15 Planning for Transit Oriented Development (TOD) Using a TOD Index

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15.1 INTRODUCTION

Transit-oriented development (TOD) has various definitions, including those given by Calthorpe (1993), Dittmar and Poticha (2004), Boarnet and Crane (1997), Schlossberg and Brown (2004), Centre for Transit-Oriented Development (2009) and many more. Most commonly, TOD is defined as a relatively high-density form of urban development that features a balanced mix of land uses and a walkable or cyclable urban environment that encourages people to walk, cycle or use various public forms of transit instead of their cars. As such, the TOD concept is an approach to sustainable development that hinges on the integration of land use and transport.

TOD plans, which primarily aim at bringing about a modal shift from transit by car to forms of transit with a lesser carbon footprint, have been made on a wide range of scales, varying from train and bus stations, and urban areas through to entire regions; see, for example, case studies found in Schlossberg and Brown (2004), Balz and Schrijnen (2009), Cascetta and Pagliara (2009), Yang and Lew (2009), Hoffman (2006), McKone (2010) and Cervero and Murakami (2009). Typically, these case studies also discuss and evaluate TOD plans, including their success or failure. The discussions in these studies tend to be very qualitative in nature, with little quantitative analysis involved. We argue in this chapter that quantitative analyses not only offer the means with which to compare different approaches and findings but also help in establishing measurable performance thresholds that can be set as goals for better performance. To aid this quantitative evaluation, a number of indicators for evaluating TOD plans have been proposed by Renne (2009), Evans and Pratt (2007) and Belzer and Autler (2002). In addition to evaluating TOD projects, Evans and Pratt (2007) emphasised the need to be able to assess and measure the degree to which a development fulfils TOD criteria. To accomplish this objective, we propose to develop a 'TOD index' that quantifies key TOD characteristics and combines them into a score of a TOD index. An index can help in assessing existing

TOD characteristics and in identifying reasons for poor TOD performance, so that specific policies, programmes and fiscal interventions can be made to improve TOD performance. Such a TOD index, when calculated over different points in time, can also help to gauge whether an area is moving towards meeting its aspirational (TOD) threshold values or slipping back. To plan more effectively for TOD or to evaluate TOD projects, a TOD index could, therefore, be a powerful tool.

In this chapter we develop a TOD index to facilitate planning for transit-oriented development, elaborate our methodology and discuss its application in a case study. We argue that planning for TOD must not be restricted to just making any development more transit-oriented: it should also include providing transit in places where development has already been highly transit-oriented, yet access to transit is still lacking. Hence, our approach towards planning for TOD has the following two objectives to fulfil (Singh et al., 2014):

1. To improve TOD conditions at locations where transit connectivity is available but where conditions for TOD are poor.
2. To improve transit connectivity at locations or in areas where conditions for TOD exist but access to transit connectivity is either absent or poor.

The TOD index elaborated in this chapter provides solid ground for achieving the above planning objectives. For the first objective, TOD needs to be measured around existing transit nodes and recommendations made at that scale to improve TOD conditions. For the second objective, TOD needs to be measured over an entire region such that areas in the region can be identified where TOD conditions are good but provision of transit connectivity is poor (Singh et al., 2014). When measuring TOD at a regional scale, TOD is characterised by typical urban development characteristics, such as urban densities, land-use diversity and others. However, when measuring for TOD at a local scale around an existing transit node, TOD is also affected by transit-related conditions such as frequency of service, travel comfort and node access, as these aspects influence people's decisions to use transit. Thus, for our first objective, development and transit-related characteristics need to be measured, while for the second objective, only development-related TOD characteristics need to be measured. Since we measure different aspects of TOD for each of these objectives, one index is not enough. We therefore developed two TOD indices, one for each objective: an 'Actual TOD index' and a 'Potential TOD index'. The Actual TOD index measures TOD around existing transit nodes, and the Potential TOD index measures TOD over an entire region, to identify areas that are potential locations for transit connectivity (Singh et al., 2014). These indices differ in terms of where they are measured and what they measure. Since TOD is an inherently spatial concept, its planning and evaluation needs to be done using spatial analyses, so both indices are measured using Multiple Criteria Analysis (MCA) or a Spatial MCA (SMCA) tool, as applicable.

BOX 15.1 Case Study Area

At the time of the study (2012–2014), the City Region Arnhem–Nijmegen, located in the Province of Gelderland, was the third largest of the eight city regions in the Netherlands. The City Region covered more than 1,000 km^2 and was home to the two large cities – Arnhem–Nijmegen. Total population of the City Region was about 735,000 in 2012, of which about 40% was residing in its two main cities, Arnhem and Nijmegen. The region had 20 municipalities and was served by a rail-based national and regional transit system. Regional and urban trains and a neighbourhood bus system also operated within the Region. There were 21 train stations in the

City Region at the time of our research; a couple more having been added since, but they are not included in this study.

