. For example, many parents do not allow their children to cycle to school because safe segregated cycle paths are rare. (TRIPP, 2006) Most of the available literature from western context targets student population, who could not afford a car, travels shorter distances and who do not like to rely on infrequent - uncomfortable public transport. (MNELLER et. al., 2008) While the focus in available literature has been on possible modal shifts, little has been researched on user behaviour, perception and needs of a typical low income country city, where there is a great potential for cycling.

High ownership of bicycles and predominance of short trips in Indian cities offer conducive conditions for bicycles. In medium size cities, 35% - 65% households own one or more bicycles whereas in the smaller cities, it varies between 33% – 48%.(CENSUS OF INDIA, 2001), Despite the high ownership of bicycles in urban areas in India, the typical modal share in large cities is comparatively low. The average trip length for all vehicles (excluding walk) in medium and large cities varies from 4.2- 6.9 km. It is observed from the trip length frequency distribution that 56% to 72% trips are short trips (below 6km, the typically cycle-able distance). This can be partly explained by the high residential density, mixed land use developments and poly-nucleated city structures present in Indian cities. (TIWARI AND JAIN, 2009). Hence, it can be argued that there should be a substantially large latent demand (of potential users) in Indian urban communities, who may use bicycles if safe circumstances prevail.

Bicycle provides other societal benefits like improved health, no pollution and emissions of green house gases, and no fuel consumption. Therefore, bicycle is a desirable mode, which should be promoted. If an increased bicycle modal share is envisaged as a policy, it is important to offer bicycle as choice mode. Hence, there is a need to evaluate potential user's perceptions on comfort and safety and include it in policy making.

Special facilities for bicycles in terms of safety, convenience, comfort, directness, and general attractiveness can influence the use of bicycles. Pucher and Buehler (2006) observed that neglect of pedestrian and bicycling safety in the United States has made these modes dangerous ways of getting around; while same is true in developing economies context. The "barrier effect" reduces cycling mobility, and increases driving. These impacts tend to be inequitable because disadvantaged populations who depend on non-motorized transport bear a disproportionate share of the costs. (LITMAN, 1995) While captivity does not have an important role in American and European context, it plays a stronger and definitive role in South Asian context.

For bicycle as a means of transport, safety plays an important role and (ORTUZAR et al., 2000) safe conditions (to park and to ride) affect bicycle use. The socio-economic characteristics, income, gender, education level and car ownership levels vary with culture and country, thus affecting the bicycle use. For instance, in Chile bicycle is more used by men, low income groups, people who don't own a car and have low education level. In India, work is the main purpose for bicycle trips, although shopping is also an important motive. (CHAWANEN, 2002; CHERRY AND CERVERO, 2007).

BICYCLE USERS PERCEPTION

Perceived costs, risks, comfort and convenience along with travel time, parking availability are some of the factors that explain the use of bicycle in a western context. Perceived safety improvements in bicycle transportation have an aggregate elasticity value that is greater than one, which means that bicycle safety improvements attract proportionately more people to bicycle commuting (i.e. a 10% increase in safety results in a greater than 10% increase in the share of bicycle commuting). (NOLAND, 1995; NOLAND AND KUNREUTHER, 1995)

Parkin et. al. (2007) state that the risk of an accident is a major deterrent to cycling. The model developed by Parkin uses the type of route and junction and indicates a high risk perception from the residential streets (with parked vehicles) especially for non cyclists, followed by busy roads (less risk perceived with bus lanes and lesser when cycle lanes are present and no change in perception with parked vehicles). Right turn (left-side driving rule) at junctions is specifically considered risky and even bicycle facilities could not offset it (perceived more by occasional –riders and young or old). Roundabouts are seen as more risky even with the facilities. The study confirmed the high value attached to segregated facilities and other attributes relevant to provision of infrastructure for bicycle traffic (development of a coherent network of well signed routes that are comfortable, attractive and direct). (PARKIN et. al., 2007)

A model for risk perception was developed by Leden et al. for estimating the changes in risk after modifications to the geometrical layout of streets. (LEDEN et. al., 2000) Discussions with cyclists about route choice revealed a number of criteria like: the possibility of using the secondary road network (21.3%); - the shortest path (14.9%); the existence (12.5%) of cycle facilities. Those cyclists who use the bicycle for utilitarian reasons tend to look for the shortest and most direct path (19.6%). (NODL AND GOSSELIN, 2002) Another survey revealed that cyclists may travel up to twenty minutes 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)

Bicycle compatibility measures, including stress-level and level-of-service indicators, measure the suitability of roadways for bicycle travel. These methods describe current bicycling conditions rather than forecasting potential demand. The measures combine factors such as motor vehicle traffic volume and speeds, lane width, and pavement quality into an index of overall suitability for travel. Bicycle compatibility is an index which reflects the comfort levels of bicyclists based on observed geometric and operational conditions of

variety of roadways. The bicycle level of service measurement usually also refers to the ability of a road segment to accommodate motor vehicle and bicycle traffic safety (ZOLNIK and CROMLEY, 2007). The most used criteria that describe these conditions are: traffic volume, lane width and motor vehicle speed. However, models have included a great number of different variables. (TAYLOR AND DAVIS, 1999). However it is utmost important to find out, that how much value people attach to various variables while choosing the mode or route.

