Promotion of non-motorized modes as a sustainable transportation option: policy and planning issues

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Cities in developing countries owing to increase in population and motor vehicles are facing problems such as congestion, traffic jams, environmental pollution, high cost of travel, longer travel distances due to city sprawl, increasing cost of fuel imports, ill-health, etc. Planners are looking for different policy options and one such solution is to promote and integrate non-motorized modes in transportation systems, planned and developed for habituated areas. This article presents the key issues and guiding principles of sustainable transportation system, and then discusses the sustainability of non-motorized modes across travel modes and within the modes. Policies related to non-motorized modes, especially walking and bicycles, are also discussed. Planning issues are discussed with reference to walking along carriageways or on sidewalks or on similar facilities constructed along the road or for crossing the road. The effects of pedestrian characteristics on pedestrian flow characteristics such as speed and flow, acceptable gaps while crossing the road, etc. are also presented. It is emphasized that due consideration should be given to the above-mentioned aspects, which would help in the provision of non-motorized facilities in an area thus making them sustainable.

Keywords: Environment emission, non-motorized modes, sustainable transportation.

Introduction

TRANSPORTATION planners in developing countries have given more importance to mobility than to accessibility. Mobility has been improved through construction of fly-overs, subsidized fee for license and vehicle registration, widening of roads, provision of alternate rail-road-based transportation systems, etc. Such provisions along with improper planning of access to transportation systems have degraded the environment; increased the social cost, which involves health, accident and congestion costs; and increased the economic burdens such as loss of employment opportunities and higher cost of travel due to delays. The inherent shortcomings of non-motorized transportation modes such as being feasible for shorter distances only, and lower speeds make them suitable for providing access to any transportation system under congested conditions or to any land use in the vicinity of our homes. Relatively smaller size of facilities at lower cost gives them a higher penetrative value in built environments. Along with the above facts, low consumption of energy and resources make them viable options for sustainable transportation. The acceptability of non-motorized transportation can be improved by the provision of properly designed facilities which should be continuous and segregated in nature as far as possible. This article discusses issues that make non-motorized transportation sustainable not only within but also across travel modes. It further discusses policies and options that can make a city, walk- or bicycle-friendly. Finally, design issues that are found important for better planning of facilities are presented.

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Sustainable transportation

There is no universally accepted definition of sustainable transportation. One such definition, from the European Union Council of Ministers of Transport[1] defines a sustainable transportation system as one that:

- Allows the basic access and development needs of individuals, companies and society to be met safely and in a manner consistent with human and ecosystem health, and promotes equity within and between successive generations.
- Is affordable, operates fairly and efficiently, offers a choice of transport mode, and supports a competitive economy, as well as balanced regional development.
- Limits emissions and waste within the planet's ability to absorb them, uses renewable resources at or below their rates of generation, and uses non-renewable resources at or below the rates of development of renewable substitutes, while minimizing the impact on the use of land and the generation of noise.

The Sustainable Transport Action Network[2] has defined key issues, whereas guiding principles were discussed at an international conference organized by

Table 1. Key issues in sustainable transportation

Key issues	Guiding principles
Access, not mobility	Principle 1 – Access: People are entitled to reasonable access to other people, places, goods and services.
Moving people, not cars	Principle 2 – Equity: The state and service providers should maintain social, environmental, economic, interregional and inter-generational equity, horizontally and vertically at all levels of the society and community.
Reclaim city space for walking and pedalled vehicles	Principle 3 – Health and safety: Transportation systems should be designed and operated in a way that they reduce social cost of system use by protecting the health and safety of all people, and enhancing their quality of life.
Stop subsidizing private motor vehicles	Principle 4 – Individual responsibility: All individuals have a responsibility of making sustainable choices for their movement between places by reducing consumption of resources so as to improve the natural environment.
	Principle 5 – Integrated planning: Transportation system planners and implementers have a responsibility to adopt integrated approaches to planning with higher emphasis being given to public transport, walking and bicycling.
	Principle 6 – Pollution prevention: Transportation systems should be evolved such that they generate lesser emissions which threaten public health, global climate, biological diversity and ecology.
	Principle 7 – Land and resource use: Transportation systems must make efficient use of land and other natural resources while ensuring the preservation of vital habitats and other requirements for maintaining biodiversity.
	Principle 8 – Fuller cost accounting: The provision of transportation systems and their operation should be based on full cost accounting, which includes social, economic and environmental costs, and make the user pay an equitable share of costs based on the use of facilities.