To stimulate a modal shift from cars to transit, the City Region wanted to make public transport as competitive and attractive as private modes of transport and encourage its use for regional travel. It saw TOD as a powerful tool that could help in achieving this. The City Region Arnhem–Nijmegen was therefore a natural choice as a case study for investigating the use of TOD indices for planning for TOD.

We chose the City Region Arnhem–Nijmegen (the Netherlands) as a case study for this work because its vision for sustainable growth involved a modal shift from cars to transit. The City Region was spread over 1,000 km^2, includes 20 municipalities and had a population of around 735,000, 40% of which resides in its main cities of Arnhem and Nijmegen. The Region is striving to become the second-most important region in the Netherlands in economic terms, after the Randstad region. Figure 15.1 shows the City Region and its location within the Netherlands.

15.2 METHODOLOGY

BOX 15.2 Methods Applied in the Chapter

This chapter presents a methodology for calculating TOD indices using a combination of quantitative GIS methods and statistical analyses. Specifically, the GIS tools used for this study included ArcGIS™ 10.1 and the (Spatial) Multiple Criteria Assessment (MCA) platform in ILWIS™ (ITC, 2007). While ArcGIS was used to analyse individual indicators that contribute to TOD indices, ILWIS was used to calculate TOD index values. For the study, a variety of spatial and non-spatial data was required, which was collected from the City Region, Statistics Netherlands (CBS), the website of transit service, ESRI Top 10NL™ and Open Street Map (OSM)™. Administrative boundaries, the rail network, rail/bus station locations, road networks and land-use data (including building footprints) were all available as spatial data layers in vector format. No primary data was collected for this study, but site visits were made to, for example, train stations, to check some data and information collected through secondary sources. The methodology adopted to produce TOD indices is logical, straightforward, easy to implement and highly transferable to different geographies. If used before and after implementation of TOD-related plans, the indices can be used to decide whether an area is moving towards meeting its aspirational (TOD) threshold values or slipping back.

The methodologies adopted for the calculation of Actual and Potential TOD indices are similar; it is in their interpretation that they differ. For the calculation of both indices, first an area of analysis needs to be defined for which each index will be calculated. Each index is measured at a different scale. The Actual TOD index must be measured around an existing transit node (in accordance with various definitions described in the literature), extending outwards to what is considered the walkable limit from the node. According to various references (Calthorpe, 1993; Schlossberg and Brown, 2004; CTOD, 2009; Cervero and Murakami, 2009; City of Calgary, 2004), this distance can range from 400 m to 800 m. For the particular case of the Netherlands, Molster and Schuit (2013) have defined a comfortable ten-minute walking distance to be 800 m. Accordingly, we defined the area

FIGURE 15.1 The City Region Arnhem–Nijmegen (the Netherlands).

to be considered for transit-oriented development as that within a radius of 800 m of a transit node, and all indicators for the Actual TOD index were measured in this area.

The Potential TOD index needs to be measured over an entire region to see how index values vary from one location to another and whether there are some areas where levels of transit-oriented development are already high. Thus, for this index we divided the City Region into a number of grid cells such that a (potential) TOD index could be calculated for each grid cell. By applying tessellation of space, different grids of 100 m × 100 m, 200 m × 200 m, 300 m × 300 m and 500 m × 500 m were created. Ultimately, the 300 m × 300 m grid was chosen because a smaller cell size had a considerably negative influence on computational performance, while a larger size could lead to a loss of accuracy. Laying this grid over the City Region's 1,000 km^2 resulted in more than 12,000 grid cells for which a Potential TOD index was calculated.

It is also important to identify the transit system and nodes that we considered in this case study. The City Region is served by a rail-based national and a regional transit service, which also includes inter-urban and intra-urban bus services. There is discussion in the literature (Newman and Kenworthy, 2007; Newman, 2009) that for TOD to be successful, a high-quality transit service is required that has a high-traffic volume, higher speeds than cars and is not affected by traffic conditions on the roads. Only rail-based transit services and Bus Rapid Transit (BRT) offer such advantages (Hale and Charles, 2006; Hoffman, 2006; McKone, 2010; Newman and Kenworthy, 2007), as regular buses can be slower than cars: they share the same road space as cars and are thus vulnerable to adverse traffic conditions.

Transit in the City Region Arnhem–Nijmegen is rail-based with 21 train stations providing connections. A BRT system was in its early planning stages and thus could not be studied, so indicators for the Actual TOD index calculations were measured in the area around each of the 21 train stations. The Potential TOD index is independent of the location of transit nodes, so indicators had to be measured for all grid cells. However, once our calculations were complete, we were able to identify cells with high Potential TOD index values for which access to rail transit was at that time nevertheless low.