Various studies related to bicycle compatibility and LOS evaluation have incorporated user's perception as well. In 1978, the Geelong bikeplan team in Australia introduced a methodology by assuming that the bicyclist want to minimize the physical effort required when choosing a roadway and also want to minimize the mental stress (conflicts with motor vehicles, high volume and high speed road way etc). In 1991, modifications were made to the Davis Bicycle Safety Index Rating (EPPERSON, 1994). The new BSIR did not include the intersection evaluation index and evaluated each segment separately. In 1994, Sorton and Walsh used the bicycle stress level concept in an effort to relate bicycle perceive on various types of roadways to specific geometric and traffic operating conditions. (TILAHUN et. al., 2007) Dixon's bicycle LOS model is based on the premise that there is a set of variables that must be present in a transportation corridor to attract non-motorized trips. (DIXON, 1996) The Federal Highway Administration (FHWA) sponsored a study in which a methodology for deriving at a Bicycle Compatibility Index (BCI) was developed. The BCI is promoted as a procedure for rating the "bicycle friendliness" of a road. (HARKEY et. al., 1998) Next BLOS developers elaborated the Intersection LOS for the bicycle through movement (LANDIS, 1994).

Bicycle compatibility and level of service models clearly indicated involvement of people's perception only to the extent of preferred volume, speed and mix of motorized vehicles. Most of these studies did not look into the street environment from the bicyclist's perspective. The measures related to land use like type of built environment, density, land use intensity and mix, presence of informal sector etc. also may influence the safety and comfort (especially in South Asian cities). An appropriate measure of safety, comfort and social security in the context of Indian cities also require people's preference evaluation on street environment.

It is evident from this discussion that the current literature does not distinguish between the perception of captive users and potential users. While bicycle users perception regarding physical features and risk from traffic may be applicable in the Indian context in general, however, the perception of potential users and captive users may differ and therefore will require different policy interventions.

CAPTIVE VS. POTENTIAL USER'S PERCEPTION

The objective of the present study is to employ Stated Preference (SP) technique for measuring perception of captive cyclists and potential users of the existing and desirable infrastructure features. This can be further used for evaluating Area Bicycle Compatibility (ABC) or for estimating relationship between land use aspects and bicycle use.

Pune city (previously known as bicycle city of India, in western state Maharashtra, India) has been selected for this study. Pune city has a history of high bicycling modal share (17%), Bicycle Master Plans since 1982 and dedicated bicycle tracks since 1980's.

Hence, a SP survey including Physical safety, Social safety (land use characters/informal sectors on road side, lighting), Barriers and Attractiveness (parked vehicles, pedestrians, bus stops, pavement quality, gradient) and Intersections (non-controlled vehicular access, type of signalized intersections) is needed for evaluating Bicycle Compatibility of the current infrastructure.

Questionnaire design

The captive cyclist's and potential user's preferences have been examined using SP questionnaire survey that consists of four main sections: (1) Respondent characteristics (e.g., gender, age, occupation, income, vehicle ownership, qualification and income), (2) Travel behaviour (e.g., frequency, trip profile, accessibility of various destinations, parking facilities etc.), (3) Respondents' rankings on the attributes (e.g., problems, discomfort, safety and security issues etc.), and (4) two SP Experiments on Street environment, Land use density and mix (for improving city designs and integration of bicycle; and benchmarking).

A testing of designed questionnaire was conducted on a focus group; in the pilot survey it was observed that despite simplification, filling out the questions appeared to be a complex task requiring a lot of explanation. Some people in the pilot survey could not suggest improvements as they appeared to be happy with the environment where they are bicycling. They had no idea what could be better in terms of type of infrastructure or segregated facilities, simply because they have never experienced it. Ranking / choice based pairs of different options seemed to be better in the situation where all the questions were asked by the interviewer orally, showing relevant pictures when necessary.