Organization for Economic Co-operation and Development (OECD)[3] that should be followed for achieving sustainable transportation in a city. These are listed in Table 1.

Sustainability across modes

The importance of use of non-motorized (NM) modes can be ascertained based on the comparison of these modes with other motorized modes.

Traffic handling capacity

Passenger capacity (per hour per metre) of rail and road-based public transport ranges between 4000 and 8000, whereas it is 3500 for walking, 1500 for cycling and ranges between 100 and 400 for motorized modes such as motorcycle and automobiles under urban traffic conditions[4–7].

Space requirement

It is found that light rail transit (LRT) and walk consume lesser space in terms of bicycle space equivalent, whereas it is high for other modes. Considering this, the road space required per person by different modes[8] is as given below: car: 120 sq. m; bus: 12 sq. m; rail: 7 sq. m; bicycle: 9 sq. m; pedestrian: 2 sq. m and air travel: 1.5 sq. m.

This clearly indicates that under congested traffic conditions, the use of walk or bicycle would result in more efficient movement.

Cost of infrastructure

The investment required for providing infrastructure depends upon the area required for the movement and storage of the vehicle[9–14]. The monthly cost of bicycle parking (surface and underground) per equivalent parking stall is less than one-tenth compared to an automobile trip or 'park and ride lot' construction. The comparative costs of facilities (for 1 km) constructed for different types of modes are observed to be as follows.

Freeway : highway/free tramway : bus lane : high quality cycle route :: 20 : 10 : 5 : 1.

Material requirement

It is found that resource requirement of the car category is much higher as compared to even pooling within them. With respect to material requirement for bicycle (30 kg/person), the material requirement for car varies between 42 and 48 times and for pooling, it varies between 7 and 22 times that of bicycle[10,15].

Energy consumption

The energy consumption share of transport sector is one-third of the total consumption and within that the road transport consumes around 80%. Compared to bicycle, the energy consumption per passenger per mile is found to be 2–2.5 times higher for public transport and 3–6 times higher for motorized modes in India. It is 3–4 times higher for public transport and 5–10 times higher for motorized vehicles when compared with walking[4,12].

Non-motorized vehicle (NMV) consumes around one-ninth of the power consumed by motor vehicles. A minor shift of 0.5% by US automobile commuters living within 0.25–2 miles from a transit route and that of 10% of existing automobile park and ride users to bike and ride travel can save about 20–40 million gallon of gasoline (75–150 million litres) per year or 1 million-gallon (3 million litres) per year respectively. Greater energy is consumed by automobiles in short hauls[1,10,13,15].

Environment emission

The National Personal Transportation Study (1990) from the USA states that passenger vehicles are responsible for 20% of the total CO_2 emissions, 45% of CO, 16% of NO_x and 25% of volatile organic compounds emission. It is estimated that cycling and walking can displace 4–15% of the projected passenger vehicle emissions of carbon monoxide, nitrogen oxides and VOCs; and 5% of passenger vehicle carbon dioxide for the projected scenario of the year 2000 (ref. 16). According to a study, 70% of air pollution in Bangkok is from motorized vehicles. The suspended particulate matter (SPM) level is 200–400% and CO is 50% higher than WHO standards, spanning 97 days a year. The air pollution exposure of 8 h at street level is equivalent to the smoking of nine cigarettes a day. In Mexico, although private cars carry only 15% of motorized person trips, they are responsible for 63% of the total emissions and 90% of the CO emissions. In Mumbai, Beijing and Kolkata; emissions exceed WHO standards by 100 days, 272 days and 268 days a year, respectively. It is found that provision of bicycling facilities is cost effective in eliminating emissions. This would result in higher savings in public cost[13,17]. It was found that on changing to pedestrianization scheme in the central area of Chester, England, CO, HC and CO_2 emissions reduced by 5–6.5%, whereas NO_x and particulate matter increased by 0.4% and 6% respectively[18].