15.2.1 Identification of Indicators

For both indices, relevant indicators needed to be identified for measurement. There are some typical physical characteristics relating to urban development that define transit-oriented development: high urban densities, high levels of land-use diversity, a walkable environment and attractive urban design, to name a few. Thus, to measure TOD one must measure development-related indicators based on the 3Ds-concept – Density, Diversity and (urban) Design – as discussed by Cervero and Murakami (2009), since these factors are expected to affect travel demand and mode choice (Cervero and Kockelman, 1997), as well as reducing peak-hour congestion levels (Zhang, 2010). Since transit is core to TOD, it is also important to measure those characteristics of transit that affect travel behaviour. These could include the frequency of transit services, access to transit services and to opportunities provided by them, user-friendliness of the system, travel comfort and so on. Transit characteristics can, however, only be measured around existing transit nodes, so they were measured along with the urban development characteristics being measured for the Actual TOD index. By contrast, the Potential TOD index is measured on the basis of grid cells, independently of the location of transit nodes, which is why only development characteristics need to be measured for this index. This helps to identify areas that, with development, would be highly suitable for transit. This will help in identifying those areas where the development has better TOD characteristics. Later, the level of access of these areas to high quality transit is assessed.

Various indicators proposed by Schlossberg and Brown (2004), Renne (2009), Evans and Pratt (2007), Belzer and Autler (2002) and others were also studied in detail to finalise a list of quantifiable TOD indicators for the measurement of the urban development and transit characteristics. These indicators can be grouped according to broad criteria, as shown in Table 15.1. The indicators are not specific to our case study and can be used to measure TOD around any transit node in any city or country.

For our list of indicators for both indices, we needed a variety of spatial and non-spatial data, which we acquired from the City Region's authorities, Statistics Netherlands (CBS), ESRI TOP 10 NL, Open Street Map (OSM) and the website of transit services. The spatial data collected were all in vector format and minor issues relating to incomplete map coverage, inconsistent administrative boundaries, conflicting land-use classifications and different map projections were addressed by comparison of the data amongst each other and with the help of a third-party reference such as Google Maps. Although we were able to collect data for most of the indicators, there were some that were deleted from both lists for want of data: specifically, indicators for tax earnings of municipalities and employment levels. The indicator 'basic amenities at station' considered the presence of waiting rooms, benches to sit on, elevators and/or access for the disabled and ticket machines at the stations. Since all these amenities were found to be present at all stations, this indicator was dropped as it did not contribute to TOD comparisons for any stations. 'Safety' at a station can be measured in a number of ways. We based our assessment on the presence of lighting and the presence of other people at a station. Since all stations were found to be properly lit day and night, we focused on the number of people at stations, since the presence of 'many eyes' in an area adds to the feeling of being safe (Jacobs, 1961). However, we had neither the data for this indicator nor the resources to collect the data ourselves. We therefore measured safety using 'number of shops/

eateries/takeaways' as a proxy for presence of other people. In the absence of these shops, fellow passengers can be expected to arrive only shortly before departure and leave immediately after arrival, reducing numbers of people around a station.

15.2.2 Computing Indicators and TOD Indices

Broadly speaking, the calculation of our two indices involves four steps: calculation of individual indicators; their standardization to account for differing units of measurement; weighting; and, finally, calculation of index values in MCA/SMCA (as applicable).

15.2.2.1 Actual TOD Index

For this index, we measured a total of 18 indicators related to urban development and transit (see Table 15.1), some of which are spatial in nature and others non-spatial. The development-related indicators were spatial and were measured in ESRI ArcGIS software using the statistical data on various urban densities, the City Region's administrative boundaries, land-use data and road network data. While the computation of the indicators is quite straightforward, we show below the equations used to calculate land-use diversity and mix of land use. These two indicators sound very similar but are quite different. Diversity of land use is a measure of how diverse the mix of all land uses is in an area and was calculated using the entropy index (Cheng et al., 2013):

$$LU_d(i) = \frac{-\sum_i Q_{lui} \times \ln(Q_{lui})}{\ln(n)} \tag{15.1}$$

$$\sum_i Q_{lui} \times \ln(Q_{lui}) = Q_{ai} \times \ln(Q_{ai}) + Q_{bi} \times \ln(Q_{bi}) + \ldots + Q_{ni} \times \ln(Q_{ni}) \tag{15.2}$$

$$Q_{lui} = \frac{S_{lui}}{S_i} \tag{15.3}$$

where:

lui = land-use class within the analysis window i
S_{lui} = total area of the specific land use within the analysis window i
S_i = total area of the analysis window i
n = total number of land use classes within the analysis window i

A high degree of land use diversity is desirable for TOD as this helps in utilizing off-peak directions/hours of transit capacity (City of Calgary, 2004), as well as adding to the liveliness of a place. The mix of land use, on the other hand, measures how well residential land use is mixed with other land uses in an area and is important because a greater mix means that residents can walk or cycle when undertaking non–work-related trips (Cervero and Kockelman, 1997; Thorne-Lyman et al., 2011; Zhang and Guindon, 2006). Thus, this indicator is used to measure the walkability or cyclability of an area and is calculated using the formula (Zhang and Guindon, 2006):

$$MI(i) = \frac{\sum_{\cap i} S_c}{\sum_{\cap i} (S_c + S_r)} \forall i \tag{15.4}$$

where:

i = area of analysis
Sc = sum of the total area under non-residential urban land uses within i
Sr = sum of the total area under residential land use within i.

