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Evaluating TOD in the context of local area planning using mixed-methods

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ABSTRACT

In this paper, we developed a three-step methodology for evaluating Local Area Planning (LAP) projects prepared to promote sustainable transit-oriented development (TOD). Using data from the Indian city of Ahmedabad, we quantified LAP-TOD indicators to evaluate TOD levels before and after LAP implementation around the planned metro corridors. We conducted expert interviews and reviewed LAP documents to better understand the results of these TOD indices and develop policy recommendations to strengthen LAPs. In our quantitative analysis, we found that normalized post-LAP TOD index scores for the studied metro station areas ranged from 0.12 to 0.30. These scores are low, and there is much room for improvement, considering that the highest normalized TOD index score that can be achieved is 1. Through interviews with carefully selected experts, we were able to get a comprehensive picture of the different opinions on local development challenges around metro stations. In reviewing policy documents, we identified several important gaps in the LAPs. We conclude that our contextual mixed-methods approach proved to be useful in this LAP-TOD planning project, as it revealed converging and conflicting results from the qualitative and quantitative analysis. Thus, this study contributes to the existing literature on LAP-TOD by arguing that a combination of both methods is best suited to capture all relevant elements and provide a sufficient basis for policy recommendations.

1. Introduction

High-density cities that invest in transit systems often face challenges in developing corridors and station areas. These challenges include scarcity of urban land, dense neighbourhoods, gentrification, unequal access, strict building codes, and inefficient parking management (Dittmar and Ohland, 2004; Lyu et al., 2016). Many cities in India face similar challenges. The planning process in these cities often focuses on harvesting the potential of urban land along transit corridors, often neglecting the potential benefits of integrated land use and transit (Nikhil & Petkar, 2021; Paul et al., 2020).

In the Indian planning system, most attention is given to regional and area-based planning; local-level planning is generally not prioritized. Fortunately, the state of Gujarat, particularly the city of Ahmedabad, has adopted local area planning (LAP) as a recognized physical planning process under the Development Plan (DP) and Town Planning Schemes (TPS) hierarchy. However, while LAPs are intended to make the current planning paradigm of DP-TPS-LAP mechanisms an iterative, well-linked, and interdependent process (Mahadevia et al., 2014), they face several pressing issues such as a reluctance to adopt place-based regulations, difficulties with multi-agency coordination, a lack of knowledge about the transfer of development rights, a lack of informed planning and design, inadequate integration of different modes of transportation, and inefficient last-mile connectivity (Bhatt et al., 2012; Joshi et al., 2017).

These problems hinder the creation of vibrant and walkable places near rail stations, which is the goal of the locally adopted concept of Transit-Oriented Development (TOD). The city of Ahmedabad has attempted to address some of these issues by building a mass transit system in combination with paratransit, shared transit, and non-motorized vehicles. Despite these initiatives, there are still issues with transit and land use integration, first and last mile connectivity, and adequate pedestrian infrastructure. Although the Bus Rapid Transit System (BRTS) in Ahmedabad became a successful example and gained global recognition (Rizvi, 2014), its shortcomings became apparent over time as it could not achieve the expected ridership. This was due to the drawbacks of external factors such as the lack of non-motorised infrastructure around the transportation system (Kaushik, 2018). Such challenges in transport planning have also recently emerged in relation to the metro system, which is still in the construction phase.

To avoid these challenges at an earlier stage, the LAPs prepared by

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Table 1
List of TOD indicators and their sources.

Authors	Indicators
Litman (2018)	Regional accessibility, density, mixed land-use, proximity to center, parking and mobility management, and street design.
Newman and Kenworthy (1991)	Provision of infrastructure, high density and dependence on the automobiles.
Calthorpe (1993)	Mixed land-use, high density, proximity to public transit, pedestrian environment, and auto use.
Li et al. (2016)	High density, mixed land-use, walking environment, and high-quality public street transportation services.
Parker et al. (2002)	Moderate to high density, distance to public transit, mix of housing, employment, and shopping.
Hale and Charles (2006)	Vibrant, dense, mixed use, high quality public spaces and access to public transit.
Higgins and Kanaroglou (2016)	Ridership
Cervero and Kockelman (1997)	Density (population density, employment density, and accessibility to jobs), diversity (dissimilarity index, entropy, vertical mix, intensity of land use categories, mix of activity centers, and proximity to commercial retail uses), and design (streetscape, pedestrian and bicycle facilities, and site design).
Ewing and Cervero (2010)	Destination accessibility (accessibility to jobs by public transit and distance to downtown), and distance to public transit (distance to nearest transit stop).
Center for Transit-Oriented Development (2008)	Ridership, street design, public space, parking management, community involvement, affordable housing, capture value of transit, station connectivity.
Denver city authority (2014)	Connectivity, innovative thinking, efficient public transport, active spaces, mix of land-uses and shift to a multi-modal city.
Ahmedabad Urban Development Authority (2017)	Floor space index (FSI), road density, population density, land cover, public domain, built form, block size, pedestrian track, bike track, public spaces and parks, off-street public parking, BRTS stops and feeder bus stops.

the local government need to be evaluated. Currently, the LAPs reveal a distinct gap. There is a lack of quantification of how the plans affects TOD, and a lack of comparison of the current and the proposed situation after the implementation of the plans. Therefore, in this study, we aim to evaluate three LAP projects before and after the TOD proposals using a contextual mixed-methods approach. While most of the literature evaluating TOD uses either quantitative or qualitative methods, in this paper we argue that a combination is best suited to capture all relevant elements and provide a sufficient basis for policy recommendations.

This paper adds to the case study literature in the following way: It provides a single assessment that uses a mixed-methods approach with a before-and-after evaluation to analyse the performance of LAPs around planned metro stations in Ahmedabad. It provides a critical overview of TOD planning in a city known for its mass transit implementation, which has been replicated in other cities. The findings from this case have helped to develop policy recommendations for increasing the level of TOD at transit stations. These recommendations can also be used to improve TODs in Asian cities, and potentially beyond.

The remaining sections are organized as follows. Section 2 reviews the existing literature on LAP, TOD, and evaluation methods and motivates the use of a mixed-methods approach. Section 3 presents the case study and the contextual mixed methodology. Section 4 presents the results and Section 5 provides policy recommendations. Section 6 concludes the paper and describes opportunities for future research.

2. Literature review

In the Indian context, local area plans create a framework for enhancing public spaces, areas under roads and existing infrastructure by enabling the redevelopment of the existing built environment (Ministry of Housing & Urban Affairs, 2017). These plans are sensitive to the broader policy context and aim to create a strategic spatial plan that helps inform decision-making for issues at the local level (Yusoff et al., 2014). When decision making is supported by local community participation and technical analysis, the adequacy of such plans can be analysed.