Social cost

The social cost comparison of different modes is studied by different researchers[6,15,19] giving due consideration to accident externalities, parking, congestion, air pollution, noise, energy externalities, land-use impacts and barrier effects. It is observed that if externalities are included in the cost comparisons, then the automobile user cost is about 27 times that of cycling and 134 times that of walking. A study[8] indicated a saving of 44% in the total cost of vehicle use by a household while shifting from automobile use to multi-modal use including walking and cycling. Out of these total savings, two-thirds will go to the multi-mode user household and the remaining one-third to the society. It will also reduce the cost of transportation, especially for the poor, who presently spend 5% to 20% of their monthly income on transportation needs[5,20–22]. With respect to an expenditure of $1 million, 4.5 jobs get created in the petroleum industry, 7.5 jobs in automobiles and 21.4 jobs in public transport and 75 jobs, if used for NM modes[9,23].

Operational and congestion cost

Automobile operating expenses, as compared to bicycle, are around 2 : 1 to 10 : 1. In heterogeneous traffic conditions, the operating efficiency of walk and bicycle is much more when compared to that of motorized modes[24,25]. The annual motor vehicle congestion cost for the US ranges between $100 billion and $300 billion. The health and productive cost varies in a wide range of $10 billion to $200 billion per year. The congestion cost as cost of fuel lost due to idling in traffic for Bangkok is calculated as $1.4 million per year[12,16,26]. In terms of person-hour lost, it is calculated as 44 working days, equivalent to 10% increase in GDP of Thailand[7] and 244 working days per year for Pune, India[27]. It has been found that as congestion increases, the speed of motorized modes gets more affected when compared to the speeds of NM modes. In general and specific to the European case, the bicycle is found superior to all motorized modes up to 5 km (ref. 10). Illich[28] and Serified (as quoted in ref. 29) have shown that the social cost for a bicycle (14 km/h) is similar to that for cars (18 km/h). The social cost takes into consideration the time that an individual spends to earn the money needed to cover the costs of each mode. Together with external costs, it makes the two modes comparable. The per capita congestion delay is found to reduce with an increase in share of NM modes[30,31].

Health and accident cost

The cost of loss of life, rehabilitation, pain and suffering is put at $363 billion per year (1990$) by Urban Institute, USA[16]. Cycling has a positive net effect on health and health benefits gained from cycling exceed accident costs[12]. The accident cost saving by cycling may be worth Rs 25.125 million (Rs 1984)[20]. In all, the total estimated social cost of highway use is between $60 billion and $860 billion per year (1990$) (most inclusive for US)[26]. The externalities caused due to accidents are found to be in the ratio of 17 : 1 for motorized modes as compared to NM modes and walking[8]. The promotion of walking and cycling also has a positive influence on accident reduction. As reported by the 'Urban Transport Strategy' of the World Bank, road accidents could be reduced largely by improved non-motorized transport (NMT) infrastructure, enhanced road design and better management policies[32]. Hook[33] argued that promoting safe cycling and walking is vital to reducing over 500,000 premature deaths from traffic accidents each year.

Travel time and trips

Non-motorized modes serve a small portion of travel distance but a larger share of travel time and trips. A UK survey indicated that walking represents just 2.8% of total mileage but 18% of travel time and 25% of trips[34]. According to the 2009 US National Household Travel Survey (NHTS)[35], the share of NM modes is substantial for trips up to 5 km and these are 46%, 31% and 19% respectively in the travel distances of up to 0.8 km, 1.6 km and 5 km. International data indicates that at the metropolitan level, a mile of additional walking and cycling is associated with 7 miles of reduced motor vehicle travel[36]. NM travel can be time competitive with driving for short trips, for walking up to 0.8 km and for cycling up to 5 km (refs 35, 37). The ban on NMT transport on Mirpur Road in Dhaka, Bangladesh[38] resulted in at least 50% increase in average journey times per passenger per trip and 10% increase in monetary costs per trip.

Non-modified policies

The policies discussed here are aimed at making a city walk and bicycle friendly.

Walk policies

There are twelve steps that planners and users should adopt to make cities walkable[39].

Provide continuously linked walkways: A sidewalk, 1.5 m wide (minimum) with viable separation, should be provided to accommodate pedestrians including persons with disabilities. Consideration should be given to clear sight distance, landscaping, streetscaping, trash receptacles, street vending machines, utility poles, lighting fixtures, transit stop shelters, benches and direction signs. A 50/50 ratio of walking space to vehicle space should be provided in business centres, beach frontages and entertainment areas. Special consideration should be given to campus environments.