TABLE 15.1
Criteria and Indicators for Actual and Potential TOD Indices

No.	Criteria	Indicators for Actual TOD Index	Indicators for Potential TOD Index
1.	Area around transit node should have transit-supportive densities.	Population density (No. persons/km^2)	Population density (No. persons/km^2)
		Commercial density [a] (No. commercial enterprises/km^2)	Commercial density (No. commercial enterprises/km^2)
			Employment density [c] (No. employees/km^2)
2.	Land-use diversity is essential for effective utilization of transit in off-peak hours.	Land-use diversity	Land-use diversity
3.	Area around transit node should be walkable and cyclable.	Mix of residential land use with other land uses	Mix of residential land use with other land uses
		Total length of walkable/cyclable paths (km)	Total length of walkable/cyclable paths (km)
		Intersection density (No. of intersections/km^2)	Intersection density (No. intersections/km^2)
		Impeded pedestrian catchment area (IPCA)	
4.	Greater economic development in area around transit leads to more transit-oriented development.	Density of business establishments [b] (number of business establishments/km^2)	Density of business establishments (number of business establishments/km^2)
		Tax earnings of municipalities in previous year	Tax earnings of municipalities in previous year
		Employment levels	Employment levels
5.	Transit system's capacity should be utilised to optimal levels.	Passenger load at peak hours	n.a.
		Passenger load at off-peak hours	
6.	Transit node should be user-friendly and visually attractive.	Safety of commuters at transit stop	n.a.
		Basic amenities	
		Information display systems	
7.	Transit nodes should be accessible for passengers and provide good accessibility to a range of destinations.	Frequency of transit service (No. trains operating/hr)	n.a.
		Interchange to different routes of same transit mode (No. of routes)	
		Interchange to other transit modes	
		Access to job opportunities within walkable distance of transit node (No. of jobs) ('cumulative opportunities' or 'contour measure' (Geurs and Van Wee, 2004))	
8.	Transit nodes should provide optimum parking supply for different modes.	Parking supply–demand for cars/four-wheeled vehicles	n.a.

[a, b] To avoid double counting of same data in 'commercial density' and 'density of business establishments', 'commercial establishments' were counted for 'commercial density' and 'non-commercial establishments' were counted as business establishments.

[c] Employment density was not measured for Actual TOD index because the same data were used to measure 'access to job opportunities around the station' and we did not want to double-count the number of jobs.

n.a. = not applicable.

The transit-related indicators are non-spatial and were calculated accordingly. A combined measurement of these indicators for each train station had to be done to arrive at the value of the Actual TOD index; this was done using MCA in ILWIS software (ITC, 2007). MCA allows computation of the index using indicators that have different units of measurement by standardizing them. In the standardization process, the highest value of an indicator among all stations was fixed as 1 and, proportionately, all other indicator values were standardised. After the standardization process, the effect of each indicator's value on the final value of the TOD index was also specified. For example, an increase in densities listed in Table 15.1 should lead to an increase in the Actual TOD index value: this relationship between the indicator and the TOD index was specified for each indicator. Most of the indicators have a similar directly proportional relationship with the TOD index value, except for mix of land use. For this indicator, the directly proportional relationship remains until a mid-value of 0.5 is reached, which implies a balanced mix of residential use with other land uses. Beyond this value (0.5), any increase in an indicator's value decreases the Actual TOD index value because it implies a less-balanced mix of uses. Four more indicators – i.e. passenger load during peak hours and off-peak hours, and parking utilization by four-wheeled vehicles and cycles – also exhibit a similar relationship with TOD index values. For these indicators, the relationship remains directly proportional up to a value of 0.9, i.e. 90% utilization of transit capacity or parking supply, after which the relationship becomes inversely proportional. That is because a utilization level of 90% or more can be quite uncomfortable for users and signals the need for additional capacity.

The next stage in MCA requires weighting of indicators, and for this step we held a workshop in the City Region's offices, with the heads of all 20 municipalities invited to attend. They were chosen to participate because they are the decision-makers for a variety of planning policies within their municipalities, as well as advising officials of the City Region on regional planning policies. For other case studies, however, the group(s) of stakeholders chosen could vary considerably. Before the workshop, all participants were sent information about the project and the purpose of the workshop. During the workshop, the interim results of our study were presented and the focus of the workshop was discussed and explained. A questionnaire (also available online; Singh, 2013) was then physically distributed so that the participants could rank criteria and indicators based on perceptions of their importance for realization of transit-oriented development. After the workshop, the ranks of criteria and indicators were compiled using the Borda Count method (Reilly, 2002) and input into ILWIS, where ranks were converted into weights using a rank–sum method (ITC, 2007). These weights (see Table 15.2) were used in the final calculations of the Actual TOD index.