Transit-oriented development (TOD) is a planning, design, policy and implementation tool for integrating land-use and transit systems. It transforms the surrounding environment of a transit station into a high-density mixed-use development that is easily accessible by foot or on cycle within a zone of influence. Peter Calthorpe defined the concept of TOD for the first time as "… a mixed-use community within an average 2,000-feet (or 10-minute) walking distance of a transit stop and core commercial area" (Calthorpe, 1993, p. 56). The concept quickly gained popularity and recognition as a solution to the current auto-dependent development, traffic congestion, air pollution and low-density sprawled developments in North America (Curtis & Scheurer, 2017). Since then, it has been widely applied in American cities to redevelop their neighbourhoods where mixed-age and mixed-income groups and diverse land uses can thrive together to promote sustainable development. Although this concept originated in the United States, its importance has been recognized worldwide, particularly in developing countries experiencing rapid urbanization and deteriorating transportation conditions (Xu et al., 2017). As a result, cities began to transform into more transit-oriented environments by incorporating TOD principles into their development plans (master plans or local plans).

Integrating TOD planning at multiple levels is critical to addressing transportation-related challenges. TOD planning can be accomplished by measuring existing and proposed levels of TOD around transit stations. Such measurement helps policy makers objectively compare the performance of stations before and after TOD (Renne, 2007). There is a large literature on TOD evaluation, but it is mainly based on quantitative analyses. Cervero and Kockelman (1997) evaluated transit stations using the 3D criteria, which characterize TOD as a combination of diversity, density, and design. Ewing and Cervero (2010) added two more D's, destination accessibility and distance to mass transit, to measure the level of TOD in an area. Evans et al. (2007) and Singh et al (2014) developed a TOD index to assess the existing level of transit stations. Similarly, Higgins and Kanaroglou (2016) developed TOD typologies and Shirke et al. (2017) evaluated TOD impacts using a discrete choice model. Table 1 provides an overview of relevant indicators for TOD planning proposed by different authors on theoretical and empirical grounds. As the list of indicators are drawn from this literature, it is not exhaustive. The table presents various indicators proposed by different authors for evaluation based on conceptual decisions or contextual circumstances. Some of them are qualitative, but most of them are quantitative. Although Ewing and Cervero (2010) 5Ds have gained popularity for measuring the built environment and its relationship to travel demand, it can be argued that the built environment and travel patterns of cities in the Global South differ significantly from those in the Global North, and that a tailored contextual selection of indicators is required.

In evaluating TOD, the size of zones of influence is an important consideration. A zone of influence is defined as the area around a transit stop or station within which land use and urban design features have a primary influence on transit ridership, and pedestrian access will generate a very significant portion of transit trips to and from the stop or station (American Public Transportation Association, 2009). It is calculated as a function of either access distance or access time or both to transit (Ann et al., 2019). Several authors have defined it differently based on the geographic context of the city and people's travel

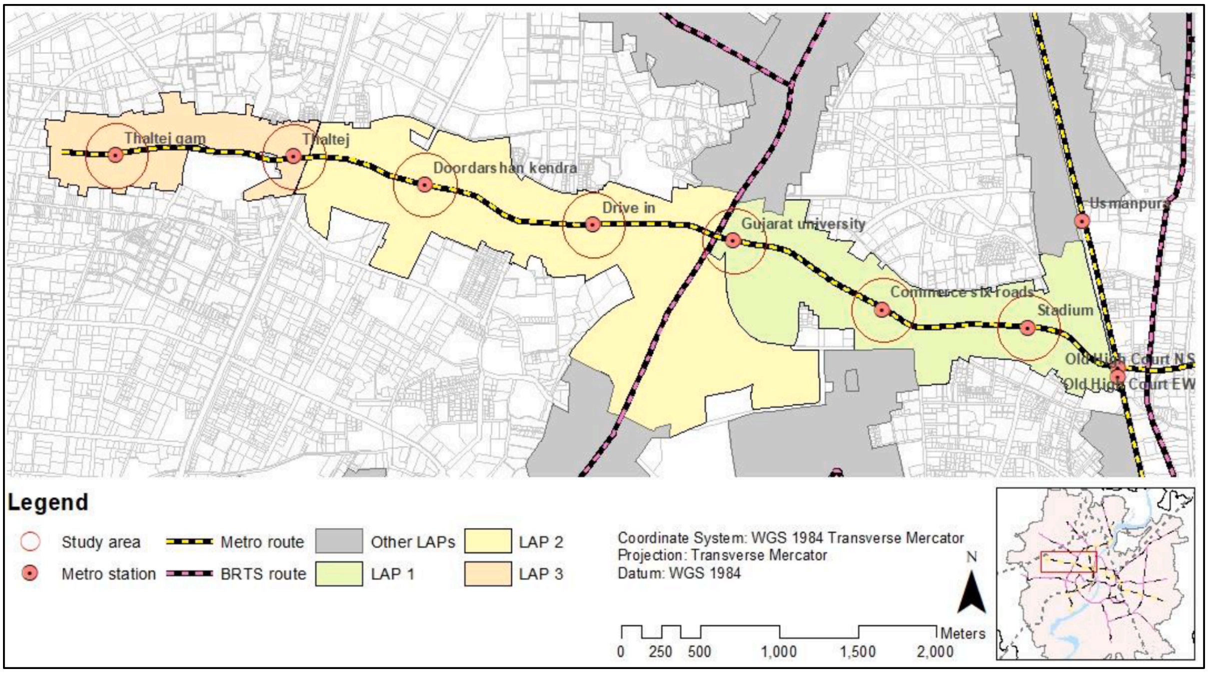

Fig. 1. LAP-TOD zone along the western corridor of the metro transit.

behaviour. Calthorpe (1993) defined an influence zone of 800-m based on access distance. Dittmar and Ohland (2004) demarcated a distance of 800-m to the transit station. Cervero and Dai (2014) determined a 500-m and 1000-m zone of influence based on access time to transit. Higgins and Kanaroglou (2016) created a buffer of 800-m around the transit stations based on an access time of 10 min. In India, the TOD influence zone is defined as the area in the immediate vicinity of the transit station, i.e. within walking distance, having high-density compact development with mixed land use to support all basic needs of the residents (Ministry of Housing & Urban Affairs, 2017). Many cities have prepared TOD plans at the local/area or city level. Ahmedabad Urban Development Authority (2017) established a 200-meter zone of influence on both sides of the transit corridor for its local area plans.