Pedestrianize intersections: The intersections should be designed with complete clarity so that movements of vehicles and pedestrians with different abilities are easily understandable, which eliminates the chances of mutual conflicts. The street crossing exposures should be reduced by using design features like slip lanes, medians and bulbouts. The geometry of the intersection should govern the speeds of the vehicles and prioritize the movements of NM modes and pedestrians.

Accommodating people who are physically and mentally challenged: Designs should be such that independent and unassisted mobility can be ensured for the physically and mentally challenged. Street corners and locations of crossings should either be provided with curbed ramps or the crossing area should be raised to curb height. Audible/tactile pedestrian signal systems should be used in areas with large physically and mentally challenged population.

Signal placement: Signals should be placed for optimum visibility during critical movements without obstructing the crossing paths. Diagonal span signals should not be used as they make motorists look away from the users crossing the intersection. Box span, mast arm and corner pole signals should be preferred. Signals can also be placed on the median mainly if there are more elderly pedestrians in the population.

Illumination: All the locations that are used by pedestrians such as crossing areas, waiting areas, sidewalks, etc. should be illuminated to provide clear visibility on approaches and otherwise. This improves psychological safety and reduces hazardous exposure of pedestrians to vehicles. Special consideration should be given to pedestrian traffic generating locations, corridors and spaces.

Simplify median crossings: The safety of pedestrians crossing the roads, which are more than two-lane wide, can be improved by the provision of raised medians to work as refuge islands for the crossing pedestrians. A cut in the median should be provided just opposite to the locations where ramped curbs are constructed for physically-challenged pedestrians to cross the roads safely.

Schools: School zones should be provided with speed limits. Roadway geometrics should be improved to accommodate higher flow of pedestrians and bicyclists. This can be achieved by using raised crossings, traffic diverters, roundabouts, on-street parking layouts, other land-uses and engineering designs. Higher emphasis should be given to segregation and clear sight distances. Identification of safe routes for walking and cycling would improve the walking and cycling scenario.

Eliminate backing: Accident hazards due to parked vehicles are one of the concerns in the design of facilities. Walking in vehicle parking area should be minimized if not possible to eliminate. Design should be such that it eliminates the need for backing the vehicle. Some of the measures may be centre walkways in landscaped areas, 'U' pattern drop-offs, long throat driveways lined with sidewalks, segregated walking space between parking garages or lots and destinations, etc.

Access management: Sufficient space should be provided to the pedestrians in front of commercial establishments to encourage street-side window shopping by pedestrians. Side lot and rear lot parking are other options to provide access to shopping areas. Independent access ways should be designed to provide access to adjacent neighbourhoods.

Auto-restricted zones and parking restricted zones: Auto restricted zones should be developed at all the high pedestrian and cycling activity areas, pedestrian corridors and malls, ocean walks, greenways, river corridors and rail to transit conversions.

Combining walk with transit: Providing access or linkage to transit increases the travel distance for the pedestrian mode of travel. About 0.5 km can be considered as an acceptable walking distance to transit (i.e. between the origin and transit stop, 5–10 min walk). Transit stops should be easy to reach by walk and stops should be provided with shaded, visible, comfortable sitting or waiting space at a setback from the walkway.

Walkable scale land-use planning: New developments should favour walking over driving. The predominating designs should be based on traditional neighbourhood design, grid design, planned mixed unit development roadway systems, transit-oriented development designs, neighbourhood schools, pocket parks, neighbourhood stores, resting places along the sidewalks and facilities, locating parking on sides and behind stores, etc.

Bicycle policies

Various policies that have been implemented by different countries to improve the usage of bicycles are discussed here.

Employee commuter subsidies: Various forms of employee commuter subsidies have been used by governments and employers to stimulate commuters to use bicycle as a commuting mode. These include breakfast and bath at office, time relaxation in office hours, monetary benefits for owning and operating bicycles, awards for adhering to green policies, etc.

Support to bicycle manufacturing industry: The substantially higher use of bicycles in China and its adjacent countries has been the outcome of support that the government has given to the bicycle manufacturers in terms of relaxation and subsidy.

Allocation of urban street space: The most efficient use of road space is by rail or bus modes operating on their own dedicated right-of-way, whereas the least efficient use is by low occupancy automobiles. Bicycles are placed in this range. Under mixed traffic conditions, it is equivalent to buses. Motorized two-wheelers are placed between bicycles and automobiles. Rail modes are not cost-effective if the trip length is short or moderate, whereas for long trip lengths, cycling and walking are not efficient or practical; in combination, they are complementary.