15.2.2.2 Potential TOD Index

For the Potential TOD index, we measured eight indicators for the more than 12,000 grid cells that cover the City Region. All indicators for this index are spatial in nature and were, therefore, calculated with ArcGIS software using the statistical data on various urban densities, administrative boundaries and land-use and road network data. The formulae used for computing land-use diversity and mix of land use were the same as for Equations 15.1 and 15.3, although there was a difference in the way they were calculated. As mentioned before, the size of a grid cell is 300 m × 300 m, so this size covers about 9 ha of area, which is not big enough to assess land-use diversity nor mix of land use. For this reason, we used a 'window of analysis' around each grid cell that covered an area bound by the eight cells surrounding the 'central' cell. The indicators for Potential TOD were calculated over this area, although the result was assigned to the central grid cell only. This ensures that these indicators also consider land use surrounding the grid cell, which is a better measure.

As a result of measuring the indicators, a map was produced for each indicator and combined into a TOD index. The maps were input into ILWIS for SMCA. For this, too, all indicators were standardised and the relationship of each indicator with the Potential TOD index was specified in the same manner as for the Actual TOD index. During the workshop held to obtain the weights of criteria and indicators, the municipal heads were also requested to rank criteria and indicators for the Potential TOD index. The ranks were compiled and input into ILWIS, where they were

TABLE 15.2
Weights of Criteria and Indicators for Actual and Potential TOD Indices

	Weights for Actual TOD Index				Weights for Potential TOD Index			
No.	**Criteria**	**Weights**	**Indicators**	**Weights**	**Criteria**	**Weights**	**Indicators**	**Weights**
1.	Area around transit node should have transit-supportive urban densities	0.15	Population density	0.67	Area around transit node should have transit-supportive urban densities	0.3	Population density	0.5
			Commercial density	0.33			Commercial density	0.33
							Employment density	0.17
2.	Land-use diversity is essential for effective utilization of transit	0.03	Land-use diversity	1	Land-use diversity is essential for effective utilization of transit	0.2	Land-use diversity	1.0
3.	Area around transit node should be walkable and cyclable	0.06	Mix of residential land use with other land uses	0.1	Area around transit node should be walkable and cyclable	0.1	Mix of residential land use with other land uses	0.17
			Total length of walkable/cyclable paths	0.4			Total length of walkable/cyclable paths	0.50
			Intersection density	0.2			Intersection density	0.33
			Impeded Pedestrian catchment area (IPCA)	0.3				
4.	Higher economic development around transit area leads to more transit-oriented development	0.22	Density of business establishments	1	Higher economic development around transit area leads to more transit-oriented development	0.4	Density of business establishments	1.0
5.	Transit system's capacity should be utilised at optimal levels	0.19	Passenger load at peak hours	0.67	n.a.	n.a.	n.a.	n.a.
			Passenger load at off-peak hours	0.33				
6.	Transit node should be user-friendly and visually attractive	0.11	Safety of commuters at transit stop	0.5				
			Information display systems	0.5				

(*Continued*)

TABLE 15.2 (CONTINUED)

Weights of Criteria and Indicators for Actual and Potential TOD Indices

	Weights for Actual TOD Index				Weights for Potential TOD Index			
No.	**Criteria**	**Weights**	**Indicators**	**Weights**	**Criteria**	**Weights**	**Indicators**	**Weights**
7.	Transit nodes should be accessible to passengers and provide good accessibility to a range of destinations	0.15	Frequency of transit service	0.4				
			Interchange to different routes of same transit mode	0.3				
			Interchange to other transit modes	0.2				
			Access to job opportunities within walkable distance from transit station	0.1				
8.	Transit nodes should provide optimum parking supply for different modes	0.08	Parking supply–demand for cars/four-wheeled vehicles	0.67				
			Parking supply–demand for cycles	0.33				

converted to weights that are tabulated in Table 15.2. The indicators were then weighted to arrive at a combined Potential TOD index value for each grid cell in the City Region.

15.3 RESULTS

The Actual TOD index values for all 21 railway stations in the City Region Arnhem–Nijmegen are shown in Figure 15.2, for which, on a scale to 1, the maximum index value is 0.76 for Arnhem railway station and minimum index value is 0.16 for Wolfheze railway station. Since Arnhem and Nijmegen are the biggest urban centres in the region, it was to be expected that they would have high TOD scores. Similarly, the quiet villages of Zetten-Andelst, Molenhoek-Mook and others like them were expected to score very low. Thus, the predictive performance of the Actual TOD index is well demonstrated.

