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Re-examination of the standards for transit oriented development influence zones in India

Sangeetha Ann
Nagoya University
sangeetha.ann@gmail.com

Meilan Jiang
Nagoya University
jiangml@trans.civil.nagoya-u.ac.jp

Toshiyuki Yamamoto
Nagoya University
yamamoto@civil.nagoya-u.ac.jp

Abstract: Transit oriented development (TOD) is a land-use and transport integrated urban planning strategy that is highly acclaimed for promoting sustainable city development. This review aims to identify the problems regarding adoption of TOD standards or guidelines formulated by developed countries in developing countries, such as India, and the necessity of conducting adaptability studies on TOD influence areas. The existing studies show that the size of the influence area varies among different cities and travel modes. Accordingly, no single size influence zone is suitable for all cases. This review highlights the necessity of carefully considering the spatial extent of influence areas and modes other than walking as access or egress modes in the Indian context. Moreover, this review aims to provide insight on how to plan TOD in the context of developing countries, because the mobility patterns in these countries differ considerably from those in the developed world.

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1 Introduction

Transit oriented development (TOD) is a concept focusing on station area development linking transit, land use and community living and was popularized by Peter Calthorpe in his book "The New American Metropolis" (Calthorpe, 1993; Carlton, 2007). TOD as a planning strategy was derived in North America where large cities have experienced low-density sprawl, which has worsened traffic congestion and degraded the quality of the environment in the 1990's (Sung, 2011). Cities in Europe and Asia have historically been transit oriented with mixed land use, pre dominance of pedestrians and cyclists, and transit services (Renne, 2009; Thomas, et al., 2018).

The TOD integrates land use and transport for the enhancement of urban communities with the primary goal of increasing transit use and other means of sustainable transport, such as walking and cycling. Moreover, various studies have been performed to understand the TOD and its elements and to specify the standards for its planning. The TOD has multiple definitions, and various cities in the

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developed world have adopted guidelines and standards for its planning and implementation. The influence area is a major element in the TOD; typically, a half-mile radius (approximately 800 m) is adopted as the basic dimension for this area in relation to the TOD planning in developed countries. However, there is lack of consensus among researchers on whether this is a correct practice. Furthermore, in recent years, cities in developing countries, such as India, have started adopting the TOD as part of their city planning strategies. The government of India published the National Transit Oriented Development Policy and corresponding guidelines to assist their cities in the adoption of TOD. However, it should be noted that these guidelines are substantially based on strategies devised by developed countries; thus, it is necessary to examine their suitability in the context of Indian cities. This study discusses the extent of the TOD influence area and the problems related to it. The objective of the paper is to establish the need for research regarding TOD influence areas in Indian cities and does not focus a general literature review. There is a dearth of data and research regarding mobility research in India and the existing studies show that the influence areas can be extended to a larger area than specified in the policy. The methodology used for this paper is given in Fig. 1.

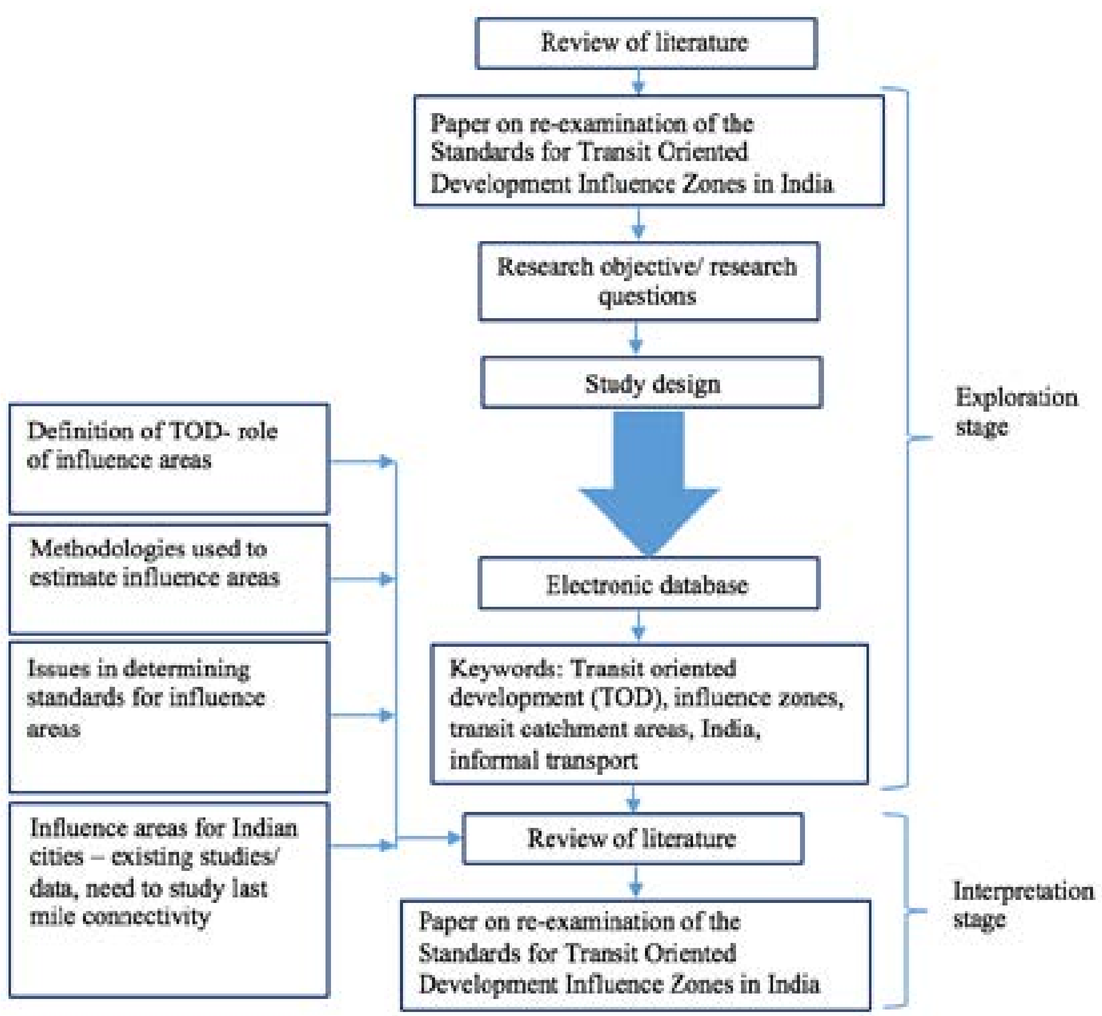

Figure 1. Study methodology

This paper is structured into six sections. The background is presented in Section 1. The definition of the TOD is discussed in Section 2. Section 3 explains the influence areas of TODs and a general view of how these influence zones are determined. Section 4 discusses the problems in determining the standards for influence areas. Section 5 presents the TOD influence zones in Indian cities. The conclusion and future direction of the study are provided in Section 6.