Bike networks: Comprehensive networks of bicycle safe roads and paths are needed to attract less-skilled cyclists to use bicycles for a significant portion of their short daily trips in motor vehicle dependent cities and to avoid the diversion of cyclists to motorized modes in mixed traffic and NM transport dependent cities. These factors need to be considered in the development of bicycle networks include continuity, facility standard and function, degree of separation of modes, anticipated traffic flows by mode and available right-of-ways. The functional network hierarchy can be as follows[40].

- Collector facilities, comprising fine-grained network often shared with pedestrians and slow motorized traffic.
- Primary slow traffic facilities, a coarser network, some shared with pedestrians and slow motorized traffic and many reserved for exclusive NM mode use.
- Exclusive arterial facilities, a coarser network of exclusive facilities designed for NM modes.

Bike on transit: Bicycle access expands the potential market area of high-speed public transport services at low cost. Integration of bicycles with public transport can help in sustaining their shares in rapidly motorizing cities with mixed traffic systems; in reintegrating them; and in dealing with network capacity saturation. Adequate supporting infrastructure, including secure parking at station entrances and safe access routes, is essential to this intermodal integration. Various such systems are bike-and-ride system, bike-on-bus system, bike-on-rail system, folding bikes system, bike-on-ferries, bike-on-vanpool, park and ride system, etc. The bike-on-bus system in USA resulted in an increase in the number of cyclists between 17% and 68% in different transportation districts[41].

Bicycle facilities: In a Chinese Urban Road Traffic Manual, bicycle facilities are divided into five types, with first two types being recommended for large- and medium-sized cities[42]. These types are as follows:

- Special bicycle roads, independent of the road network and dedicated to bicycle use only, e.g. a network in the Central Business District (CBD) of Shen Zhen City.
- Semi-independent bicycle roads, positioned on one or two sides of motor vehicle lanes with physical separation.
- Non-independent bicycle roads, positioned on one or two sides of motor vehicle lanes but without physical separation.

- Mixed traffic roads, where motor vehicles and bicycles share the same right-of-way.
- Pedestrian-bicycle roads, where bicycles and pedestrians share the same right-of-way.

Poor person's car: Many low-income people in Asian and African cities cannot afford even subsidized public transport fares and have no choice but to walk or cycle for even distances of 10–20 km. Cycling often offers four to five times greater speed and is cheaper than public transport. A bicycle lasts for years and its price is equivalent to six to eight months of bus fare[42].

Employment generation by NMVs

Throughout developing countries, NMVs form the foundation for a large informal sector providing goods or services on the street or transporting people and goods on a for-hire basis. In Bangladesh, cycle rickshaws (pullers and ancillary employment) represent about 3.5% of the nation's recognized labour force. Such services or employment is vital in providing employment to unskilled low-income workers. Promoting the NMT sector can stimulate substantial economic growth in terms of employment and microenterprise development especially in low-income cities, particularly benefiting the poor[42].

Creation of environmental districts

NMV networks can be best preserved by keeping cars and motorcycles out of many existing streets in neighbourhoods thus creating environmental districts, i.e. motor vehicle restricted and traffic calmed areas. Such districts are increasingly common in many affluent cities in Europe and Japan. In some cities, extensive alley systems offer opportunities for creating NMV networks while improving traffic management like solving problems of congestion, safety and environment degradation.

Changes in regulations influencing NMV use

Replogle[42] has, on the basis of studies conducted in Asian cities, indicated that regulations and policies including taxes, fees and import duties and credit financing systems have influenced NMV production and usage of the mode has become somewhat costly. Heavy import duties on parts of NMVs on the pretext of protecting domestic or local manufacturers have rather resulted in increased cost of NMV production and operation. Instead a subsidy needs to be provided for the same. Similar is the case of the licensing fee. Restrictions on vehicle and operator licensing policy (number of licenses, license fee, etc.) create black marketing causing further monetary burden on the NMV operator. License fee for NMVs should be nominal and operator fee should be dispensed with. The restriction on the use of NMVs at different locations with the notion that they increase congestion due to slower speeds is not true and rather these are the most productive modes under congested traffic conditions.