Next to the studies discussed above that use quantitative methods, there is also literature that looks at improving TOD through qualitative methods, as well as another category that uses other methods such as policy review and document analysis. Examples of the former are (Bhatt et al., 2012; Doulet et al., 2017; Mahadevia et al., 2014; Mu and De Jong, 2012; Thomas and Deakin, 2008; Wang et al., 2019; Embarq India, 2011). Examples of the latter are (Cervero & Dai, 2014; Cervero & Murakami, 2008; Gilat & Sussman, 2003; Rangwala et al., 2014; Wilkinson, 2006).

Of particular interest to us is the application of mixed-methods. By mixed-methods, we refer to a combination in which quantitative and qualitative analyses are used and integrated whenever possible. In the first method, numerical data are obtained from survey questionnaires, census data, statistical tests, and inventories (Kraska, 2019). Qualitative analysis gathers information from residents or other stakeholders through interviews, focus group discussions, field observations, or review of policy documents (Given, 2008). The quantitative analysis provides a benchmark to calculate the differences between existing and proposed TOD levels and to examine whether the proposed level would improve TOD around station areas (Singh et al., 2018), while the qualitative information examines spatial planning dynamics and local development challenges around station areas.

We have not come across many studies that conduct an integrated evaluation of TOD based on a mixed-methods approach. Surprisingly, most of these studies are from Indonesia, where the planned construction of metro systems in Jakarta and Bandung has sparked interest in this topic. In this context, Budiati et al. (2018) evaluated current TOD conditions along the planned Jakarta MRT corridor using the 5-D approach (Ewing & Cervero, 2010) and stakeholder opinions to rank the selected criteria. Nagari et al. (2020) conducted a partial assessment of TOD development in a listed area in Jakarta using mixed-methods, examining connectivity and accessibility. Mohamad et al. (2021) carried out a mixed-methods assessment of TOD, however, with the aim of developing a typology. Outside the Indonesian context, others have primarily focused on specific aspects of TOD evaluation. Millard-Ball (2021) used a mixed-methods approach to evaluate the effect of TOD plans in San Francisco and Seattle on development outcomes in general, while Liu et al. (2022) examined the impacts of TOD on sprawl in Tokyo and Jones (2020) discussed the impacts of TOD planning on gentrification in a Vancouver neighborhood.

We believe that the use of a qualitative or quantitative methodology alone is insufficient for evaluating local plans. In the absence of a quantitative analysis, it is impossible to make a measurable and reproducible assessment that can be used to make relative and absolute judgments about the quality of TOD in different stations (Singh et al., 2018). However, failure to involve local people and experts in decision-making and LAP development could limit adequate understanding of the local context (e.g., by including relevant indicators) and the ability of plans to make context-sensitive policy recommendations. A mixed-methods approach allows for the collection of information from multiple sources to improve the validity of results (AlArasi et al., 2018; Martinez et al., 2016; Yusoff et al., 2014).

Mixed-methods approaches can be developed in different ways (i) as separate methods, each providing their own findings (ii) more integrated, where the qualitative method provides input in the quantitative method (or vice versa) e.g. in the selection and scoring of indicators in a multi-criteria analysis, and (iii) a combination, where one part of the analysis is integrated, but in addition, there are direct findings from the quantitative and qualitative analysis. In this study we employ the third approach, as it allows us to carry out the evaluation of the LAP's on TOD in more depth, and also to derive policy recommendations for strengthening the overall TOD development.

Table 2
List of indicators to evaluate TOD, in the context of the LAP and consulted literature.

No	Indicators	Rationale	Measurement
LAP document indicators			
1	Block size	Smaller blocks allow for a fine-grained street network that is interconnected and designed for pedestrian convenience.	Average block perimeter per station
2	Road density	Roads increase accessibility and create a dense network of streets and paths.	Road area per cell
3	Population density	The more people who live near public transit, the greater the percentage of people who use public transit.	People per station
4	Pedestrian and cycle track density	A complete street design provides well-designed, continuous and encroachment-free pedestrian and cycle tracks that prioritize non-motorized traffic over motorized traffic.	Pedestrian and cycle track area per cell
5	Public space density	The presence of public spaces near stations encourages people to meet and interact, thereby making their experience more rewarding.	The area under public space per station
6	Last-mile connectivity	A high level of connectivity by various modes of transport encourages the use of public transport over the automobile use.	Number of modes per station
7	On-street car parking density	When public transport is not as convenient, fast, and reliable as cars, on-street parking can discourage the use of public transportation.	Area occupied by cars per cell
Indicators from consulted literature			
8	Land-use diversity	Mixed land-uses reduce the need to travel longer distances.	Specific land-use per total area of all land-uses
9	Building footprint density	Higher building densities can lead to higher share of public transport.	Building footprint per station
10	Signalised intersection density	Signalized intersections create safer streets, decreases vehicle speeds, and reduce conflicts between road users.	Number of signalized intersections per station
11	First-mile connectivity	A high level of connectivity by various modes of transport encourages the use of public transport over the automobile use.	Number of modes per station

3. Methodology

We used a three-step methodology to collect data and evaluate TODs within the LAPs. In step 1, we quantify each LAP-TOD indicator in two scenarios (pre-LAP and post-LAP) (section 4.1). Alternatively, we carried out two qualitative analysis. First, we conducted eight semi-structured interviews with local experts to obtain their opinions on the TOD indicators and the policy objectives of the LAPs (section 4.2). Second, we reviewed the three LAPs documents prepared by the municipality (section 4.3). In step 2, based on the perception of the carefully selected experts, we assigned a score to each indicator in each station and multiplied it with the indicator scores derived from the quantitative analysis to develop the final LAP-TOD indices for each station in a pre- and post-situation (section 4.4). In the last step, we compare the final LAP-TOD indices with the findings from the interviews and review of the LAP documents (section 4.5). This step is key to our mixed-methods approach, as we incorporate the results of one method and compare it to another to gain a better understanding of the spatial planning for TOD and make recommendations for TOD planning.

3.1. Case study of Ahmedabad

Ahmedabad in India is a growing metropolitan city. Like any other populous Asian city, Ahmedabad faces the problems of traffic congestion and long travel times (Rizvi, 2014). This is because of the low ridership of public transport (11%), which is due to inadequate pedestrian infrastructure, lack of last-mile connectivity, car dependency, and a lack of investment in public transport, to name a few (Center of Excellence in Urban Transport, 2018). In order to increase public transport ridership and discourage the use of private vehicles, the local government introduced a metro transit in the city. The metro covers a north–south and an east–west corridor and consists of 32 metro stations. Local Area Planning (LAP) has been introduced by the government to plan these station areas. The spatial planning was provided for a zone of 200 m on both sides of the metro line (Fig. 1). Three LAP documents were prepared for the western corridor of the metro line.