2 Definitions of TOD

The TOD has no universal definition. Some of the definitions found in literature are given below:

1. "A mixed-use community within an average 2,000-feet (or 10-minute) walking distance of a transit stop and core commercial area. TOD mixes residential, retail, office, open space, and public uses in a walkable environment, making it convenient for residents and employees to travel by transit, bicycle, foot, or car" (Calthorpe, 1993)
2. "Development within a specified geographical area around a transit station with a variety of land uses and a multiplicity of landowners" (Salvensen, 1996)
3. "The practice of developing or intensifying residential land use near rail stations" (Boarnet & Crane, 1998)
4. "A mixed-use community that encourages people to live near transit services and to decrease their dependence on driving" (Still, 2002)
5. "Mix of uses, at various densities, within a 1/2-mile radius around each stop" (Dittamar & Ohland, 2004)
6. "An approach to expansion that aims to encourage the development of mixed use and compact, increasing the number of passengers of public transport and creating more livable communities" (Arrington & Cervero, 2008)
7. "Concentrated mix of moderately dense and pedestrian friendly development around transit stations to promote transit riding, increased walk and cycle travel and other alternatives to use of private cars" (Cervero, 2009)
8. "A planning technique that aims to reduce automobile use and promote the use of public transit and human-powered transportation modes through high density, mixed-use, and environmentally friendly development within areas of walking distance from transit centers" (Sung, 2011)

One of the main learnings gained from the review of these definitions is that the TOD is typically defined as a highly dense and mixed-use development around the transit station where the benefit of proximity to the station would promote transit usage rather than simply a planning strategy. The practice or the strategy itself can also be called TOD; moreover, it can be regarded that the term TOD can be synonymous with planning strategy, design, and development. The basic objective of the TOD is to reduce car dependence by reducing trip lengths as well as promoting the use of mass transit and sustainable modes, such as walking and cycling. The benefits that were achieved through the implementation of successful TOD projects include reduced traffic congestion, improved air quality, and affordable housing. Moreover, livable communities were created, sustainable transport was achieved, and the use of transit and non-motorized transport (NMT) as well as opportunities to live, work, shop, and relax increased (Cervero & Kockelman, 1997; Cervero, Ferrell, & Murphy, 2002; Shastry, 2010; Cervero & Ewing, 2014). The aforementioned definitions provide the basic features that are essential for developing the TOD. A variety of factors and their combinations are typically utilized to define and explain the TOD. These factors include the proximity to a transit station (based on distance or time), density levels, mixed land use, walking and cycling accessibility, effect of reducing car use, main travel mode, and the availability of public spaces to build communities (Cervero, 1997; Cervero, et al., 2002; Lund, Cervero,

& Wilson, 2004). Based on these definitions, a definition for the TOD is suggested in this review: *an urban planning strategy that aims to promote sustainable transport by creating more affordable housing and job availability by means of increased densification around mass transit stations. This especially developed area will have a mixed land use that supports a vibrant community life, and its extent will be determined by the types of mobility modes serving first or last-mile connectivity and area characteristics.*

3 Influence areas of TOD

The influence area can be defined as the "area polarized by a center for a set of relations (influence area of a city) or a category of relations (area of cultural or commercial influence, trading area)" (Rodrigue, 2017); moreover, it is often described as the use of access distance and access time (or both) to transit. These specifications are further based on the various travel modes that are used for last-mile connectivity. This section discusses the various means reported in literature to specify the influence area of the TOD. In literature, this area has been specified based on access distance, which directly provides the geographic extent of the TOD. A distance of 600 m (2000 ft) was introduced by Calthorpe (1992, 1993). Untermann (1984) and Dittamar and Ohland (2004) determined the distance as 800 m (1/2 mi). These aforementioned distances have been specified based on the walking distance that people prefer to transit (Cervero, Bernick, & Jill, 1994; Bernick & Cervero, 1997; Guerra, Cervero, &Tischler, 2012). Guerra et al. (2012) raised doubts about the feasibility of adopting 800 m (1/2 mi) as the de facto standard for TOD in the United States as it is "more an artifact of historical precedent than a statistical or analytical construct". To determine the extent of TOD influence areas, some literature refer to a single distance, whereas it is reported that others use a distance range as basis. Guerra et al. (2012) and Flamm and Rivasplata (2014) emphasized that in the U.S, the radius of influence area can vary between 400 and 800 m (1/4 - 1/2 mi); consequently, various cities have adopted different radii for the TOD. In California, ordinances support the extent of the TOD projects to radii of 400, 550, and 800 m (1/4, 1/3, and 1/2 mi, respectively) around the transit station (Cervero et al., 1994). Portland has adopted a 400 m radius (1/4-mi); Washington County, Oregon has adopted 800 m (1/2 mi); San Diego has adopted 600 m (2000 ft), which is approximately 550 m (1/3) (Community Design + Architecture, 2001). These distances have also been expressed in terms of time. Researchers defined the extent of the TOD based on the distance that transit stations can be accessed by people within a specified time. Bernick and Cervero (1997) suggest that a 5-min walk corresponds to a 400 m (1/4-mi) distance. On the other hand, Calthorpe (1993) assumed that a 10-min walk is equivalent to an 800 m (1/2-mi) distance.

Few researchers have attempted to establish these distances based on empirical analysis. Guerra et al. (2012) conducted a study that used secondary data from across 20 US transit agencies; they also built station-level direct demand models of transit ridership based on regression modeling. Chia and Lee (2015) used the walking time decay function to determine the willingness of people to walk. Zhao, Chow, Li, and Gan (2003) combined both regression and distance decay methods to determine the accessibility levels around transit stations. In other cases, simple statistical methods, such as the mean or median (or both) distances and percentile distances were calculated to determine the influence areas of transit stations (Agrawal, Schlossberg, & Ir, 2008; El-Geneidy, Grimsrud, Wasfi, Tétreault, & Legault, 2014; Flamm & Rivasplata, 2014). Most of these studies focused on walking as access mode (Agrawal et al., 2008; Guerra et al., 2012; El-Geneidy et al., 2014; Chia & Lee, 2015), whereas a few focused on cycling (Martens, 2004; Flamm & Rivasplata, 2014). The results are summarized in Table 1.

