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A Systematic Literature Review on Station Area Integrating Micromobility in Europe: A Twenty-First Century Transit-Oriented Development



Moinse Dylan

Abstract The increasing popularity of the bicycle, coupled with the emerging new micromobility solutions, such as personal electric micro-vehicles or sharing systems, calls for renewed attention to the smart urban and transport planning strategy advocated by the conventional Transit-Oriented Development (TOD) model. These personal and shared mobility devices constitute an opportunity to enhance accessibility to the public transport network, leading to a TOD vision revisited by the contribution of individual light modes. Given the relatively recent and extensive documentation related to micromobility and public transport integration, a systematic literature review was undertaken to reflect the state of research literature on the redefinition of the TOD perimeter by micromobility, with a focus on the European context. Nineteen of the 3955 articles recorded met the inclusion criteria specified in the methodology protocol. The analyzed papers clearly highlight TOD boundaries extended to about 3 km, suggesting the redistribution of variables toward residential and cycling-friendly areas beyond the first walking kilometer. This chapter uncovers gaps in existing academic literature, with the near absence of Eastern and Southern Europe case studies, innovative micromobility options such as private or shared electric bikes and scooters, impact assessment on neighborhoods, and the application of qualitative research methods.

Keywords Catchment area · Micromobility · Systematic literature review · Transit-oriented development

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1 Introduction

1.1 *Research Questions*

The aim of this chapter is to reflect the state of research literature on the redefinition of the TOD perimeter through the contribution of micromobility. Which forms take the TOD model when looking at extended station areas? What distance ranges are covered by this modal synergy? Do TOD characteristics evolve? Are there similarities and distinctions according to local contexts?

To collect, analyze, and compare all the studies on this subject, a systematic literature review of peer-reviewed papers was conducted. Only English-written studies that address accessibility around European stations with the use of micromobility were included. This chapter presents the current state of knowledge by identifying international scientific articles that address the relevant geographical perimeter of station areas for micromobility use. The aim is to provide a spatial overview of these intermodal practices on a European TOD, although this work does not pretend to be exhaustive.

In this way, this chapter is organized as follows: Section 2 describes the methodological approach. Section 3 discusses the results. Section 4 considers avenues for future research on a TOD integrating micromobility.

1.2 *Conceptualizing Renewed Smart Growth Regions*

Since the 1990s, the urban and transport planning strategy of transit-oriented development (TOD) has become the dominant urban growth planning paradigm, particularly in the United States (Papa & Bertolini, 2015, p. 70). Closely connected with Smart Growth and New Urbanism movements, TOD, as formalized, promotes urban development along with public transport (PT) corridors as a tool and a target for mitigating uncontrolled urban sprawl and achieving more sustainable regions and smart transport networks. These urban approaches represent an invitation to revisit the suburban, car-oriented, and segregated way of life (Jamme et al., 2019, p. 411).

While TOD is not a recent concept, drawing inspiration from Garden Cities for the development around railway nodes, the challenge of adapting it to the auto-oriented metropolis is novel (Dittmar & Ohland, 2012, p. 5). European and Asian planners consider TOD to be an innovative instrument but not an invention (Jamme et al., 2019, p. 411), although the origin of the label is commonly attributed to Calthorpe (1993). This emerging vision of smart territories facing auto-oriented systems is seen as delivering multiple benefits, such as improving quality of life, creating attractive places, enhancing transit, walking, and cycling, while supporting polycentric regions and economic growth (Papa & Bertolini, 2015, p. 77). Internationally formulated TOD has the potential to fundamentally rethink multi-scale communities (Dittmar & Ohland, 2012, p. 19), even if most theories on how

to design successful TOD projects have been developed in the United States (Pojani & Stead, 2015, p. 131).

The transit-oriented development (TOD) urban model is designed mainly to encourage the use of public transport and create a pedestrian-friendly urban environment to reduce vehicular traffic congestion (Nasri & Zhang, 2014, p. 172). TOD's fundamental principles are based on the formulation of the 3Ds (Density, Diversity, and Design) built environment hypothesis measured by Cervero and Kockelman (1997, p. 199) to reduce vehicle miles traveled (VMT) and encourage transit use.

Additional D-requirements also complete the list of factors coordinating and integrating planning and transportation issues, including the 6Ds with 3Ds variables supplemented by distance to transit, destination accessibility, and demand management (Ewing & Cervero, 2010, p. 274). As a critical dimension in the TOD equation, the "Distance to Transit" variable is crucial to measure the accessibility of a transit station and to make decisions on land development. "Destination accessibility" is based on the logic of providing greater mobility by moving people around the city more swiftly, while "demand management" can be considered actions that are implemented at specific sites or strategies that are implemented at an area-wide level (Ogra & Ndebele, 2014, p. 541).