Sampling, target groups and zoning

The questionnaire was then revised, and applied to the full sample. Since, the study needed to look into diverse combinations of attributes in neighborhoods, a 6km x 3 km cross section from centre of city (Laxmi road CBD, old city) to boundary was selected. (Figure 2) Sample is evenly distributed among various population groups. In Indian context, bicyclists are mostly literate with at least secondary education but are unwilling to fill questionnaire themselves. Hence pictorial presentations were adopted for ease and the number of levels is kept to a minimum of 2 with only 4 attributes at a time.



Figure 2 - Selected 8 typical neighbourhoods for data collection / survey of study

NOTE: Type 1 – old city; Type 2 – plotted developments; Type 3 - flatted developments; Type 4 - slums / informal sector.

A sample of 302 captive bicyclists and potential users were chosen to capture the representation of typical socio-economic strata like students (age 10-22 years); workers (age 18 -60 years) and others (house makers, retired people etc.) These are the people who are likely to be affected by the improvements in bicycle infrastructure and facilities. The target groups were broadly divided as captive cycle riders and potential users, using the first section of the questionnaire.

The eight zones in Pune city were selected covering an area of 18 sq km. Typical 8 neighborhoods / zones comprising of (predominantly) old city (165, 146), plotted development (105), flats / apartments type development (104, 126, 125) and slums and informal areas (147,166), have been identified of size 1.5km X 1.5km each (Figure 2).

ANALYSIS

A sample of 302 captive cyclists and potential users was interviewed and about 30% were using bicycle as a mode of commuting (captive riders). About 75% were male and 25% of total interviewed were students below age of 18 years, about 50% young adults (19-35 years) mostly males in jobs / work, and about 25% in their late adulthood (36 – 60 years). Qualifications of the captive cyclists are mostly middle or secondary education. Cycling use in an urban context decreases with increasing education and income. Potential users are mostly more educated with higher professional and academic degrees. Similarly current captive cyclists belong to the category of the poor (9%) and / low income group (26%). While the potential bicyclists are observed to be in categories of middle income groups (60%) and higher income groups (5%).

TABLE 1 Current Mode of Travel for Captive Cycle Riders and Potential users

Mode	No. of respondents	%
Auto / taxi / van	18	6
Bicycle	90	30
Scooter / motor cycle	112	37
Car	29	10
Public Transport Bus	35	11
Other vehicles	18	6
	302	100

The mode of travel for total respondents has been shown in TABLE 1. Bicycle is used by 30% of the people surveyed. It was found that these are all captive cyclists. Captive riders are defined here as those who use bicycle for commuting, cannot

afford other modes of transport and whose work place is beyond walkable distance. And the remaining 70% people surveyed are the potential users. Potential bicycle users are defined here as those whose (one side) trip length is less than 6 km, own a bicycle but are commuting using either bus or motorized vehicle (car/scooter/motorbike/auto). For appropriate estimation of perceptions related to bicycle compatibility, the potential rider respondent must have ridden bicycle at least once in past 10 years.

About 40% of current captive bicycle users are school students, while another 18% users are college students. Also 29% of cycle destinations are work related like office, job, and factory etc. and shops (for work as well as grocery shopping). The average trip distance is 3.9 km for cyclists (ranging between 1.8 km to 6.2 km) taking about an average 22 minutes (ranging 10-40 minutes) at the speed of 10-12 km /hr. The travel costs are negligible in the range of 0-2 INR per day referring mainly to maintenance and in some cases parking.

Preferences to Surroundings

Current cyclists (captive riders) preferred green / vacant areas (32%) with extremely low densities as routes; followed by the mix of commercial activities in the residential areas (23%). Some preferred purely residential (18%) areas as well for the regular bicycle routes. Similarly, the low density areas and mix of commercial in residential areas (30% and 28%) are perceived as the ones more attractive by potential users. By all kinds of captive cyclists and potential users, purely commercial areas and increasing mix of commercial and manufacturing activities are seen as non attractive for cycling.

The preference and weights attached to each aspect while choosing the route are similar for current cyclists and potential users. For cyclists and potential users, the highest importance is attached to physical safety. For both of them the biggest deterrent to bicycle use is vulnerability of the mode and exposure to physical safety hazards (32%). The 25% of weight is attached to the problems in crossings roads and intersections relating to difficulty in operation. The social security (22%) in less dense roads / colonies, green and vacant areas and bigger / purely commercial areas, in less lit and or night times is of concern. The other concern is barriers on the road (21%) like pedestrians, hawkers, vendors, bus commuters,

frequently stopping buses at bus stops; sometimes permanent and temporary elements like stray animals, poles, garbage dumps, construction materials etc.

Ranking based analysis for Key Variables

Table 2 shows the weights assigned by the captive cyclists and potential users for different parameters like physical safety, social safety, barrier etc which affect the use of bicycle as travel mode.