3.2. Data collection

The Ahmedabad Urban Development Authority (2017) (AUDA) developed the LAPs based on five TOD principles: creating walkable neighborhoods; increasing density around metro stations; ensuring complete streets; increasing the number of parks and plazas around metro stations; and achieving last-mile connectivity. Each principle is subsequently broken down into indicators. These principles were established for various factors related to local climate, street vitality, block pattern, and high density around metro stations to boost sustainability through TOD development. Although the LAPs address most of the TOD principles, based on the literature (Table 1) we argue that some indicators of a sustainable TOD are overlooked by the municipality. These include land-use diversity, building footprint density, signalised intersection density, and first-mile connectivity. We also believe that inclusion of some of the indicators such as on-street parking is debatable. However, in the context of Ahmedabad city, on-street parking is a very important aspect of daily mobility. Therefore, to evaluate their strategy, we included on-street parking in our analysis, albeit that we have introduced this indicator as a cost indicator for TOD. We believe these additional indicators are important in the context of the city and in light of the policy goals of the LAP. We have summarized the indicators from the LAP documents and the contextual indicators from the literature in Table 2 below.

Secondary data was acquired with Ahmedabad Urban Development Authority. Semi structured interviews were held with eight local experts to collect their opinions on each contextual indicator as identified based on the literature, but also on three LAP documents prepared for the western metro corridor. In addition, other qualitative techniques such as photo documentation and direct observations in the field allowed collecting all the necessary data to quantify the indicators. Although land-use diversity (item 8 on Table 2) and building footprint density (item 9 on Table 2) are important indicators for TOD planning, they are excluded from the analysis because the proposed values for these indicators were missing from the provided secondary data and difficult to collect in the field.

3.3. Quantitative analysis

For each of the seven station areas, we quantified nine indicators (Table 2) within a 200-m buffer on both sides of the metro line using GIS. Due to the granularity of the available spatial data and ease of interpretation, we created a 50-m tessellation. Indicators such as road density, pedestrian and cycle density and on-street car parking density were calculated using tessellations, while block size, population density, signalized intersection density, public space density, and first- and last-mile connectivity were calculated using a single value calculated for the

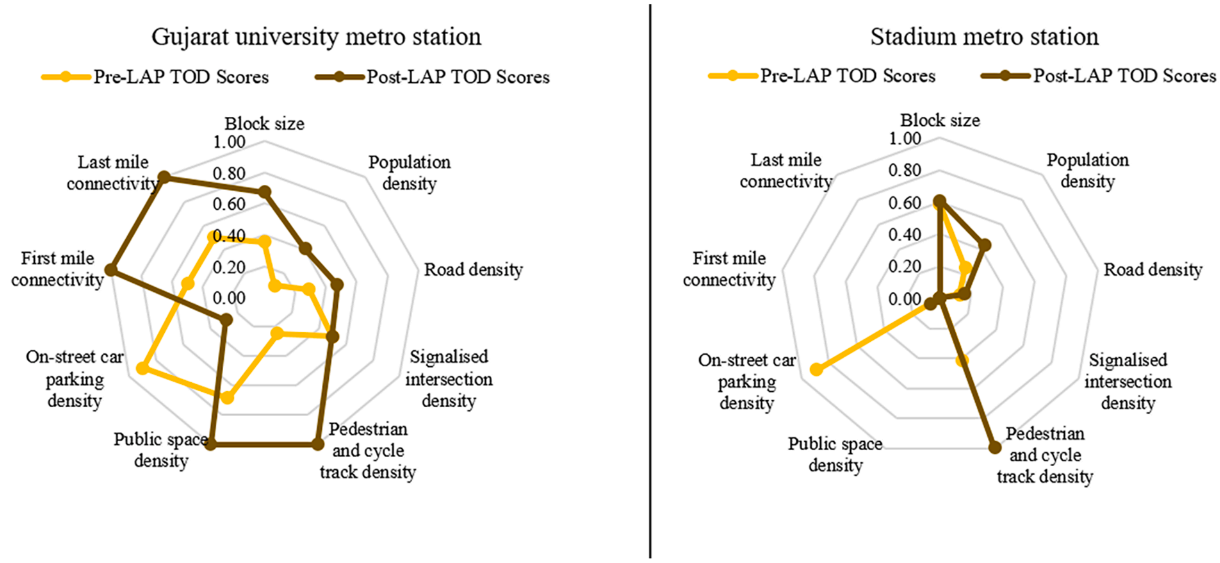

Fig. 2. Stations with highest (left) and lowest (right) Post-LAP TOD scores.

whole station area because the spatial information warranted aggregation. Then, an interval-standardized technique was used to standardize the indicators, to obtain a comparable score for the pre- and post-situations.

3.4. Qualitative analysis

Eight semi-structured in-depth interviews were organized with key local experts-those who were involved in LAP planning or in other transport-related projects at the local level. The interviews included open-ended questions about the experts' opinions and perceptions of various TOD indicators and the policy objectives associated with LAPs. The interviews lasted 45 to 60 min and were audio-recorded with the permission of the interviewees. They took place in locations preferred by interviewees and were anonymized upon request. After the interviews, the transcripts were thematically coded using Atlas.ti. The findings from the interviews were used to score each TOD indicator for each station in order to calculate the final pre- and post-TOD index scores.

Although only eight interviews were conducted, we believe we reached out to the key experts in the field, as there is a limited number of experts on TOD planning in Ahmedabad. We feel that by selecting these key experts, and through open-ended questions, we were able to provide a rich picture of the different opinions on local development challenges around metro stations. Past literature suggests that open-ended questions provide deep insights into people's perceptions, feelings and opinions, and are a powerful way to understand realities on the ground (Handy, 2002; Patton, 2014). We also believe that our approach is different from usual approaches because instead of asking the interviewee to rate the indicators, we rated them ourselves by first comparing the perceptions of different respondents and then determining the importance of each indicator based on the discussion with each respondent.

Alternatively, we also reviewed the LAP documents and compared their findings with the findings from the quantitative analysis. This contributed to a better understanding of the spatial planning dynamics around the metro stations and allowed us to anticipate the challenges in implementing the LAPs.

3.5. Constructing the final LAP-TOD index

The insights from the semi-structured expert interviews were used to determine the importance of each indicator. Based on their perceptions, each indicator for each station was assigned a score on a five-point scale, with 5 representing most importance and 1 representing least. The scores were then added together. These final scores were then normalized on a scale of 0 to 1, with 1 representing ideal TOD and 0 representing worst TOD performance. The normalized score resulting from the interviews for each indicator was multiplied by the interval standardized scores quantified for each indicator. The scores for each indicator were then aggregated to calculate the final LAP-TOD index score for each station in the pre- and post-LAP-TOD situation. The final TOD scores are presented as spider diagrams.