Data availability and the accuracy of these data are crucial in performing such studies. Data regarding access and egress are not collected or are limited in most countries (Rietveld, 2000). In addition, the distances reported by commuters often do not match the actual distances travelled. This is a point Agrawal et al. (2008) highlighted; accordingly, their study also included a spatial analysis to measure

the actual distances. Typically, commuters tend to round distances to some extent when responding to surveys. To overcome this drawback, route mapping with the use of geographic information system (GIS) is an effective approach. Otherwise, methods such as multiple imputation can be used to correct the rounded data (Heitjan & Rubin, 1990; Drechsler & Kiesl, 2016). In cases where origin–destination data were available, these data may be geocoded and validated to obtain more accurate distances (El-Geneidy et al., 2014).

Table 1. Studies on determining influence or catchment areas

Study	City/area	Main mode	Access mode	Trip purpose	Data on distance	Methodology	Result
Zhao et al. (2003)	Southeast Florida, USA	Public transit	Walking	All	Based on questionnaire, addresses were assigned to streets using GIS to calculate shortest distance	Regression analysis; distance decay method was employed; GIS was used to calculate walking distances from route map	No noticeable increase in accessibility was observed after 800 m; drops were noticed at 550 m(1800 ft) and at 820 m (2700 ft)
Martens (2004)	Netherlands, Germany, the United Kingdom	Bus, metro rail, tram, train	Cycling	All	Based on results and secondary data from other studies[1]	Compared travel behavior of bicycle riders and commuters in Netherlands, Germany, and UK based on other studies	Faster main modes attract bicycle and ride users from distances of up to 4–5 km; slower modes attract users from no more than 2–3 km
Agrawal et al. (2008)	California and Oregon, USA	Rail transit	Walking	All	Based on questionnaire, distances walked reported by respondents and route were entered into GIS database	Simple statistics; reported and actual mapped distances were compared	Mean distance was 800 m (0.5 mi)
Guerra et al. (2012)	20 transit agencies, USA	Heavy rail, light rail, bus rapid transit	Walking	All	Based on secondary data; model used distance bands to estimate direct demand models for 1449 high-capacity American transit stations; population and number of jobs within these bands were estimated	Regression modeling was used to predict average weekday boarding and alighting using a variety of radial transit catchment buffers of 400 m width (1/4- mi)	800 m (1/2 mi) catchment in residential areas and 400 m (1/4 mi) for work trips; for estimating station-level transit ridership, the radius only had a minor influence on the model's predictive power
El-Geneidy et al. (2014)	Montreal, Canada	Bus, commuter rail	Walking	All	Data on 2003 transit users in Montreal; OD survey was used in which trip-ends are geocoded and routes were also recorded	Multi-level regression, geocoding applied on OD data	For bus transit, 524 m; for commuter rail, 1259 m
Flamm & Rivasplata (2014)	Philadelphia and San Francisco, USA	Bus, light rail, heavy rail, ferry	Cycling	Work and non-work	Based on questionnaire; distances were based on estimates given by cyclists; to cross-check these distances, origin–destination distances were calculated using Google maps	Simple statistics	Average of 4500 m (2.8 mi) and 8700 m (5.4 mi) for Philadelphia and San Francisco, respectively
Chia & Lee (2015)	South East Queensland, Australia	Public transit	Walking	All	Secondary data were obtained from 2009 South East Queensland Travel Survey (SEQTS), in which self-reported distances are available	Walking time decay function; one-way analysis of variance used to differentiate among user groups	Two major drops where people were willing to walk were observed: 268 m (4 min) and 670 m (10 min)

[1] Van Goeverden and Egeter (1993) for Netherlands; Bickelbacher (2001) for Germany; Taylor and Mahmassani (1996) for UK.

4 Issues in determining standards for influence areas

Various researchers have suggested different radii or a range of acceptable distances based on empirical studies (Guerra et al., 2012; Park, Deakin, & Jang, 2015). The standards for influence areas are based on walking as the access mode; these areas do not represent the catchment area of commuters who cycle, skate, or use informal modes, such as auto rickshaws or pedi-cabs, for their first or last-mile connectivity. Calthorpe (1993), Bernick and Cervero (1997), DoT Maryland (2000), DoT California (2001), and Jiang (2012) have explained the TOD and the corresponding influence area using walking as the access mode. The normally accepted radius of 800 m (1/2 mi) and other distances, such as 400, 550, and 1200 m (1/4, 1/3, or 3/4 mi, respectively), have been quoted in these aforementioned works bearing in mind the distance that "most" people are willing to walk to transit (Cervero et al., 1994; Bernick & Cervero, 1997; Guerra et al., 2012). The half-mile (800 m) radius commonly represents the walk shed of pedestrians and has been derived based on the observation that most pedestrians are willing to walk 15 min to access transit stations at an average speed of 3.2 km/h (2 mi/h) (Agrawal et al., 2008). Untermann (1984) adds that this distance is also dependent on whether the environment is conducive and pleasant. This conclusion is based on the travel patterns in American cities; however, it does not necessarily hold true for European and Asian cities, which have distinctly different travel patterns (Park et al., 2015).

There are researchers who have included other mobility options in explaining TODs but it is limited to bicycles. The distances covered by these modes are typically greater than the distances covered by walking. Studies conducted show that cyclists travel longer distances to reach transit stations than people who walk (Hochmair, 2013; Flamm & Rivasplata, 2014; Lee et al., 2016). Flamm and Rivasplata (2014) examined the behavior of cyclists in Philadelphia and San Francisco and found that they travelled an average of 4500 m (2.8 mi) and 8700 m (5.4 mi) on cycle-transit trips, respectively; these indicate larger catchments for bicycle users. Lee, Choi, & Leem (2016) stressed the importance of bicycles to increase the extent of TOD and its benefits. The study estimated the distances accessed by bicycles in Korean cities as 1.96 and 2.13 km for origin (home)-to-station and station-to-work trips, respectively. This indicated that if a bicycle is used for planning the TOD, then 73.7% and 93.6% of the entire area of Seoul would be covered, whereas a conventional walking-only TOD can cover only 29.9% of the area. The catchment ranges of feeder buses and car (kiss and ride) was estimated in the range, approx. 2000 – 6000 m and approx. 1000 – 7000 m respectively (Gil & Read, 2012); increasing the influence area of transit services to a larger extent. Therefore, a walk-based TOD is not always necessary; however, it should include other modes of last mile connectivity.