TABLE 2 The Key Variables and their Scores from the Stated Preference Survey

Parameter	Attributes	Cyclists score	% weight attached	Potential cyclists score	% weight attached
Physical safety		290	32.2	681	32.1
1	Frequency of buses	227	25.3	525	24.8
2	Speed of motorized vehicles	219	24.3	511	24.1
3	Volume of motorized vehicles (PCU)	218	24.2	516	24.3
4	Non-controlled vehicular access	236	26.2	568	26.8
Social security /comfort / attractiveness		196	21.8	475	22.4
1	Formal LU-diversity & intensity	189	21	411	19.4
2	Informal LU at road side	297	33	483	22.8
3	Lighting	167	18.5	661	31.2
4	Other NMT	247	27.5	565	26.6
Barriers		187	20.8	445	21
1	Pedestrians on the road	237	23.3	599	28.4
2	On street Parked vehicles	209	26.3	500	23.5
3	Pavement quality	225	25	535	25.2
4	Gradient	229	25.4	486	22.9
Intersections		227	25.2	519	24.5
1	Crossings	247	27.4	572	27
2	Roundabouts	236	26.3	536	25.3
3	T junctions	200	22.2	494	23.3
4	Uncontrolled MV entry/exit	217	24.1	518	24.4

The parameters physical safety and intersections are assigned approximately 32% and 25% weights respectively both by captive riders and potential users. A further detailed disaggregated analysis of the physical non-safety perception reveals various aspects which affect it. This is not in any particular order or hierarchy with almost the same weight age attached to each attribute. Slightly higher importance is attached with uncontrolled vehicular

access (~26.5%) merging in the road. It is considered a threat by captive riders and potential users alike. The other concerns like buses in curb lane, speed and volume of motorized vehicles (ranging 24%-25%) are also considered as equal threat or dangerous aspects to cycling. (Table 2)

The predominant differences were evident (Table 2) among the captive riders and potential users with respect to comfort and attractiveness aspects. Detailed ranking results showed that captive riders attach high positive value to informal sectors on road side (33% weight) and to the fellow bicyclists and pedestrians (27.5%). On the other hand, potential users attach high value to street lighting (31.2%) and to other bicyclists and pedestrians (26.6%).

While, a detailed understanding of the type and frequency of barriers on the curb side lane revealed that pedestrians / bus commuters waiting (about 28.4%) at the curb side lane are considered as predominant barriers by potential riders. But it seems current captive cyclists are more tolerant to them. One of the other factors which act as major deterrents for bicycle travel is street side parked vehicles on the curb side lanes (26.3%). Pavement quality (25%) and gradients / undulating topography are also considered to be barriers. (Table 2)

The intersections have been disaggregated to roundabouts, T junctions, crossings and type of intersections (signalized / un-signalized). The perception of risk among captive riders and potential users does not show much difference. Signalized crossings are ranked much higher (27.4% weight) on risk and are still considered more difficult to cross (especially while turning right in left side driving Indian context). This is closely followed by the roundabouts (26.3%) mostly without any markings, signals and signage. Uncontrolled motorized vehicles entry /exit (un-signalized junctions) rank just higher than the T junctions. (Table 2)

The rankings is limited to the linear weights given by analyst for the various aspects. In the last part of the survey paired pictorial sets were used to determine respondent's preferences to physical and environmental attributes of neighbourhoods in a SP choice experiment

Choice Based SP Experiment

In accordance with the informal and non motorized transport, Cervero (2000) suggested that discrete-choice (logit) analyses could be a typical technique for gauging the perceived value of service features more than other traditional methods. SP techniques are especially useful for studying non-existing market situations, such as building new light rail line, building new bicycle tracks and implementing road pricing. They have been used to evaluate the effects of relevant attributes (attribute valuation) of a system on individuals' responses and to provide forecast of changes in demand and travel behaviour. Similarly in the present study 2 full factorial SP experiments have been conducted related to street operations and street environment.

The study examines a sample from typical neighbourhoods of the city and explores the perception of safety and comfort among captive riders and potential users. Based on the focus groups and previous ranking based study, 6 basic components were determined for

the SP experiment for measuring bicycle compatibility. These are: (1) Network characteristics, (2) Street environment and (3) Land use variables, (4) Topographic variables (5) Comfort variables, and (6) Safety and security variables. The levels are kept to a minimum of two so as to keep the design small, predominantly exploratory and easy to comprehend for respondents. The alternatives are hypothetical streets in neighbourhoods, type A and B (unlabelled) as the situation is in numerous combinations in different areas of Pune city.