Land use, investment patterns and NMVs

Urban form of a city has a major influence on mode choices and it also responds to transport mode needs when the city is under development. Compact form of a city promotes use of walking, cycling and public transport. The two systems interact as self-regulating systems. The pattern of buildings and transport infrastructure in a neighbourhood tells people how to travel within certain broad choice parameters. There are benefits in shifting some investment from expensive motorized transportation infrastructure and heavily subsidized public transportation to instead provide subsidies or credit to low-income workers to expand access to NMVs[42].

Planning issues

While planning for NM modes, especially for walking and cycling, the following issues need to be given due consideration.

- A policy marked as a most probable solution should be evaluated for its acceptability. A user-preference survey can be conducted for this purpose. A study conducted in the CBD area of Shanghai, China indicated higher preference for more bicycle lanes and bicycle parking spaces[43]. An underpass is preferred to an overpass and signalized crossing by pedestrians in Beijing, China based on attributes such as convenience, safety, crossing time and appearance of a facility[44]. A study conducted in Mumbai, India indicated that pedestrians prefer sheltered footpath and signalized crossing facility, based on whether the second facility is available or not. In case of bicycle facilities, physically separated bicycle lanes are preferred the most. Almost equal preference is given to bicycle paths between dwelling units in dense settlement areas, whereas in open areas marked/painted lanes are preferred. It is highlighted that compacted land use and provision of pedestrian or bicycle facilities would promote use of these modes[45].
- Walk and bicycle can both be used for short travel distances. Studies conducted in the Indian scenario indicate that pedestrians have accepted walking distances of 1700 m in Tiruchirapalli[46] and 910 m in Mumbai[47]. It is observed to be varying between 250 and 600 m in south-east countries. Similarly, the acceptable cycling distance was 5100 m in Delhi, India[20], 5200 m in Tiruchirapalli, India[46] and 2724 m in Mumbai, India[47]. It is found to be 3300 m in Indonesia[48] and 6000 m in China[11]. This indicates that users at a location or in an

area should be interviewed before planning the walk or bicycle networks.