Currently, remedies are being implemented to resolve this problem. In their policy regarding pedestrian and bicycle mobility improvements (FTA, 2011), the Federal Transit Authority (FTA, USA) proposed 800 m (1/2 mi) and 2400 m (3 mi) for pedestrians and cyclists, respectively. This proposal revises the earlier 400 m (1500-ft) radius that considered only pedestrians. Additionally, the policy mentions that a 800 m (1/2 mi) radius is a conservative measure and the area can be extended assuring that people can walk safely and conveniently to reach the transit. Evidently, adherence to standards is not extremely strict. Hence, policy changes have been implemented in the past based on studies that reflect the last-mile mobility patterns of commuters. The states of Maryland and Oregon explain the TOD areas based on walking, bicycles and automobiles, thus emphasizing multimodal access to transit stations (DoT Maryland, 2000). Gutiérrez, Cardozo, & Garcia-Palomares (2011) considered the importance of feeder buses for rail transit-based TODs. If modes other than walking can be considered, the distance can be effectively increased. Therefore, the commonly accepted standards may not be appropriate in cities where different access modes other than walking are used.

The use of different modes to access transit stations is especially relevant in urban and suburban areas. Literature also suggests that catchment areas have to be different based on the type of transit used (either in urban or suburban areas). In suburban areas, the walkable distance in the catchment area has been set to 400–800 m (Ker & Ginn, 2003). Ker and Ginn (2003) indicated that commuters walked shorter distances to suburban stations (800 m) compared with distances covered to reach urban stations (1 km). However, when delineating a catchment area, Cervero (1997) suggests that these catchment areas in urban areas could be larger than those in suburban areas because of low residential densities and extensive parking spaces. Therefore, it can be deduced that even if people walk shorter distances to transit stations in suburban areas, the catchment areas of these stations are larger than those in the urban areas.

Various studies show that the size of influence zones is also based on the type of transit (main mode). The common understanding is that people walk more to access rail stations (800 m or 1/2 mi) compared with the distance covered to access bus stations (400 m or 1/4 mi) (O'Sullivan & Morrall, 1995; Morrall & O'Sullivan, 1996; Gutiérrez & Garcia Palomares, 2008; Zielstra & Hochmair, 2011). However, opinions differ among researchers regarding these catchment area sizes. A guide published by Snohomish county indicates that commuters are generally willing to walk more to the rail transit (400–550 m) compared with accessing the bus transit, which is a 300 m (1000 ft) walk; this highlights the difference in catchment areas based on the transit mode. In Ireland, the basic rule is that commuters are willing to walk 1 km to access rail stations (O'Connor & Harrison, 2012).

The difference in catchment areas can be observed based on the type of rail transit (APTA, 2009). The APTA standards also indicate that transit ridership decreases as the distance from transit stations increases; the standards adopted by APTA are summarized in Table 2.

Table 2. APTA specifications for transit catchment areas (Source: APTA, 2009)

	Local street transit	Rapid street transit	Semi rapid transit	Regional transit	Rapid transit
Core station area	NA	200 m (1/8 mi)	400 m (1/4 mi)	400 m (1/4 mi)	550 m (1/3 mi)
Primary catchment area	200 m (1/8 mi)	400 m (1/4 mi)	800 m (1/2 mi)	800 m (1/2 mi)	1100 m (2/3 mi)
Secondary catchment area	800 m (1/2 mi)	1600 m (1 mi)	3200 m (2 mi)	8000 m (5 mi)	4800 m (3 mi)

Hochmair (2013) suggests that this difference in catchment areas also applies to cyclists and specifies the distance as 1600 m (1 mi) and 3200 m (2 mi) for community hubs and gateway hubs, respectively. Additionally, certain studies show that based on trip purpose, the distance people walk or cycle to access transit stations can vary (Guerra et.al., 2012; Lee et.al., 2016). Therefore, it can be remarked that a single standard or de facto value cannot be applied for determining the scale of TODs. The various influence areas based on different factors are summarized in Table 3. It emphasizes that the adoption of a single standard for the influence area is not advisable.

Table 3. Size of influence areas

Factors used for defining TOD	Quantitative or Qualitative values assigned
Distance	-400 m (Bernick & Cervero, 1997)
	-800 m (Untermann, 1984; Dittamar & Ohland, 2004; FTA, 2011)
	-400–800 m (Cervero et al., 1994; Cervero, 1997; Community Design + Architecture, 2001; Guerra et al., 2012; Flamm & Rivasplata, 2014)
	-2000 ft or 600 m (Calthorpe, 1992, 1993)
Time	-5-min walk (Bernick & Cervero, 1997)
	10-min walk (Calthorpe, 1993)
Access mode	-Based on walk as access mode, distances vary from 400 to 800 m (Calthorpe, 1993, 1994; Cervero et al., 1994; Bernick & Cervero, 1997; Cervero, 1997; Untermann, 1984; Dittamar & Ohland, 2004; Community Design + Architecture, 2001; Guerra et al., 2012; Flamm & Rivasplata, 2014
	-4800 m for cyclists (FTA, 2011)
	4500 m and 8700 m in Philadelphia and San Francisco for cyclists, respectively (Flamm & Rivasplata, 2014)
	-1.96 and 2.13 km for home-to-station and station-to-work trips for cyclists, respectively (Lee et al., 2016)
Type of area	-Walkable catchment area in suburban areas, 400–800 m, and in urban areas, 1 km (Ker & Ginn, 2003)
Main mode	-800-m access to rail station (Morrall & O'Sullivan, 1996; Gutiérrez & Garcia Palomares, 2008; Zielstra & Hochmair, 2011)
	-1 km access to rail station (O'Connor & Harrison, 2012).
	-400-m access to bus station (Morrall & O'Sullivan , 1996; Gutiérrez & Garcia Palomares, 2008; Zielstra & Hochmair, 2011)
	-The primary catchment area for local street transit (200 m), rapid street transit (400 m), semi-rapid transit and regional transit (1/2 mi or 800 m), and rapid transit (2/3 mi or 1100 m) (APTA, 2009)
Trip purpose	-800 m catchment areas for home-based trips of residents and 400 m catchment areas for access to work (Guerra et al., 2012)
	-1.96 km for origin (home)-to-station and 2.13 km for station-to-work trips for cyclists (Lee et al., 2016)
	-150–300 m for external employees and 2400 m for residents (City of Redmond Planning Commission, 2014)