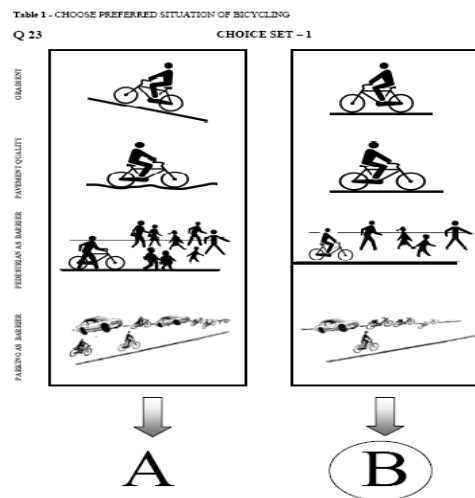
Each individual had to choose between two alternative hypothetical situations (unlabelled experiment) to assess its impact on travel/ route choice behaviour. All the respondents were asked to give preferences for situation where they will like to cycle from the given pair. Each of the 302 respondents gave 8 observations (total – 2416) for street environment (Table 3 and Figure 3) and 6 observations for land use related aspects (total - 1812) (Table 4 and Figure 4)

In reality, there are many combinations of attributes for various kinds of neighbourhoods (unlabelled experiment) in the city. In this study only the most important categories (derived from the pilot experiment) and a main effects only design were used. A multinomial Logit model was then used to process the stated choice data to derive the utility function (for which beta values need to be estimated). This was done using the maximum likelihood method for the MNL model (Louviere et al., 2000).

TABLE 3 The design for SP experiment -1

Attributes	Levels	Design codes	Orthogonal codes
Slope	Rolling	0	1
	Flat	1	-1
Quality of pavement	Uneven	0	1
	Good	1	-1
Pedestrians as barrier	More / lots	0	1
	Few / less	1	-1
Parked vehicles as barrier	More / lots	0	1
	Few / less	1	-1

Figure 3 The choice set example presented to respondents for SP experiment 1



The utility function for SP experiment 1 are expressed as -

$$U_{BCui} = \varepsilon_{in} + \beta_{sl} * SL_u^i + \beta_{pv} * PV_u^i + \beta_{pd} * PD_u^i + \beta_{pk} * PK_u^i \quad \text{(Equation 1)}$$

Where –

U_{BCui} = utility of Area Bicycle Compatibility of neighbourhood

SL_u^i – the slope / gradient of the road

PV_u^i – the quality of pavement at curb side.

PD_u^i – the pedestrians (including bus commuters) on curb side acting as barrier to cyclists

PK_u^i – the parked vehicles (including non motorized) acting as barrier to cyclists

β_{sl} = weight or coefficient associated with attribute slope

β_{pv} = weight or coefficient associated with attribute pavement quality

β_{pd} = weight or coefficient associated with attribute pedestrians as barriers

β_{pk} = weight or coefficient associated with attribute parked vehicles as barriers

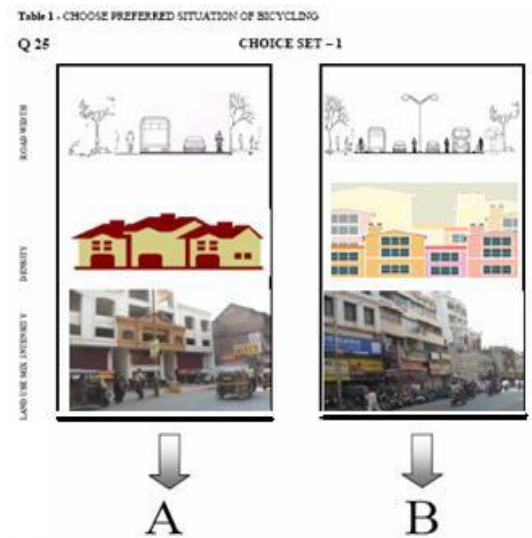
i = the neighbourhood zone i (TAZ i)

u = the current captive cyclists or potential users (short trip makers)

TABLE 4 The design for SP experiment -2

Figure 4 The choice set example presented to respondents for SP experiment 2

Attributes	Levels	Design codes	Orthogonal codes
Road width	<12m row	0	1
	>12m row	1	-1
Density	Low (plotted / low rise)	0	1
	High (flatted / high rise)	1	-1
Land use mix	< 30% other land uses	0	1
	> 30% other land uses	1	-1



The utility function for SP experiment 2 are expressed as -

$$U_{BCui} = \varepsilon_{in} + \beta_{rw} * RW_u^i + \beta_{dn} * DN_u^i + \beta_{lum} * LUM_u^i \quad \text{(Equation 2)}$$