We subjected our results to a sensitivity analysis to make sure they were robust enough. For sensitivity analysis, we varied the weights of each criterion one at a time by ± 10% (Malczewski, 1999) and assessed its effect on the final TOD index values.

For the Actual TOD index there were eight criteria, so 16 scenarios of weights were created by changing each criterion by ± 10%. For the sensitivity analysis, the Actual TOD index was recalculated for all 16 scenarios: the top five ranking stations remained the same and the lowest and highest Actual TOD index values in the region ranged from 0.152 to 0.162 and from 0.76 to 0.77, respectively, which makes them close to the original values. Thus, the Actual TOD index was confirmed to be robust and reliable. The inferences that can be drawn from the results of the Actual TOD index are discussed in next section.

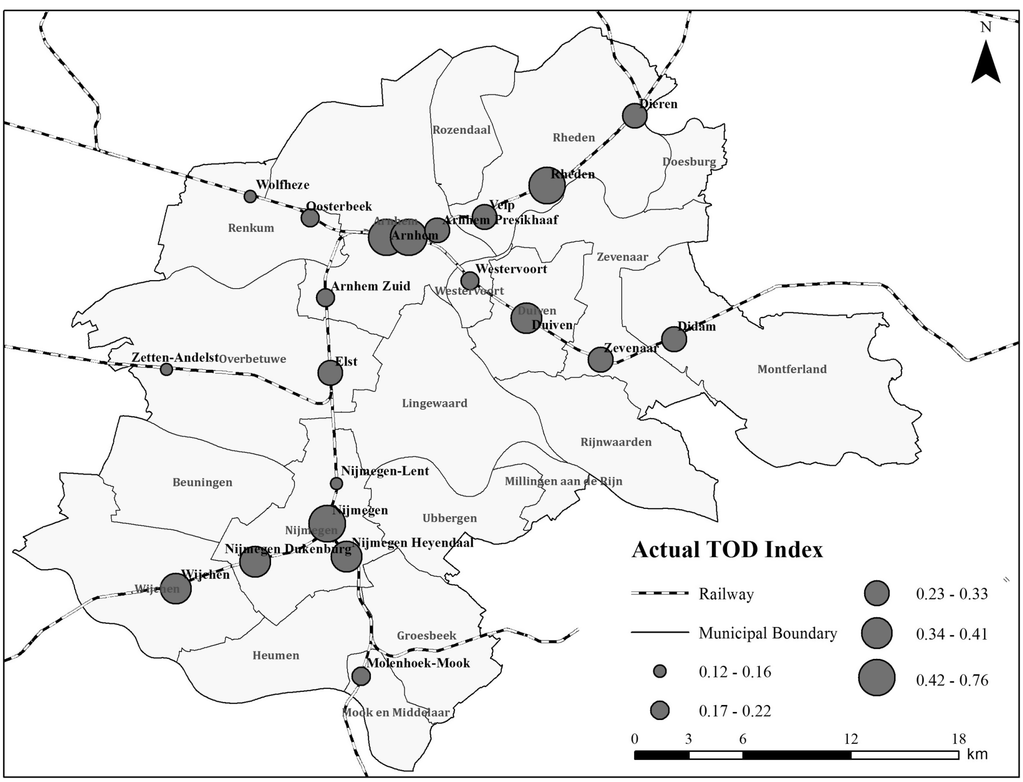

FIGURE 15.2 Actual TOD index values for 21 train stations in the City Region Arnhem–Nijmegen.