5 TOD influence areas in Indian cities

The TOD concept is not new to Asian countries; however, the term "TOD" may not have been used (Sung, 2011). Some researchers claim that the TOD in Asia has not been applied on the basis of sustainability; instead, it has been treated as a function of density and land shortage—a function that is yet to be applied to the US or Australian cities (Kachi, Kato, & Hayashi, 2005). In Japan, the concept is explored using the term "compact city" (Kachi et al., 2005). Seoul is another example of an Asian city with dense development characteristics; Hong Kong similarly illustrates such characteristics. Loo, Chen, and Chan (2010) considered two different regression models with different factors and in different combinations to study the rail-based TOD and take into consideration the difference between New York and Hong Kong. The study stressed that place-specific factors should be considered while examining railway patronage in different cities. Therefore, it can be deduced that the direction in which cities approach factors, such as density, diversity, and design, varies according to the character and customs of a city and is essentially reflected in its mobility culture (Wilson, 2013).

In 2015, the Ministry of Urban Development of India gave notification pertaining to the National (TOD) Policy (MoUD, 2015) to promote sustainable urbanization in Indian cities. The cities have been advised to incorporate the TOD in their master and development plans and identify transit influence zones along transit corridors. The central government issued the TOD Guidance Document in May 2016 (MoUD, 2016) to facilitate the planning and implementation of TOD plans in cities. The TOD is also being promoted in the country through the 2017 Metro Policy (MoHUA, 2017a) and the proposed 2017 Green Urban Mobility Scheme (MoHUA, 2017b). Under the policy, the TOD has been made under the Green Urban Mobility Scheme, and the satisfaction of these criteria has been made a priority for receiving financial assistance in the development of metro infrastructures. The TOD guidance document asserts that the priority should not focus on increasing density, but on promoting NMT infrastructures, mixed land uses, and improving the first-and-last-mile connectivity, street-oriented buildings, and parking management. In the document, the mass transit system is not specified as a prerequisite for the TOD because high-quality local bus systems are also included as part of the TOD. Evidently, there is a necessity to adopt the TOD considering the different characteristics of the proposed areas.

The National Transit Oriented Development (TOD) Policy defines the influence zone of transit stations as walking distances of 500–800 m (i.e., 10–12-min walking distances) when the transit station spacing is approximately 1 km. When the distance between the transit stations is less than 1 km, then the influence areas of adjacent stations overlap, and the influence zone becomes a delineated zone with a radius of 500 m. The influence zone is defined as "the area in the immediate vicinity of the transit station, i.e., within a walking distance, having high density compact development with mixed land use to support all basic requirements of the residents is called the influence zone of a transit station/ corridor" (MoUD, 2015). The policy calls for these zones to be clearly demarcated by responsible authorities based on supporting principles for its selection and should be verified through master plans and local area plans before implementing the TOD project. The influence area standards adopted for some of the Indian cities are summarized in Table 4.

Table 4. Influence area standards adopted by various Indian cities

	Influence area	Transit mode	Comments
National Transit Oriented Development (TOD) Policy	500–800 m	Transit mode not specified	Delineated zone of 500 m is specified on either side of transit corridor when distance between transit stations is less than 1000 m
TOD Guidance document	500–800 m, (10-min walk or cycling), Buffer along transit line, 400–1000 m (5–10-min walk around stations), Individual parcel within a 5–10-min walking distance (800–1000 m) from station	MRTS, Public transit including buses	Specifies influence area on corridor and station area level
New Delhi	Intense zone - 300 m, Standard TOD zone - 800 m (10-min walk), TOD transition zone - 2000 m (10-min cycling) (UTTIPEC, 2012), Delhi Master Plan 2021 specifies a belt with a width of approximately 500 m on both sides of MRTS corridor	MRTS, Metro	Buffer on both sides of MRTS line, Different scales for station areas, Advise to conduct ped-shed analysis
Naya Raipur	400 m (5-min walk) and 800 m (10-min walk)	Bus Rapid Transit System (BRTS)	Circular buffer around transit station
Ahmedabad	200 m - BRTS 200 m – Metro	BRTS, Metro	200-m buffer on both sides of transit route, local area plans developed
Mumbai	Gateway zone - 250 m Intermediate zone – 500 m Outer zone -1000 m	MRTS-Suburban rail, metro	
Cochin	500 m buffer	Metro	Buffer on both sides of MRTS line, Pedestrian networks drawn for each station; 250 m inner circles for station area

The "half-mile radius" (800 m) is the de facto standard that is used in TOD plans, especially in the United States (Guerra et al., 2012). Although this standard, which is based on the willingness to walk, might be applicable to North American cities, it is necessary to determine whether it is applicable in the context of developing countries, such as India. A comparison of typical transport characteristics of various global cities has been shown in Table 5. The table highlights that the unlike other global cities, Indian cities have existence of modes like auto rickshaws, cycle rickshaws, etc. which is not present in other cities.