Where –

U_{BCui} = utility of bicycle compatibility in street /neighbourhood

RW_u^i – the hierarchy of roads which is preferred for cycling

DN_u^i – the density of area / land use which is preferred for cycling

LUM_u^i – the Intensity of land uses mix which is preferred for cycling

β_{rw} = weight or coefficient associated with attribute road width

β_{dn} = weight or coefficient associated with attribute density

β_{lum} = weight or coefficient associated with attribute land use mix

i = the neighbourhood zone i (TAZ i)

u = the current captive cyclists or potential users (short trip makers)

The result focuses on the three most important issues of SP analysis: (1) SP data analysis, (2) bias elimination, and (3) SP estimation and SP interpretation. The estimation results of

random coefficients, and individuals specific coefficients have been obtained using appropriate computer software i.e. BIOGEME version 1.5. The results of the discrete choice estimation provide four main outputs: (1) Coefficient estimates (2) T-statistics and standard errors, (3) Log-Likelihood measures, and (4) Rho Squared goodness of fit. (Table 5)

TABLE 5 Choice set analysis results for captive riders and potential riders

Variables	Parameter estimate	T test	Std error	Final Log likelihood	Rho squared goodness of fit
SP experiment 1					
ASC -c	-2.38	-20.76	0.115	-291.15	0.416
Slope -c	0.143	1.91	0.0216		
Pavement -c	0.286	2.87	0.00214		
Pedestrian Barrier -c	-0.0037	-0.84	0.199		
Parking -c	0.4201	3.75	0.00197		
SP experiment 2					
ASC -c	0.0983	2.86	0.813	-2652.603	0.134
Road width -c	1.27	-6.66	1.46		
Land use mix -c	0.00535	-4.17	0.391		
Density -c	-0.0679	5.69	0.682		
ASC -pu	1.06	1.56	0.619	-302.459	0.164
Road width -pu	-0.0918	-5.26	0.838		
Land use mix -pu	0.0397	10.96	1.002		
Density -pu	-0.182	1.54	0.919		
Attribute - c = attribute for captives			Attribute - pu = attribute for potential user		
ASC - alternative specific constant					

As the terrain is flat, the utility is high; also when the pavement quality is better, the utility is high. Also when the Parked vehicles are less the utility is high. The results indicate that sign and coefficient values for pedestrians as barriers are negative and much too low. The pedestrians as barriers for captive cyclists and potential users are insignificant. It is evident that cyclists are more tolerant to pedestrians on the curb side lane. This may be inferred as having direct implication to safety. Hawkers and pedestrians presence makes streets

relatively crime free and safer for women, children and the elderly. Also it is comparatively easier to negotiate pedestrians while cycling than motorized vehicles (moving / parked) in the curb side lane. Parked vehicles pose a greater threat to physical safety of cyclists while moving in and out of parking or when a motorized four wheeler door suddenly opens. For both the captive and potential rider model in the SP experiment 1 has comparatively good to extremely good goodness of fit.

Density for potential users is significant at only 90% confidence level. All the other values for captive and potential users attributes are significant at 95% confidence level or higher. Table 3 shows similar coefficients attached by the captive riders and the potential riders to different attributes; except for the coefficient value attached to slope. This can be partially explained by the non-existent bicycle infrastructure / facilities which led captive cyclists to choose shortest distance and on at least one side of the trip, the slope is in favour. While potential cyclists who have a choice of other motorized vehicle see it as bigger threat to bicycle compatibility.

While comparing the road related factors (the SP experiment 2 for comfort and attractiveness), there is a difference in captive riders preferring wider roads (despite high speeds, high volumes of motorized vehicles) against the narrower / lower hierarchy roads preferred by potential cyclists. This may explain the difference in safety and comfort perception of captive cyclists and potential users. Since captive cyclists have no other affordable option available, they are used to higher risks in mix and fast traffic and prefer shorter direct routes for quick commutation (which are often served by arterials and sub arterials). Potential users attach high weightage to comfort and less conflicting road situations. And also for both captive and potential users, land use mix seems to be not a major concern (low coefficient) while the sign indicates that higher commercial / public semi-public land use mix increases the utility. The negative sign of density indicates that low density has high utility i.e. preferred environment. For both the captive and potential user model in the SP experiment 2 has comparatively low goodness of fit.

SUMMARY AND CONCLUSIONS

This paper attempts to evaluate the perceptions of captive and potential users of bicycles regarding different aspects of traffic characteristics (speed of motorized vehicles, presence of buses) and land use (intensity of mixed land use, density of development, presence of street vendors).

- Key issues like familiarity with new scenarios (situations) (e.g. bicycle tracks and bicycle prioritized intersection) and safety / security improvement (e.g. lighting, informal sector integration) must be well designed to present to respondents. Stating preferences by choice is likely to be more appropriate than rating or ranking.
- The parameters physical safety and intersections are assigned approximately 32% and 25% weights respectively both by captive and potential users. Uncontrolled

vehicular access (~26.5%) merging in the road is considered a threat by captive cyclists and potential users alike.