- While designing the facilities, it is important to have an idea about the walking and cycling speeds of the users. These have been found varying in different countries and cities where the studies have been conducted. The general range for walking speed is observed to be varying between 79 and 88 m/min in USA, England and France; 64 and 94 m/min in Japan; and between 65 and 74 m/min in India, China, Philippines, Saudi Arabia, Kuwait and Thailand. Bicycle speeds are found varying between 6 and 15 kmph in Indonesia[48] and between 11 and 13 kmph in different cities of China[43,49]. The analysis of bicycle movements showed that the speed of bicycle ranges between 10 and 16 kmph in a class-I city of India[50]. The maximum bicycle speed is observed to be around 23 kmph.
- It is important to give due consideration to the composition of NM mode users. The effect of gender and age is found to be prominent in different studies conducted worldwide. In a study conducted in India[50], the difference in the speeds of male and female cyclists is not found statistically significant, although female cyclists cycle at a slower speed compared to male cyclists. The cycling speed of older cyclists is found to be significantly different from the speed of children, young and adult cyclists; and that of children is significantly different from the speed of adults. In another study[51], the walking speed of pedestrians has been observed to be decreasing with the increase in age of the pedestrians. It ranges between 63 and 66 m/min for the elderly and between 83 and 87 m/min for children. Male pedestrians are found walking faster (78 m/min) than female pedestrians by around 10%. Walking as a group causes reduction in walking speed in the range of 11% to 18%. It is also affected by the land use of the area. It is found that it increases substantially in educational land uses, whereas it reduces in shopping land uses. Group effect is prominent if the size is 5 or more[52]. Indulgence in any activity during walking obviously results in reduction in walking speeds and this is found statistically significant. Similarly, significant difference has been noted in the walking speed of health conscious pedestrians in the morning and leisure walking pedestrians in the evening.
- In case of pedestrians walking along the carriageway, another point of consideration is the type of pedestrian facility. Usually sidewalks are provided at the side of the carriageway, but in their absence, the pedestrians are forced to walk along the carriageway making them vulnerable to vehicle hits. The relationships between different flow characteristics are found to be different for the movements on the two types of facilities as defined here. The relationship for pedestrians walking on a walkway is found to be exponential between pedestrian speed and density; pedestrian flow and density; and for pedestrian flow and area module, but was logarithmic between pedestrian speed and flow. In case, pedestrians are walking on a carriageway, it is linear between pedestrian speed and density, but quadratic in the rest of the cases[53]. In another study[52], female pedestrians are found getting less affected due to change in the size of the facility, whereas it is the opposite for young adults and elderly pedestrians. The increase in the size of the facility has resulted in lower walking speeds than normal. The gap in individual speeds due to gender effect is found reducing with an increase in the size of the facility.
- It is suggested that pedestrian flow values for the design of facility purposes should be adjusted based on the speed of the pedestrians. Depending upon the change in walking speed with respect to the overall mean walking speed, this is found varying between 0.79 and 1.34. The size of the facility should be decided based on the adjusted flow value[52]. Pedestrian speeds also get influenced by the geographical region character[54].
- From this discussion, it is obvious that due consideration has to be given to the crossing requirements of the pedestrians. In general, a speed of 1.2 m/s is used in different design manuals as the walking speed of pedestrians while crossing a road and the same is used for the design of pedestrian signals as well. Vamsheedhar[55] observed that 15th percentile crossing speeds were in the range of 0.83 and 1.02 m/s (mean 0.95 m/s), which were quite lower than the one used in signal designs. These get influenced by the width of the road, traffic volume, size of an urban area, type of an area/land use, etc. Significant difference was found in the crossing speeds of pedestrians on a three-lane-undivided, four-lane-divided and six-lane-divided roads, as well as, between gender-based speeds and speeds in different age groups. Friction experienced while crossing the road due to two-way traffic affects the higher crossing speed band rather than the lower crossing speed band. The speeds are found lower than those reported from studies conducted in USA, UK, Canada, Sweden, Bangkok and Jordon.
- In a study[56] on pedestrian crossing movements, it was found that the average gap accepted by a pedestrian in India is higher than that reported in the literature. Female pedestrians usually accept larger gaps than male pedestrians, but with an increase in width of the road, this difference becomes insignificant. Pedestrians are observed crossing the road in three patterns, namely single, rolling and two stages. The average values of the accepted gap for single, rolling and two stages crossing are 8.7, 9.3 and 9.14 s respectively. The skewness value is found to be positive for different pedestrian characteristics indicating that pedestrians prefer a safety margin while crossing the road. The relationship between conflicting flow and accepted gap follows an inverse function while a power function best suits the relation between crossing speed and the accepted gap. The critical gap was found to increase with road width and decrease with traffic volume. Average critical gap was found to vary from 3.44 to

11.86 s depending upon the road width. Based on gender, the critical gap is found varying between 2.9 and 12.8 s and based on age between 3.0 and 13.8 s.

- A problem that is faced by pedestrians in many developing countries is that of encroachment of the pedestrian facility by hawkers, vendors and shopkeepers. The reduction in the width of a facility acts as a bottleneck. It has been observed that bottlenecks cause reduction in walking speeds up to 20% depending upon the size of the bottleneck; female pedestrians increase their speed when approaching narrow bottlenecks and even walk faster than male pedestrians; a pedestrian pair walks faster than pedestrian groups at bottlenecks, whereas bigger group sizes split themselves in suitable parts to cross the bottleneck; if possible pedestrians avoid passing through a bottleneck by readjusting themselves to side openings if available, or to the carriageway; and this decision is taken in a time frame of 1–4 s before reaching the bottleneck.

Conclusion

Economically efficient, equitable and sustainable urban transportation planning can be achieved by switching from complete automobile dependence to multi-mode transportation system, including NM modes. The use of these modes can reduce the investment requirements from sixth to sixtieth fraction of that required for motorized facilities. The external cost component if accounted may be found to be equivalent to some of the small economies of the developing countries. At the household level, the shift from automobile dependence to multi-mode dependence can save 44% of these costs, out of which one-third goes to the society and two-thirds to the user household. They provide more capacities at a very less cost compared to automobiles. For deriving benefits of NMV use, various push-and-pull policies have been suggested. The basic emphasis has been on the provision of facilities, restriction on automobile use and on devising land-use development approach matching settlement patterns, community size and transport technology. Further, planning for NM modes is based on the two-flow characteristics, namely speed and flow. The information gathered through various studies has been disseminated, which can help in the planning of facilities.

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