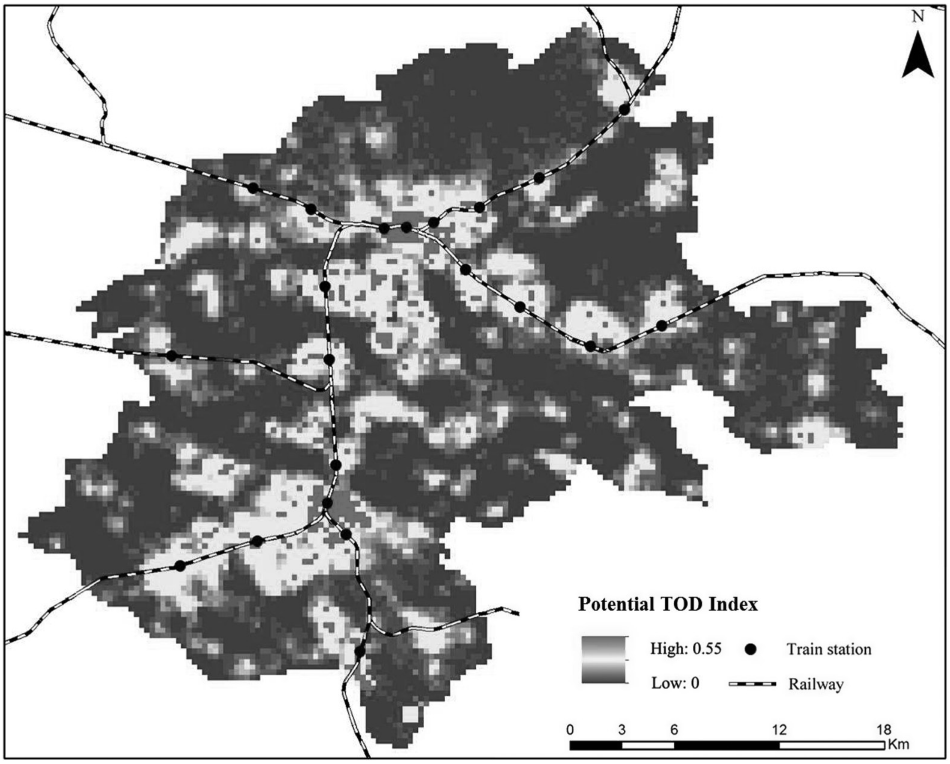

FIGURE 15.3 Potential TOD index values throughout the City Region Arnhem–Nijmegen.

The Potential TOD index map for the City Region Arnhem–Nijmegen is shown in Figure 15.3; the maximum value in the region was 0.55 on a scale of 0 to 1. Potential TOD index values are generally low throughout the region: the mean index value for the region is only 0.044. Similar to Actual TOD index results, the Potential TOD index shows the highest TOD scores around the biggest stations of the Arnhem–Nijmegen region, which matches the pattern expected for this index.

A sensitivity analysis was also carried out for the Potential TOD index. We measured four criteria for this index, so eight scenarios of weights were created by changing weights of each criterion by ± 10%. Potential TOD index values were recalculated for all eight scenarios for the sensitivity analysis. The results showed a marginal change in the spread of Potential TOD index values: the maximum index value only ranged from 0.55 to 0.56, with the mean index value also ranging from 0.0432 to just 0.0461. Thus, the results of Potential TOD index were confirmed to be robust.

15.4 INFERENCES AND RECOMMENDATIONS

High TOD index values in an area imply that transit is a core concern that needs to be taken into account when planning for development. Proper inferences are required to be able to make recommendations for effective TOD planning.

15.4.1 Actual TOD Index

On a scale of 1, the highest value of the Actual TOD index was 0.76, which seems like a good score. However, as this study is the first of its kind, we do not have any benchmarks or reference values to infer in any other way. Even if there were other, similar case-studies, their results might not be comparable to ours since each case has different characteristics: their weights would differ, making a whole lot of difference in the results. It was expected that at the regional scale Actual TOD scores would be highest for Arnhem and Nijmegen's railway stations and that scores would become gradually lower as distance from these cities increased, just as the degree of urbanization declines with distance. However, no such pattern is visible in Figure 15.3, except for areas to the south of Nijmegen station. At the regional level, planners may like to first work towards improving the TOD levels at neighbouring stations to Arnhem and Nijmegen, where the scores drop abruptly. Yet even these top-ranking stations have some scope for improvement of TOD levels, and this may be investigated further.

To understand the reasons behind a good or a bad score in terms of index values, we created web charts for all stations. The web charts of the three best scoring stations – Arnhem, Arnhem Velperpoort, Nijmegen – are shown in Figure 15.4. For Arnhem Velperpoort station, for example, even though the Actual TOD index value is one of the highest in the region, it clearly scores very low on user-friendliness, the urban densities access to and from the station and parking utilization. Low parking utilization indicates the need to redirect investment in any extra supply of parking to other uses that support transit while still keeping enough supply to accommodate existing and forecast parking demand. At Arnhem station, user-friendliness is highest of all stations, but it can still be improved. The web charts make clear which criteria need to be improved upon to enhance conditions for TOD around each station. Planners and decision-makers could take this information into account before making specific planning proposals on, for example, how to improve urban densities or land-use diversity around stations.

15.4.2 Potential TOD Index

Like the Actual TOD index, there are no benchmarks or reference values to guide us on whether a Potential TOD index value of 0.55 is high or not. It can, however, be safely inferred that overall the region's scores are low since its mean index value is 0.0447, with nearly 86% of grid cells scoring below 0.30 and 40% grid cells scoring below 0.15. Figure 15.3 shows the spread of Potential TOD index values over the City Region, but this does not help in identifying TOD hot-spots. Thus, spatial statistical analyses were needed to carve out clusters or hot-spots of high TOD index values. Global Moran's *I* statistic confirmed that statistically significant clustering of similar values is possible within the region. Subsequently, statistical analysis using Anselin Local Moran's *I* was carried out to identify clusters or hot-spots of similarly high TOD index values. Of these hotspots, those within 800 m of existing train stations were omitted since these could be expected to have access to transit and have also been studied when Actual TOD index values were being calculated. The remaining hot spots were those areas that had high Potential TOD index values but at that time poor access to high-quality transit modes; see Figure 15.5. These areas can be considered by the planners for better transit connectivity. We would not recommend connecting these areas by rail since it is a highly cost-intensive mode. Rather, the more cost-effective option of BRT could be implemented for these areas. Conversion of existing regular bus routes to BRT routes would also be an option worth considering.