3.6. Comparing the quantitative and qualitative findings

The final TOD index scores for each station in the pre- and post-scenarios provide a holistic picture of how well each station area is performing in terms of TOD levels and how the LAPs are contributing to TOD. We use this understanding in combination with insights from the expert interviews and the LAP documents review. Such a mixed-methods approach, where one part of the analysis is integrated, but in addition, there are direct findings from the quantitative and qualitative analysis allows us to carry out the evaluation of the LAP's on TOD in more depth, and also to derive policy recommendations for strengthening the overall TOD index.

4. Results and discussion

The first subsection below presents the quantification of the TOD indicators in the before-after scenario of the LAP-TOD. Then, results of the eight carefully selected expert interviews are presented, followed by the review of the LAP documents. The final TOD index for each station area is then computed. Finally, the results of both methods are compared to identify converging and conflicting findings.

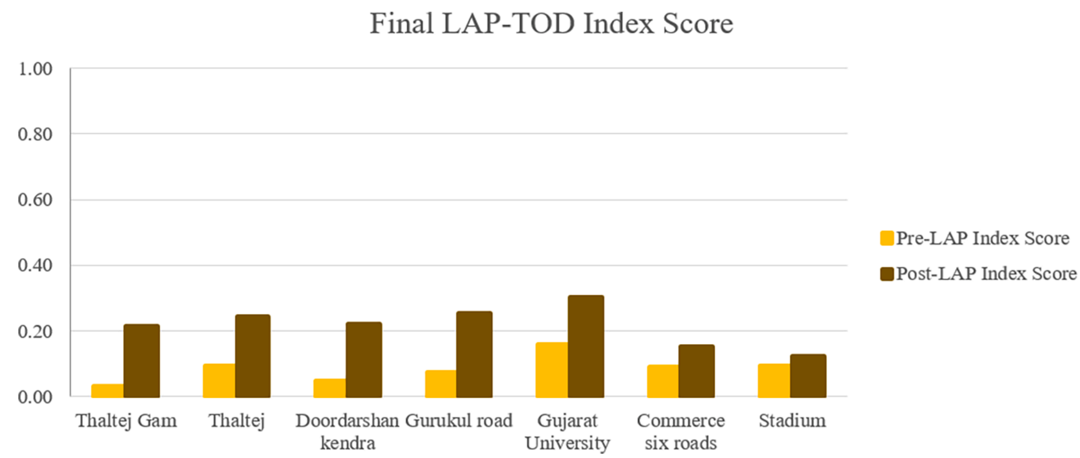

Fig. 3. Final pre-and post-LAP-TOD scores using quantitative and qualitative analyses.

4.1. *Quantitative findings of each indicator*

Pre-LAP-TOD scores were calculated to quantify the indicators for the existing situation, separately for each station area. Then, post-LAP-TOD scores were calculated using the municipality's proposed LAP design. These scores were standardised using an interval standardized technique. Indicators such as pedestrian and cycle track density, public space density, and etc. that contribute positively to TOD are benefit indicators (Relation (1)), while indicators such as block size and on-street car parking density that are negatively associated with TOD are cost indicators (Relation (2)). Each indicator in both pre- and post- situations was standardised on a scale of 0 to 1, with 0 indicating the worst TOD performance and 1 indicating the best TOD performance, based on their placement between the minimum and maximum scores in the pre- and post-sets (see Table 4 and Table 5 in Appendix). The results are presented in the form of spider diagrams (Fig. 2).

$$\text{Interval standardisation (benefitind icators)} = \frac{\textit{value} - \textit{minimum value}}{\textit{maximum value} - \textit{minimum value}} \tag{1}$$

$$\text{Interval standardisation (cost indicators)} = 1 - \frac{\textit{value} - \textit{minimum value}}{\textit{maximum value} - \textit{minimum value}} \tag{2}$$

Two cases were selected to be presented in this paper. The first is the Gujarat University station area, which has the highest post-LAP-TOD score, while the second is the Stadium station, which has the lowest post-LAP-TOD score. The diagram on the left shows the pre- (yellow colour) and post-LAP-TOD (brown colour) scores from Gujarat University. The good pre-scores suggest that some of the indicators in the existing built-environment of Gujarat University are good for TOD-friendly development. In the post-scenario, the scores have improved further as the brown polygon gets closer to 1. This suggests that the LAP plan for Gujarat University metro station indicates a significant improvement and has addressed the indicators in a good way. It is important to note that some indicators such as first and last-mile connectivity have a perfect score of 1 in the spider diagrams because of the interval-standardization technique. Indicators where there is most room for improvement include block size, population density, road density, and signalised intersection density. This could be accomplished with policy recommendations, which will be presented in Section 5.

In contrast, Stadium station, which is closest to the city centre, shows the least improvement. First, most of the indicators in the pre-LAP scenario have a score close to zero, indicating a low level of TOD. In exception, the score for on-street car parking is closer to 1 in the pre-LAP scenario, which means that provision for on-street parking is minimal, indicating good TOD. However, in the post-LAP scenario, the score for on-street car parking is closer to 0, along with scores of other indicators, representing an overall low TOD index score. It appears that due to the proximity to the city centre, there is a low propensity for improvement in Stadium station area. Since the built-form in this area is fairly consolidated, there is less room for improvement and therefore low post-LAP-TOD scores.

4.2. *Findings from the expert interviews*

The analysis of the interviews focused on eliciting information about the TOD indicators and the intentions of the LAP plans. Two types of experts were asked to provide their opinions. Some were government officials involved in the LAP planning, while others were academics and professionals working on the ground in Ahmedabad on other transport-related projects. We refer to the latter group as non-government officials.

The experts were asked to comment on all selected indicators. Regarding the block size density indicator, government officials agreed that block size is one of the most important indicators for the development of walkable neighbourhoods in the city. Smaller blocks encourage people to walk around the city and target TOD-friendly development. In light of this, the LAP will reduce the average block size from 440 m to 340 m. Although non-government officials also made similar observations about this indicator, government officials gave less importance to it.

Non-government officials expressed concern about the population density indicator. With the introduction of the metro, the Floor Space Index (FSI) in LAP zones will increase from 2.7 to 5.4. With such an increase in population, LAPs need to contain the city rather than allow sprawling. Because of their concerns about the city's existing dense development, they considered population density to be a more important indicator for TOD planning than government officials. On the other hand, government officials were not very concerned about population growth, as LAP plans have already allocated space for an influx of nearly 3.8 million people into the city by the end of 2041.