Table 5. Comparison of typical transport characteristics in cities

City/country	Mode share	Type of urban transit	Modes used for last mile connectivity	Average GDP	Cost of monthly public transport pass	Average vehicle ownership
New Delhi, India	Walking (35%), bus (27%), two-wheelers (14%), car/taxi (9%), auto rickshaw (5%), bicycle (4%), metro (3%), cycle rickshaw (2%), sub urban train (1%) (Report of High Powered Committee on how to decongest Delhi, 2014)	Bus, subway, sub-urban rail (Report of High Powered Committee on how to decongest Delhi, 2014)	Auto rickshaws, cycle rickshaws, electric rickshaws, Gramin seva (Ann et al., 2019), taxis (Basu, Varghese, & Jana, 2017)	US $370 billion (2016) (Deloitte, 2019)	US $22 (Deloitte, 2019)	Approximately 352 private vehicles per 1000 persons (2018) (calculated with data from (Delhi government, 2018) and (UNESCAP, 2018)
Mumbai, India	Public transit (70%), private car (14%), walking (1%), bicycle (2%), other (13%) (Deloitte, 2019)	Metro, bus, light rail, commuter train (Deloitte, 2019)	Feeder buses (Embarq, 2014), auto rickshaws, taxis (Basu, Varghese, & Jana, 2017)	US $416 billion (2017) (Deloitte, 2019)	US $15 (Deloitte, 2019)	68 cars per 1000 persons, 122 motorcycles per 1000 persons (2014) (Schiller & Kenworthy, 2017), 131 vehicles per 1000 persons (calculated with data from (Statista, 2019) and (UN, 2016))
Singapore	Public transit (44%), private car (29%), walking (22%), bicycle (1%), other (4%) (Deloitte, 2019)	Metro, bus, ferry, light rail (Deloitte, 2019)	Walking, bus, LRT (Mo, Shen, & Zhao, 2018), bicycle (Shen, Zhang, & Zhao, 2018)	US $296.9 billion (2016) (Deloitte, 2019)	US $68 (Deloitte, 2019)	109 private vehicles per 1000 persons (2018) (calculated with data from (LTA, 2018) and (Statistics, 2018)
Hong Kong, China	Public transit (88%), private car (7%), walking (3%), bicycle (2%) (Deloitte, 2019)	Metro, tram, bus, ferry (Deloitte, 2019)	Light rail, bus, mini bus, tram (Transport Department, 1998) , car (Govt. of Hong Kong, 2018), bicycle , walking	US $326.4 billion (2017) (Deloitte, 2019)	US $67 (Deloitte, 2019)	74 motor vehicles per 1,000 people , 56 cars per 1000 people (2009) (Trading economics, 2009) 82 private cars per 1000 population (2019) (calculated with data from (CEIC, 2019) and (Worldometers, 2019)
Tokyo, Japan	Public transit (19%), private car (45%), walking (19%), bicycle (16%), other (1%) (Deloitte, 2019)	Metro, bus, ferry, light rail, commuter rail (Deloitte, 2019)	Walking, bicycle	US $1.6 trillion (2017) (Deloitte, 2019)	US $73 (Deloitte, 2019)	231 automobiles per 1000 persons (Ministry of Land, Infrastructur, Transort and Tourism, 2017)
Bogota, Brazil	Public transit (36%), private car (13%), walking (46%), bicycle (4%), other (1%) (Deloitte, 2019)	Bus (Deloitte, 2019)	Bicycle (Deloitte, 2019), walking	US $159 billion (2014) (Deloitte, 2019)	US $40 (Deloitte, 2019)	165 motor vehicles per 1000 persons (Secretaría Distrital de Movilidad, 2013)
New York, USA	Public transit (30%), private car (33%), active means (38%, including bicycle (1.3%) (Steer, 2019)	Buses, commuter rail, light rail, ferries, subway (NYC Department of City Planning, 2011)	Walking, cars, bicycle (Steer, 2019), taxis, pedicabs (NYC Department of City Planning, 2011)	US $1275.14 billion (Department of Numbers, 2016)	US $121 (Gothamist, 2017)	220 cars per 1000 persons (New York City Mobility Report, 2016), 430 vehicles per 1000 persons (Newton, 2010)
Vancouver, Canada	Public transit (14%), private car (72%), walking (10%), bicycle (2%), other (2%) (Deloitte, 2019)	Bus, metro, ferry, commuter rail (Deloitte, 2019)	Walking, bicycles (Kenneth, 2019)	US $129.9 billion (2016) (Deloitte, 2019)	US $133 (Deloitte, 2019)	111 vehicles per 1000 persons (Citified.CA Staff, 2018)
Copenhagen, Denmark	Public transit (27%), private car (26%), walking (6%), bicycle (41%) (Deloitte, 2019)	Metro, bus, commuter rail (Deloitte, 2019)	Walking, bicycle, car, bus (Halldórsdóttir, Nielsen , & Prato, 2017)	US $122 billion (2016) (Deloitte, 2019)	US $106 (Deloitte, 2019)	291 cars per 1000 persons (Copenhagenize.com, 2012)
London, United Kingdom	Public transit (49%), private car (26%), walking (20%), bicycle (5%) (Deloitte, 2019)	Metro, tram, bus, commuter rail, ferry, bicycle (Deloitte, 2019)	Walking, bicycle, taxi, bus (Network Rail, 2011)	US $831 billion (2016) (Deloitte, 2019)	US $195 (Deloitte, 2019)	300 cars per 1000 persons (Transport for London, 2012)
Amsterdam, Netherlands	Public transit (17%), private car (20%), walking (29%), bicycle (32%), other (2%) (Deloitte, 2019)	Metro, bus, ferry, tram, commuter train (Deloitte, 2019)	Walking, bicycle, public transport (bus/tram/metro to and from rail transit) (Meng, Koh, & Wong, 2016) – for Netherlands	US $121 billion (2013) (Deloitte, 2019)	US $108 (Deloitte, 2019)	247 cars per 1000 persons (Central Bureau voor de Statistiek, 2014)
Sydney, Australia	Public transit (25%), private car (59%), walking (4%), bicycle (3%), other (9%) (Deloitte, 2019)	Commuter rail, light rail, bus, ferry (Deloitte, 2019)	Walking, bicycle, buses, cars, taxi (Charles & Galiza, 2013)	US $123 billion (2015) (Deloitte, 2019)	US $129 (Deloitte, 2019)	720 motor vehicles per 1000 persons aged 18-84 in private dwellings (Charting transport, 2016)
Melbourne, Australia	Public transit (16%), private car (72%), walking (3%), bicycle (2%), other (7%) (Deloitte, 2019)	Commuter train, tram, bus (Deloitte, 2019)	Bus, tram, car, bicycle (Galiza & Charles, 2013), walking	US $303.6 billion (2015) (Deloitte, 2019)	US $111 (Deloitte, 2019)	800 motor vehicles per 1000 persons aged 18-84 in private dwellings (Charting transport, 2016)