- The perception of risk at type of intersections among captive cyclists and potential users does not show much difference. Signalized crossings are ranked high (27.4% weight) on risk, closely followed by the roundabouts (26.3%).
- Pedestrians / bus commuters waiting at the curb side lane are considered as predominant barriers (about 28%) by potential users while captive cyclists are more tolerant to them.
- Results indicate that perception of safety and comfort are not related to age, gender, type of zone and distance travelled.
- However, the presence of informal sector on the street side is social security element and comfortable and attractive for providing services for captive cyclists. But for potential users informal sector is like a barrier, although, lighting seems to be important for social security concerns.
- As the terrain is flat, the utility is high; and when the pavement quality is better, the utility is high. Also when the Parked vehicles are less the utility is high.
- The results indicate negative sign and low coefficient values for pedestrians as barriers. It is evident that captive cyclists are more tolerant to pedestrians owing to easier negotiation and their presence makes streets relatively crime free and safer.
- Potential users who have a choice of other motorized vehicle see slope as bigger threat to bicycle compatibility as compared to captive riders. In absence of alternative mode, captive cyclists choose shortest route and prefer the direct / quicker commute.
- Captive cyclists prefer wider roads (despite high speeds, high volumes of motorized vehicles) against the narrower / lower hierarchy roads preferred by potential cyclists. Since captive cyclists have no other affordable option available, they are used to higher risks in mix and fast traffic and prefer shorter direct routes.
- Also for both captive and potential users, land use mix seems to be not a major concern (low coefficient) while the sign indicates that higher activity mix increases the utility. The negative sign of density indicates that low density has high utility i.e. preferred environment.

The attached values/ weights from this study can be used for calculating bicycle compatibility of the area/ roads, along with other quantitative aspects of streets. This study can also help in prioritizing the road improvement projects and integration of formal - informal land use aspects in transportation/city planning. The implication from the SP survey could be valuable information for planning authority or policy makers, which can be used for forecasting the

future (new travel behaviour) after the system changes. Such demand estimation will be sensitive to each of the quality attributes.

FURTHER WORK

This study presents results of a survey including 300 respondents only. The results for experimental designs of street operations and street environment are indicative as none of the variables are statistically significant. Further work is required to increase the sample size for better estimation of differences in choice of the captive and potential bicycle users. The more number of levels will improve the research from merely exploratory and linear relationship to more defined real relationship. This can be further utilized in developing mode choice model for bicycle trips. Also with appropriate sample, this technique could show the cross-elasticity in demand due to the system change in bicycle compatibility; reflecting more accurate traveller's decision and thus could yield more accurate demand prediction.

ACKNOWLEDGEMENTS

This survey study is supported by Volvo Foundation Research Scholarship and Cycling Academic Network (CAN) scholarship. The authors are grateful to two anonymous reviewers for their critiques which helped in improving the paper.

REFERENCES

- Balsas, C. J. L. (2003) Sustainable transportation planning on college campuses. *Transport Policy*, 10, pp. 35-49
- Census of India (2001) Population and household tables, Census of India, Registrar General of India, Government of India
- Cervero, R. (2000) *Informal transport in the developing world*. Nairobi: United Nations Centre for Human Settlements (Habitat)
- Chawanen, T. (2002) Urban Form and Commuting Behaviour, A cross European Perspective, *Journal of Economic Social Geography*, 93, pp. 336-343
- Cherry, C. and R. Cervero (2007) Use characteristics and mode choice behavior of electric bike users in China. *Transport Policy*, 14 (3), pp. 247-257
- Dixon, L. B. (1996) Bicycle and Pedestrian Level of Service Performance Measures and Standards for Congestion Management Systems. *Transportation Research Record*, 01-09
- Epperson, B. (1994) Evaluating Suitability of Roadways for Bicycle Use: Toward a Cycling Level of Service Standard. *Transportation Research Record*, 09-16
- Gatersleben, B. and, K. M. Appleton (2007), Contemplating cycling to work: Attitudes and perceptions in different stages of change. *Transportation Research Part A: Policy and Practice*, 41, pp. 302-312
- Harkey, D. L. Reinfurt D. W., Sorton A., Knuiman M., and J. R. Stewart (1998). *The Bicycle Compatibility Index: A Level of Service Concept. Implementation Manual*.