Most government experts did not believe that signalized intersection density is a high priority indicator for TOD planning. In contrast, transport planners felt that signalized intersection density is often overlooked in TOD planning, but that it should be given high priority from a traffic safety perspective because it aims to create safer streets for non-motorized traffic.

All interviewees strongly supported that pedestrian walkways should be the most important indicator in any TOD planning effort. The lack of proper pedestrian infrastructure has created an unsafe situation for pedestrians and cyclists. Government officials have recognized this gap in existing street design and have made provisions for usable sidewalks along streets in LAP zones.

Some experts pointed out that parks and plazas are the backbone of TOD planning because they create breathable spaces in the city. However, others, primarily government officials, felt that their land could be used for development because parks and gardens do not generate revenue for the city. As a result, the LAP design reflects low density of proposed parks and plazas.

A consensus was found in the experts' opinions on road density, which was given low importance. According to the experts, TOD planning is not about increasing road density but about providing proper pedestrian infrastructure. This is contrary to what was noted regarding the on-street car parking indicator. From the perspective of government officials, on-street car parking is essential to support the local economy, while from the perspective of transport planners, on-street parking limits the growth of public transport and should therefore be avoided in LAPs. Unfortunately, the current plans aim to increase on-street car parking by adding parking spaces wherever possible. This is contrary to the overarching principle of TOD and was therefore considered by non-government experts to be a disadvantage of the LAPs.

All interviewees stressed the importance of connecting the first and last mile within the LAP zones and linking them to the broader transport network of the city. Therefore, sufficient provisions have been made in the plans to ensure connectivity to the first and last mile wherever possible by providing auto-rickshaw stands, docking stations and feeder bus stops near the planned metro stations.

The above findings from the semi-structured expert interviews were used to rate each indicator for each station on a scale of 1 to 5, with 5 representing the greatest importance and 1 representing the least importance (see Table 6 in the Appendix). The ratings were aggregated and normalized on a scale of 0 to 1, where 1 represents the best rating and 0 the worst. All in all, the experts believed that block density, pedestrian and cycle density, and first and last mile connectivity should be top priorities for LAP-TOD planning in the city. This is consistent with the overarching principles of TOD. In Ahmedabad, the pedestrian walkways are not continuous and not usable. The blocks are very large, making walking uncomfortable and undesirable. Although the city has an extensive bus infrastructure, including BRTS, transit ridership is still very low, with only 11% use of public transport in general and 1% BRTS in particular (Center of Excellence in Urban Transport, 2018).

Most experts give low priority to indicators such as public space density, road density, and signalised intersection density. Similarly, in the LAP proposals, on-street car parking is provided on all roads regardless of whether they are near a public transit or not. Such an adhoc provision of parking weakens the idea of true TOD. Past literature suggests that sustainable TOD needs to be supported by public spaces, safer streets for pedestrians with signalized intersections, and the elimination of on-street car parking in immediate surrounding of TOD zones (Curtis et al., 2009). From the discussion with these interviewees, it appears that these aspects are out of place in the overarching framework of the LAP and need to be adequately addressed.

4.3. Review of LAP documents

The qualitative analysis also included a review of the three LAP documents prepared for the western corridor of the metro to determine how the plans can be further improved and what challenges exist in implementing these plans.

The LAP documents took the form of a report that provided details on the LAP-TOD principles, which were then subsequently broken down into indicators. After scrutinizing these LAP documents, three major limitations were found. First, most of the indicators in the LAPs represent the travel behavior dimension. However, other important dimensions of sustainable TOD such as the built-environment, local economy, the social and the natural environment are not given due consideration (Renne, 2007). It is important to consider these different dimensions to evaluate TOD following a sustainability paradigm. Second, the LAPs do not reflect major contextual issues in the city of Ahmedabad, such as the provision of public housing, land-use and transport integration strategies, parking management plans, increasing ridership of the public transport, and reducing carbon footprints.

Lastly, there may be doubts about the implementation of the LAPs. This is because they are planned on brownfield sites. It goes without saying that most indicators such as pedestrian and cycle density or public space density, can only be implemented if parts of the TOD zones are redeveloped. However, if a property chooses not to redevelop, the whole idea of creating contiguous walkable areas by acquiring the front edge of private properties will not be implemented. Instead, the area will become an eyesore to the development due to irregular surfaces, which will then lead to informality, encroachment, or, potentially, even crime. Because these few operative principles are missing from the LAPs, we argue that the overall purpose of promoting sustainable TOD has been weakened and that the effectiveness of these LAPs to promote TOD friendly development is questionable.

In summary, it appears that the priorities in the LAPs are not set correctly and that there are key problems in the implementation of these plans. We were able to identify the main problems in the plans by reviewing the LAP documents and comparing them to the indicators in the quantitative analysis. Therefore, we believe that in order to gain a holistic understanding of the plans, it is essential to conduct both qualitative and quantitative analyses. By integrating these two methods, LAPs can be strengthened and better planning for TOD can be pursued.

4.4. Constructing the final LAP-TOD index and its interpretation

After normalizing the scores generated from the semi-structured interviews (Table 6), they were multiplied by the interval-standardized scores obtained from the quantitative analysis (Table 4 and Table 5). Then these scores were aggregated to obtain a single value for each station area in the pre-and post-LAP scenarios. To facilitate interpretation, we normalized the aggregated scores on a scale from 0 to 1 (see Table 7 in the Appendix). Fig. 3 shows that scores closer to 1 represent ideal TOD, whereas scores closer to 0 represent poorer TOD performance.

There is clearly a substantial improvement between the pre- and post-LAP scenarios. All station areas have low pre-LAP scores. This is not surprising since Ahmedabad was not a planned city. It developed naturally based on market demand and the local economy. Although the Town Planning Schemes (TPS) determined land use and road infrastructure in the city until recently, there was never an effort to make the city TOD friendly. Nonetheless, there has been a significant increase in the TOD index across all stations, from the pre- to the post- scores. Thaltej Gam station area experienced the largest increase. This is due to the fact that the spatial conditions around this station provide numerous opportunities to reduce block size, create space for future population, expand road and pedestrian infrastructure, decrease on-street car parking, and improve first and last mile connectivity. Against this backdrop, some stations have improved significantly, while others have seen only marginal improvements. Gujarat University station, once LAPs are implemented, will have the highest normalized TOD score of 0.30, followed by Gurukal station with a score of 0.25. Stadium station, which is closest to the city center, has the worst score of 0.12. Due to the consolidated built-form in this station area, there is limited room for improvement.