In Indian cities, walking has a high share in the overall modal share, and people tend to walk longer distances (Embarq, 2014). Moreover, differences in the average walking distances across various cities should also be considered. However, the lack of adequate data and studies pertaining to Indian cities mainly limits the examination of this walking culture and the access–egress patterns; a few studies could be found to determine the walking or cycling distances in Indian cities. The NMT studies conducted in cities of Mumbai and Tiruchirapalli show that the willingness to walk can be pegged at 910 and 1700 m, respectively, whereas the willingness to cycle was 2724 m in Mumbai, 5200 m in Tiruchirapalli, and 5100 m in Delhi (Arasan, Rengaraju, & Krishna Rao 1994; Rastogi, 2011). Only a few studies have been conducted in cities, such as Mumbai and Delhi, to determine the distances that people walk to access transit stations. Rastogi (2010) performed studies in Mumbai to examine the distances that people have walked and cycled to access suburban rail. The acceptable walking and bicycling distances to reach the transit access environment were found to be 1250 m for 80% of the commuters (Rastogi & Rao, 2003; Rastogi, 2010). Johar, Jain, Garg, and Gundaliya (2015) studied the distances walked by commuters from bus stops to various destinations in New Delhi and found that the mean walking distances (based on lognormal distribution) were 677, 660, 654, and 637 m for shopping, recreation, education, and work trips, respectively. Research shows that commuters walk longer distances to access rail transit than reaching the bus transit (O'Sullivan & Morrall, 1995; Morrall & O'Sullivan, 1996; Gutiérrez & Garcia Palomares, 2008; Zielstra & Hochmair, 2011); therefore, it can be assumed that commuters walk longer distances to reach metro stations in Delhi. These results indicate that the assumed standard of 500 m in the TOD guideline has to be rechecked and it cannot be used as a common standard because the distances that people are willing to walk vary among cities. This can be done by conducting detailed studies on the last-mile-connectivity walking patterns of commuters.

Indian cities also have numerous types of travel modes, such as auto rickshaws, cycle-rickshaws, electric rickshaws, gramin sevas, and minivans, which are not employed in developed countries; some of these modes are shown in Fig. 2. These informal transport modes (or para transit or intermediate public transport modes) and their systems of operation perform a considerably important function in Indian cities. These modes are highly acclaimed by the public in Indian cities because they flexibly evolve by themselves to satisfy local and specialized requirements. They frequently provide multiple options in terms of modes, types of services, and fares to meet the mobility requirements of commuters in cities. Studies also show that in developing countries, the commuters habitually tend to use available informal transport modes for distances that could be easily covered by cycling and walking (Guillen, Ishida, & Okamoto, 2013); this highlights the convenience of these modes. It has been shown that passengers who use informal transport modes like pedi-cabs tend to travel approximately 1 km longer than people who walk. (Fillone & Mateo-Babiano, 2018). Compared with cities in developed countries where walking and cycling are the predominant modes for last-mile connectivity, a considerable size of the population in Indian cities relies on these informal modes to reach transit stations. In such cases, planning and policy making need to include these modes into last mile connectivity and overall planning and develop adequate infrastructure.

However, the standards that have been adopted tend to ignore the multimodal nature of Indian cities. In Mumbai, informal modes account for approximately 31% of the mode shares for access trips and 25% of the mode shares for egress trips (Rastogi & Rao, 2003). In their study in Mumbai, Rastogi and Rao (2003) found that auto rickshaws or taxis accounted for 10% of the access trips, and for distances longer than 1250 m from suburban rail stations, these modes accounted for 16.5% of the access trips. A report published by Embarq (2014) proposed that a radius of 150–250 m (5-min walk) for the pedestrian priority area (primary area), a radius of 500–700 m for pedestrian and cyclist priority area (secondary area) and the radius of the catchment area will depend on the areas served by informal transport and route lengths of feeder bus services; highlighting the need to include these modes for station area planning. It is necessary to study these modes to understand the functions they perform in access or egress trips and the influence they exert on the TOD.

(a) (b)

(c) (d)

Figure 2. Examples of informal modes available in New Delhi: a.) Auto rickshaw, b.) E-rickshaw, c.) Gramin seva, d.) Cycle rickshaw

(Source: a. www.wikipedia.org, b. www.ndtv.com, c. www.dailymail.co.uk, d. www.livemint.com)

A survey conducted by Delhi Metro Rail Corporation (DMRC) in 2015 for metro stations shows that after walking, informal modes are the most preferred access modes for the last-mile connectivity to reach metro stations; the survey results are shown in Fig. 3 and 4. Fig. 3 shows the share of various access and egress modes; walking and informal modes are the most preferred modes. Fig.4 shows the distribution of walking distances.