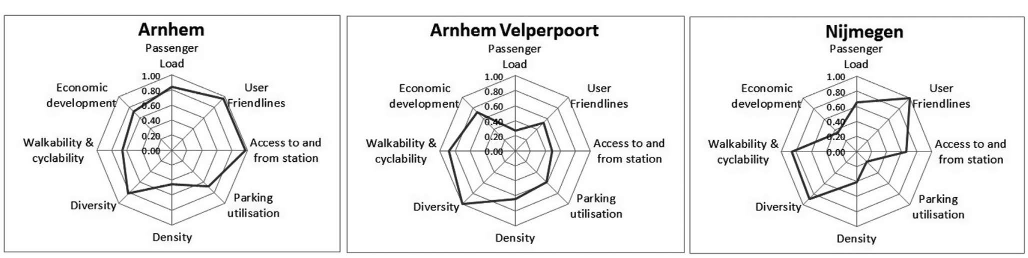

FIGURE 15.4 Web charts of indicators of the Actual TOD index for the three highest-scoring stations in the City Region Arnhem–Nijmegen.

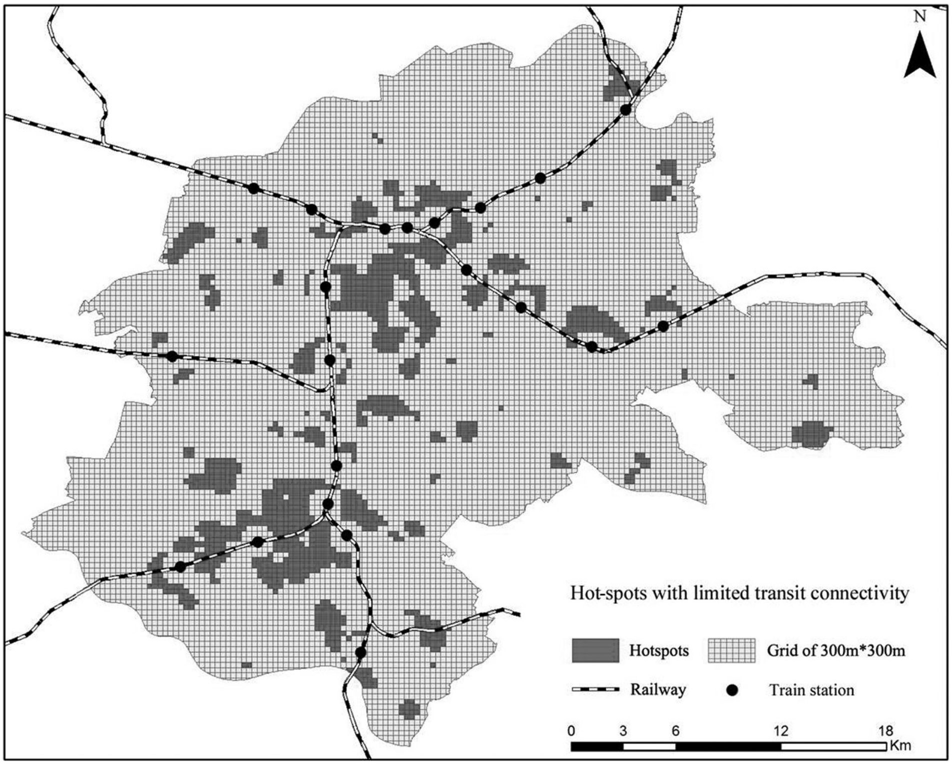

FIGURE 15.5 Hot-spots that have high Potential TOD index scores and poor access to transit.

15.5 CONCLUSIONS

We demonstrate in this chapter how a TOD index can be a useful tool in pursuing the TOD planning objectives we set out early in this chapter. The methodology adopted to calculate TOD indices is logical, straightforward and easy to implement, which, together with its high degree of suitability across different geographies, are the strengths of this approach. With the sort of results presented here, urban planners are able to make more accurate planning proposals, knowing what exactly is missing around each transit node and what can be changed to improve conditions for TOD. The ambiguity of qualitative assessments can thus be avoided by replacing them with quantitative assessments.

Once TOD plans have been drawn up and implemented, the same index can be used to measure the conditions for TOD later and so gauge the success of TOD initiatives. Identification of hot-spots in a region also helps to highlight areas that would benefit from better access to high quality transit. For the first time in a case study, the views of decision-makers have also been incorporated in defining and measuring TOD. TOD index results from other cases would also be extremely helpful to urban planners when making specific TOD planning proposals at regional and local scales. Application of a TOD index to different contexts would further improve this tool, perhaps leading to ready-to-implement assessment and evaluation guidelines that would help in optimizing planning of TOD.

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