There is a noteworthy improvement between pre- and post- scores, but there is still much potential to improve. The maximum normalised score that a station can achieve is 1, and the highest is only 0.30 in the Gujarat University area. Station-specific and citywide recommendations on how these scores can be further improved, and consequently strengthening LAPs, will be discussed in Section 5.

4.5. Comparing the findings of the quantitative and qualitative analyses

Using the proposed mixed-methods approach, we were able to identify some converging and conflicting findings. First, government officials assumed that all stations would achieve the same level of improvement from pre- to post because all LAPs were developed using the same planning strategy. However, this was not the case. In the quantitative analysis, we found differences in the degree of improvement in all stations. Second, when quantifying the TOD indices, we found that these can be substantially improved. This conclusion could not be achieved by simply reviewing the LAP documents. Third, with the expert interviews, differences in opinions were found regarding the perception of transit-oriented policy goals. From the perspective of government officials, on-street car parking was a necessary indicator on the LAPs, while non-government officials, identified on-street car parking as the last priority of the LAP. These differences in ideologies among the experts enriched the analysis and understanding of the LAPs. Fourth, without reviewing the LAP documents, it would not be possible to uncover these implementation problems through quantitative analysis alone. Only after reviewing and examining these plans these misaligned priorities could be identified. Finally, the review of existing literature allowed identifying additional relevant indicators required for the evaluation of LAPs with contextual indicators.

These results demonstrate that conducting a mixed-methods study in this context helps to understand not only local development challenges, but also the spatial development dynamics around transit stations. We conclude that such an approach is superior to a single-method study because it helped identifying station-specific and citywide policy recommendations to promote sustainable TOD while strengthening the LAPs.

5. Policy recommendations

In this section, we propose station-specific and citywide recommendations suggesting what policymakers and planners can do with the results of this research to improve the TOD levels in Ahmedabad. For station-specific recommendations, we chose the Stadium and Gujarat University station areas. The former has the lowest normalized post-LAP TOD index score, while the latter has the highest. We included these two stations to show how we can improve the normalized post score where the potential for improvement is lowest, and how we can increase the normalized post score where there is potential for intervention. Overall, these recommendations will help increase the normalized post-LAP TOD index score and bring them closer to a pro-TOD development.

5.1. Station-specific recommendations

In the Stadium station area, the LAP plan resulted in a slight increase in normalized index scores before and after the TOD implementation, from 0.09 to 0.12. The normalized post-LAP TOD index score of 0.12 is the lowest for all stations. This is mainly because Stadium station is closest to the city centre. Its development is more consolidated, so there is less room for intervention. Our strategy for increasing TOD is to start with indicators that have a normalized post-LAP TOD score of less than 0.16. These indicators are signalized intersection density, public space density, on-street car parking density, and first and last mile connectivity. Below are our recommendations:

- Due to its proximity to the city centre and the north–south metro line, intersections should be signalized to streamline traffic flow and create safer streets for pedestrians (Marisamynathan & Vedagiri, 2020).
- Increasing green spaces is an important aspect of TOD (Center for Transit-Oriented Development, 2008). To increase the density of public space around Stadium Station, vacant land reserved by the municipality for park and garden development should be used. We recommend that these plots be connected to the metro station and nearby gardens by a tree-lined corridor. Such a strategy will encourage people to walk within the TOD zone and create a seamless integration between the metro station and the city's pedestrian infrastructure.
- Previous studies have shown that access to and from metro stations has received the least attention in most Indian cities (Bivina et al., 2020). With this in mind, the LAP should invest in public transport infrastructure to improve first and last mile connectivity. To this end, a small portion of on-street car parking lanes can be strategically delineated to provide bus and auto-rickshaw stops near metro stations. This will create a seamless connection to and from the metro stations. However, there is less room for improvement on other indicators, so increasing development density or road infrastructure does not seem feasible unless existing developments undergo retrofitting.
- The policy goal of the LAP is to provide on-street car parking on all streets, whether or not they are near a public transit hub. This is a policy-level issue in itself, and it is not pro-TOD. Therefore, instead of a blanket policy for on-street car parking in the TOD zone, we propose two options. First option is to prepare a parking demand plan. With such a plan, policymakers can make on-street car parking very expensive, especially near metro corridors (Cervero & Dai, 2014), or they can set a maximum parking demand within the TOD zone (Thomas et al., 2018). This will increase the attractiveness of the metro, encourage people to walk, and lead to more TOD. Nevertheless, special parking spaces for disadvantaged people need to be created around the stations based on the parking demand plan. Second option is to remove on-street car parking entirely from the LAP-TOD zone and provide it immediately outside the zone. Since the LAPs only have a 200-m in radius on either side of the metro corridor, which is different from the typical 800-m radius, it seems plausible to completely eliminate on-street car parking. To support our argument, we repeated the analysis and calculated the normalised "post-LAP-TOD" scores for all seven stations without on-street car parking. We then compared them to the normalized "post-LAP-TOD" scores with on-street car parking (Table 3), and found that the removal of on-street car parking substantially increases the normalised "post-LAP-TOD" score for all stations. This underscores our argument that for true TOD, on-street car parking should not be included in TOD planning. Such an approach will discourage car use, reduces congestion on the streets, decreases car cruising, and may lead to an increase in carpooling or park-and-ride.

Table 3
Difference in the Post-LAP-TOD scores with and without on-street car parking.

Stations	Normalized Post-LAP-TOD (with parking)	Normalized Post-LAP-TOD (without parking)
Thaltej Gam	0.22	0.24
Thaltej	0.24	0.27
Doordarshan kendra	0.22	0.25
Gurukul road	0.25	0.28
Gujarat University	0.30	0.34
Commerce six roads	0.15	0.17
Stadium	0.12	0.14

In the Gujarat University area, the LAP intervention doubled the normalized TOD score from 0.16 to 0.30. This is the highest normalized post-LAP TOD index score achieved in any station. Even then, there is room for improvement. We suggest starting with the population density, street density, signalized intersection density, and on-street car parking density indicators, as their normalized scores are 0.41, 0.47, 0.50, and 0.29, respectively. Improving on-street parking density leads to a significant increase in the post-LAP TOD index. A similar approach as mentioned above can be applied for on-street car parking density and signalized intersections density. The low score for population density is to be expected because the Gujarat University station area, as the name implies, includes a large university. Therefore, the residential population is low, but the flowing population is similar to other station areas. Given the nature of this area, we expect low population density.