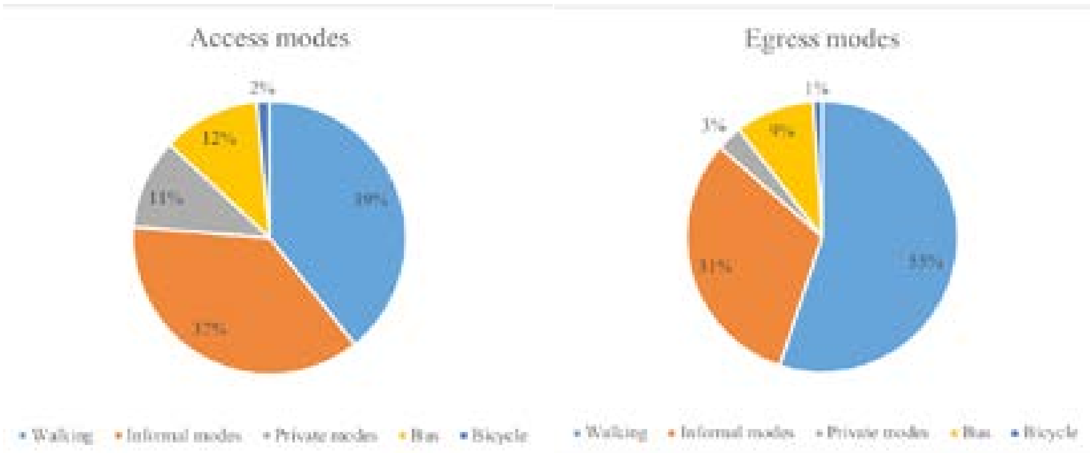

Figure 3. Modes used for access and egress to metro stations in New Delhi

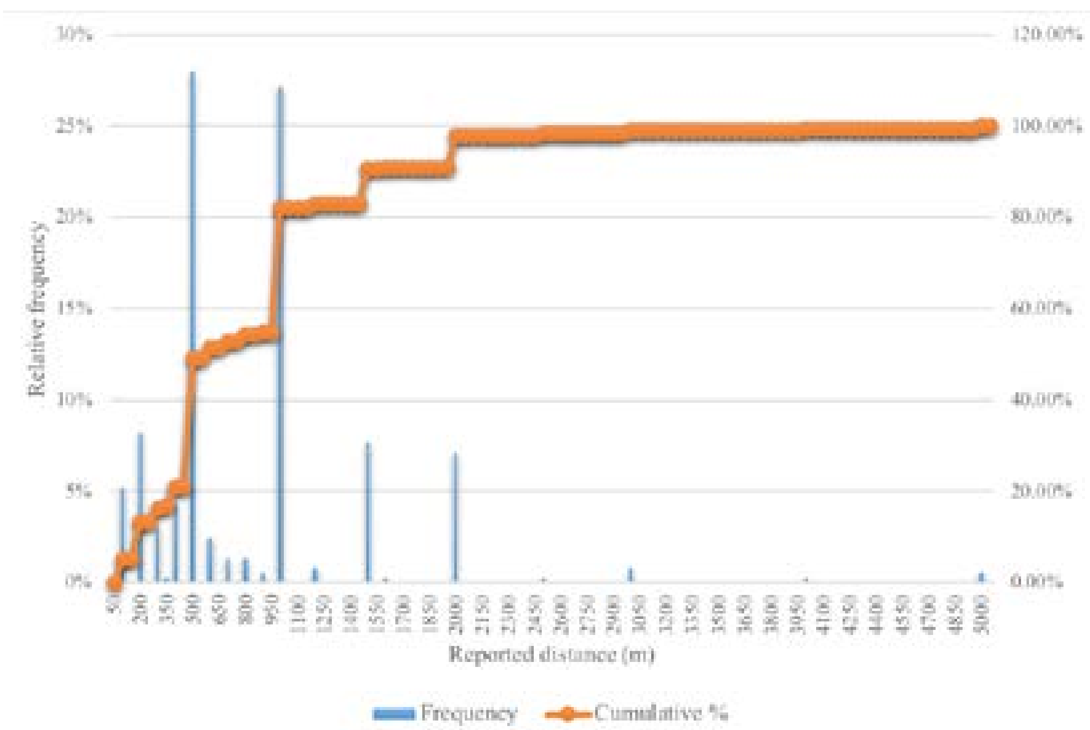

Figure 4. Distribution of reported distances for access by walking

The analysis of the data has been shown in Table 6. The mean walking distances are in the range of 700-800 for both access and egress. This matches the 500-800 m standard given in the National Transit Oriented Development (TOD) Policy and TOD Guidance document. However, the mean distances are much higher for informal modes, bus and private modes. Hochmair (2013) and El-Geneidy et al. (2014) use the 85th percentile value to calculate catchment areas around transit stations for walking and cycling and the 85th percentile distance for walking for access and egress is 1000 m; further extending the spatial extent of influence areas of transit stations than specified in the policy. Detailed research needs to be carried out to find the threshold of last mile distances by different modes.

Table 6. Summary of travel distances

Last mile distances	Access				Egress		
(in meters)	Walking	Informal modes	Bus	Private modes	Walking	Informal modes	Bus
Minimum	100	500	500	500	50	400	500
Maximum	5000	20000	35000	40000	5000	15000	35000
Mean	800	3300	6600	5500	700	3200	7100
Median	600	2500	4000	3000	500	2000	3500
75th percentile	1000	4000	8000	6000	1000	4000	7000
80th percentile	1000	5000	10000	8000	1000	4000	10000
85th percentile	1500	5000	12000	12000	1000	5000	12000

Evidently, few studies determine whether the TOD standards formulated by developed countries are appropriate for Indian cities. Moreover, the applicability of a common standard has to be verified because each city is different in terms of mobility characteristics. The current walking mobility culture in Indian cities has to be thoroughly examined in relation to the TOD planning. The informal modes have the capacity to ensure better public transit services (Kumar, Singh, Ghate, Pai, & Wilson, 2016) and therefore have the potential to facilitate the TODs. The function of informal transport and feeder buses to reach transit stations has to be considered in determining influence zones.

6 Conclusion and future direction

This review provides insight on the gap between the theoretical and scientific establishment of standards for transit catchment areas and the TOD influence areas. Existing studies show that the size of the influence area varies among different cities; it also varies with different access modes. Evidently, a single influence zone size is not suitable for all cases. In developed countries, the TOD influence area has been primarily formulated based on walking as the main access mode. Even though cycling is also a predominant access mode, it has been deemed insignificant in the planning practice. Because there is no consensus among researchers on whether the half-mile radius is the appropriate distance for catchment areas, such a criterion should be carefully examined in the planning of TODs in Indian cities. It holds for most of cities in India whose walking mobility patterns vary compared with those of developed countries. Accordingly, it is proposed that the local characteristics of cities be carefully studied in relation to the influence zone of the TODs. Moreover, it is not advisable for cities in India to consider only the walk-based TODs. This is because last-mile travel patterns are multimodal. Therefore, these multimodes need to be taken into consideration in the design of TOD. To reach a conclusion on how the influence area of TOD can be defined is difficult because the last-mile connectivity of cities, various mobility modes used, trip purpose, travel distances, time taken to reach the transit station and the type of transit itself have to be analyzed in detail. It is necessary to examine the adequate size of the influence area in Indian cities by considering the characteristics of each city.

The practical implication of this research is that current planning practices may have to be reviewed to take into consideration of actual environments. The standards given in literature can only be used as initial reference. It is ideal to recommend to city authorities that extensive studies on existing conditions be conducted. These may be implemented in the form of surveys to identify the mobility modes that are used by the public. These modes include walking, cycling, and the use of auto rickshaw to access or egress mass transit modes in the city. Therefore, insight on actual conditions can be gained. The current necessity is to derive a methodology that can be used to analyze and extract the last-mile-connectivity distances for mass transit influence zones of different cities. It should also be noted that these distances will vary across cities and within the zones of a city, depending on the type of main transit mode and the station area characteristics.

The future work of this research is to focus on Indian cities with mass transit systems to understand the last-mile connectivity to transit stations and its impact on determining the influence zones for the TOD along the transit lines. Therefore, this future work aims to link the influence of actual mobility patterns to the TOD policies and guidelines in the country. The research will further examine the existing informal transport culture along with the NMT in Indian cities, their contribution to last-mile connectivity, and their possible function in expanding the influence zones for the TODs. Further research to analyze the travel choice behavior of individuals on acceptable access modes and distances covered by different modes is necessary to obtain a city level guidance for the TOD planning. All of these would be beneficial for cities in India and other developing countries that intend to implement the TOD.

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