- Washington, D.C.: Federal Highway Administration, FHWA-RD-98-095. Full text at:<http://safety.fhwa.dot.gov/tools/docs/bci.pdf>
- Landis, B. W. (1994) Bicycle Interaction Hazard Score: A Theoretical Model. *Transportation Research Record*, 03-08.
- Leden, L., Gsrder, P. & U. Pulkkinen (2000) An expert judgment model applied to estimating the safety effect of a bicycle facility. *Accident Analysis & Prevention*, 32, pp. 589-599
- Litman T. (1995) Land Use Impact Costs of Transportation, *World Transport Policy & Practice*, Vol. 1, No. 4, pp. 9-16.
- Louviere, J., et al. (2000) *Stated choice methods analysis and applications*, Cambridge: Cambridge University Press
- Mnller, S. Tscharaktschiew, S. & K. Haase (2008) Travel-to-school mode choice modelling and patterns of school choice in urban areas. *Journal of Transport Geography*, 16, pp. 342-357
- MPD 2021 (2006), Master Plan for Delhi –2021 (MPD-2021), Delhi Development Authority (DDA), Delhi, 2006
- NCRB (2001-06) *Accidental Deaths and Suicides in India*, (Annual reports 2001-2006), National Crimes Record Bureau (NCRB), Ministry of Home Affairs, Government of India
- Nodl, N. & M. Lee-Gosselin (2002) Achieving a better understanding of cycling practices a detailed study of the travel behaviors of cyclists in the Quebec Metropolitan Region. *Recherché - Transports – Securite*, 74, pp. 26-49
- Noland, R. B. & H. Kunreuther (1995) Short-run and long-run policies for increasing bicycle transportation for daily commuter trips. *Transport Policy*, 2, pp. 67-79
- Noland, R. B. (1995) Perceived risk and modal choice: Risk compensation in transportation systems. *Accident Analysis & Prevention*, 27, pp. 503-521.
- Ortuzar, J. de D., Iacobelli, A., C. Valeze (2000) Estimating demand for a bicycle-way network. *Transportation Research Part A* , 34, pp. 353-373
- Parkin, J., Wardman, M. & Page, M. (2007) Models of perceived cycling risk and route acceptability. *Accident Analysis & Prevention*, 39, pp. 364-371
- Pucher, J. & R. Buehler (2006) Why Canadians cycle more than Americans: A comparative analysis of bicycling trends and policies. *Transport Policy*, 13, pp. 265-279
- Pucher, J., Peng, Z., Mittal, N., Zhu, Y. and, N. Korattyswaroopam (2007) *Urban Transport Trends and Policies in China and India: Impact of Rapid Economic Growth*, *Transport Review*
- Replogle, M. (1991) *Non-Motorized Vehicles in Asian Cities*, World Bank Technical Report 162, available from the Environmental Defense Fund, 1875 Connecticut Ave. NW, Washington, DC 20009 USA
- Singh R. B.(1997), 'Urbanization, Environmental Crisis, and Urban Planning in India', *The Geographer*, Vol. XLIV, No. 2.
- Taylor, D. & W. J. Davis (1999). Review of basic research in bicycle traffic science, traffic operations, and facility design. *Transportation Research Record*, 102-110
- Tilahun, N. Y., Levinson, D. M. & K. J. Krizek (2007). Trails, lanes, or traffic: Valuing bicycle facilities with an adaptive stated preference survey. *Transportation Research Part A: Policy and Practice*, 41, 287-301.

- Tiwari G. (2002), Urban Transport Priorities – Meeting the Challenge of Socio-economic Diversity in Cities; A Case Study of Delhi, India, *Cities*, Vol. 19, No. 2, pp. 95-103
- Tiwari G. and H. Jain, (2009). 'Bicycle Compatibility in Indian cities', Context- built, living and natural - Journal of the Development and Research Organization for Nature, Arts and Heritage (DRONAH), Volume VI, Issue 1, Spring/Summer, pp. 85-92\
- Tiwari, G. and H. Jain (2008) Bicycles in Urban India, *Urban Transport Journal*, Volume-7, No. 2, Institute of Urban Transport, India, pp. 59-68.
- TRIPP, 2006, 'Bicycle use and barriers to use, Transportation Research and Injury Prevention Program (TRIPP) IIT Delhi, for LOCOMOTIVES (I-ce) project, 2006.
- Walle, S. V. and T. Steenberghen (2006) Space and time related determinants of public transport use in trip chains. *Transportation Research Part A: Policy and Practice*, 40 (2): 151-1622.
- Wilber Smith Associates, (2008), 'Study on traffic and transportation : Policies and strategies in urban areas in India', for Ministry of Urban Development, India
- Zolnik, E. J. & E. K. Cromley (2007). Poisson multilevel methodology of bicycle levels of service for road networks. *Transportation Research Record*, 1-8.