5.2. Citywide recommendations

The LAPs were developed using a bottom-up approach that included meetings with local stakeholders, meetings with LAP residents, and incorporating their opinions into the final LAPs. We recommend that the local government supplement the bottom-up approach with a top-down approach. This means that it should organize meetings with professionals outside Ahmedabad who are knowledgeable about planning urban development projects. The comparison and combination of knowledge between these experts coming from different contexts could lead to sustainable TOD planning. In addition, we recommend that these station areas be reviewed every year. In other words, establishing a monitoring cycle, as longitudinal analysis provides better comparisons and useful information (Renne, 2007). We also recommend that the following indicators be included in the next LAP TOD assessment framework.

- Indicators such as land-use diversity, building footprint density, on-street car parking density, signalised intersection density, and first mile connectivity should be included in LAP planning in Ahmedabad. We proposed these indicators for the LAP-TOD planning because we believe these indicators are important in the current context of the city. There is evidence that these indicators have been used in the past to evaluate TOD performance in other similar contexts.
- Consider public input (residents and business owners) on LAP plans.
- Evaluate traffic flows within the TOD zones and develop a traffic safety plan.
- Conduct a resident survey on how TOD zone residents perceive their neighbourhood (do they feel safe, do they find their downtown attractive, is there a pleasant space to walk, etc.). Moreover, use the survey results to derive weights for the TOD indicators.
- Develop a parking management plan (how much space is needed to provide parking within the TOD zone and how much space is needed to support disadvantaged commuters within the TOD zones).

6. Conclusion

In this paper, we developed a three-step methodology to contextually evaluate pre- and post- LAP-TOD indices around the stations, using qualitative techniques such as expert interviews and review of LAP documents, and quantitative techniques such as the construction of a TOD index in the western corridor of Ahmedabad metro. Using this mixed-methods approach, we identified converging and conflicting results from qualitative and quantitative analyses within the LAP-TOD zones. In the quantitative analysis, we found that normalized post-LAP-TOD index scores ranged from 0.12 to 0.30 for the seven stations studied. These scores are low, and there is much potential for improvement, considering that the highest normalized TOD index score that can be achieved is 1. From the carefully selected eight interviews with key experts, we were able to obtain a comprehensive picture of the different opinions on local development challenges around metro stations. In addition, our review of the LAP documents revealed several important gaps in the LAP documents. Overall, we conclude that the sequential technique of using input from one method to gain knowledge from another, and vice versa, proved very useful in this LAP-TOD planning study. In doing so, we argue that a mixed-methods approach is more appropriate and far superior to a single-method approach because it explains the whole story and provides additional information to interpret and validate the results. In this way, we have developed policy recommendations to improve TOD indices and strengthen LAP documents. However, in the future, this methodology can be used to assess stations in the eastern and north-southern corridors of Ahmedabad. The methodology can also be extended to other cities that have a similar context and face similar local development challenges.

CRediT authorship contribution statement

Richa Maheshwari: Study conception and design, Data curation, Methodology, Formal analysis, writing (methodology, results and discussion, policy recommendation, and conclusion), Writing – review & editing. **Anna Grigolon:** Funding acquisition, Supervision, Writing – review & editing. **Mark Brussel:** Supervision, writing (introduction and literature review), Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix

Table 4
Pre-LAP-TOD interval standardization scores for seven metro stations.

	Thaltej Gam	Thaltej	Doordarshan Kendra	Gurukul road	Gujarat university	Commerce Six Roads	Stadium
Block size	0.00	0.84	0.21	0.56	0.36	0.38	0.58
Population density	0.19	0.36	0.00	0.31	0.10	0.49	0.25
Road density	0.03	0.63	0.06	0.00	0.29	0.12	0.12
Signalized intersection density	0.00	0.50	0.50	0.50	0.50	1.00	0.00
Pedestrian and cycle track density	0.03	0.00	0.11	0.07	0.24	0.23	0.41
Public space density	0.00	0.00	0.00	0.00	0.69	0.00	0.00
On-street car parking density	0.90	0.97	0.91	1.00	0.90	0.85	0.89
First mile connectivity	0.00	0.00	0.00	0.00	0.50	0.00	0.00
Last mile connectivity	0.00	0.00	0.00	0.00	0.50	0.00	0.00

Table 5
Post-LAP-TOD interval standardization scores for seven metro stations.

	Thaltej Gam	Thaltej	Doordarshan Kendra	Gurukul road	Gujarat university	Commerce Six Roads	Stadium
Block size	0.38	1.00	0.53	0.92	0.67	0.73	0.61
Population density	1.00	0.53	0.36	0.81	0.41	0.59	0.43
Road density	0.26	1.00	0.33	0.49	0.47	0.22	0.16
Signalized intersection density	0.00	0.50	0.50	0.50	0.50	1.00	0.00
Pedestrian and cycle track density	0.69	0.82	0.79	0.83	1.00	0.94	0.99
Public space density	0.11	0.08	0.21	0.23	1.00	0.04	0.00
On-street car parking density	0.33	0.00	0.45	0.11	0.29	0.30	0.07
First mile connectivity	0.75	0.75	0.75	0.75	1.00	0.00	0.00
Last mile connectivity	0.75	0.75	0.75	0.75	1.00	0.00	0.00

Table 6
Scoring of the indicators based on the perception of the interviewees.

Interviewees / Indicators	1 Block size	2 Population density	3 Road density	4 Signalized intersection density	5 Pedestrian and cycle track density	6 Public space density	7 On-street car parking density	8 First-mile connectivity	9 Last-mile connectivity
1	4	3	3	3	5	3	4	5	5
2	3	4	2	2	4	5	1	4	4
3	4	3	2	3	4	3	5	4	4
4	5	3	3	2	5	2	3	4	4
5	3	4	4	4	5	4	1	3	3
6	3	4	2	4	5	4	2	5	5
7	4	3	3	2	4	3	5	4	4
8	4	3	3	2	4	3	5	3	3
Total score	30	27	22	22	36	27	26	32	32
Normalized score	0.44	0.33	0.11	0.11	0.67	0.33	0.22	0.56	0.56

Table 7
Aggregated Pre-LAP-TOD and Post-LAP-TOD scores for seven metro stations.

	Pre-LAP-TOD Index Score	Post-LAP-TOD Index Score	Pre-LAP-TOD normalized Index Score	Post-LAP-TOD normalized Index Score
Thaltej Gam	0.28	1.94	0.03	0.22
Thaltej	0.83	2.20	0.09	0.24
Doordarshan Kendra	0.43	1.98	0.05	0.22
Gurukul road	0.68	2.27	0.08	0.25
Gujarat University	1.43	2.72	0.16	0.30
Commerce Six Roads	0.80	1.36	0.09	0.15
Stadium	0.83	1.11	0.09	0.12

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