One-half mile has become the accepted distance for gauging a transit station's catchment area in the United States (Guerra et al., 2012, p. 2), being a standard for planning TODs. The scope of TOD in most countries corresponds to a "pedestrian pocket" around a transit stop (Calthorpe, 1993, p. 44), with a radius between 400 and 800 m by walk or bike (Cervero et al., 2004, p. 238). The conventional TOD approach is based on the development of a dense commercial and employment "Primary Area" in proximity to a station (600 m), followed by residential zones with densities gradually decreasing (Calthorpe, 1993, pp. 43–87). However, this standardized rule is likely to evolve and change the model by revisiting the stations' service area.

1.3 An Extension of the Walking Bull's Eye

Academic works focusing on the revision of TOD principles seem to reflect two trends. The first one considers that the range of access and egress walking exceeds the established spatial limit of 500–800 m (Pojani & Stead, 2015, p. 133). The second is interested in mobility feeder solutions inviting the integration of first- and last-mile connections to public transport (Park et al., 2021, p. 38). Both approaches converge on a common critique of this distance threshold and suggest a broader view of TOD neighborhoods to include a more diverse share of communities. Calthorpe (1993, p. 60) refers originally to the surrounding environment as the "Secondary Area" (Fig. 1). According to him, lower density and auto-oriented urban systems characterize this 1.6-km adjacent perimeter (Banai, 1998; Ibraeva et al., 2020).

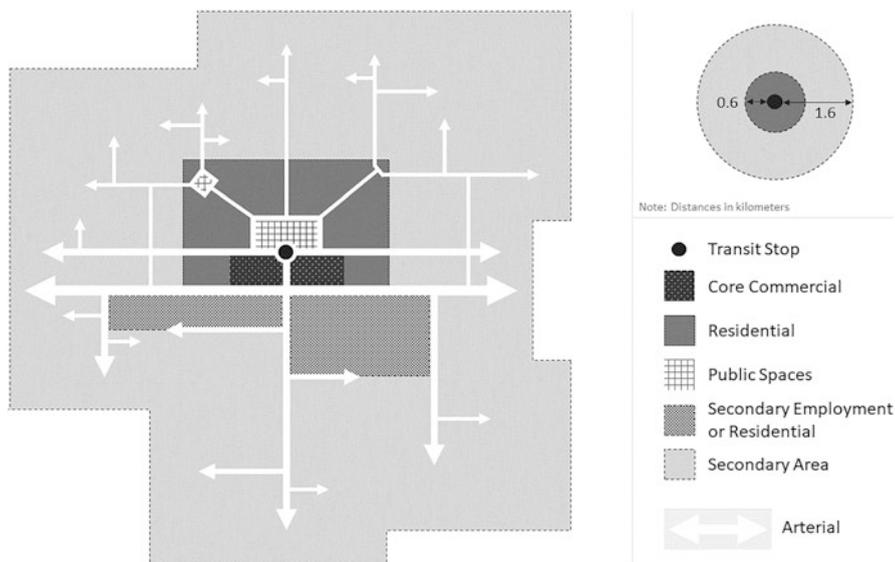


Fig. 1 Spatial configuration of TOD at the station level. (Redesigned from Calthorpe (1993, p. 60). Source: Author elaboration)

The first trend observed on the pedestrian side has been extensively studied in the scientific literature in connection with the idea of “bursting the [pedestrian TOD] bubble” (Canepa, 2007, p. 34). A variety of studies and reports have shown the increased reach of walking around high frequency hubs surrounded by attractive facilities, and the boundaries of a TOD district do not have to be confined to 1 km (Ker & Ginn, 2003, p. 79). Through a review of existing scientific works, L’Hostis (2016, p. 5) shows that the arbitrary idea of the 0.5 mile is not a relevant limit for getting to the stations and therefore requires extending the analysis beyond this boundary.

In contrast, the research body lacks, as far as the author knows, a discussion of the role of sustainable feeder modes in the redefinition of a TOD model. In fact, many studies dealing with the close links between cycling and transit are emerging but generally do not explicitly mention the urban planning vision of an extended TOD perimeter. Among the modes analyzed that require a new understanding of TOD are bikes (Lee et al., 2016, p. 979), buses, and personal rapid transit (Schneider, 1992, p. 151), as well as shared and digitized mobility solutions (Knowles et al., 2020, p. 7).

This trip chain perspective is leading to the development of emerging concepts, such as the “Extended-TOD” (E-TOD) and “Bicycle-based TOD” (B-TOD), which complete the guiding philosophy of TOD. The two derivatives of the urban model attempt to provide access to stations and to places further away than the conventional distance of walking by means of the development of a secondary mobility system offering intermediate capacity. E-TOD assumes a Feeder-Distributor-Circulator network (Schneider, 2012) similar to Personal Rapid Transit (PRT),

whose deployment strategy has evolved (Schneider, 1992, p. 152). Part of the common thought of an extension of the TOD, B-TOD, focuses on the contribution of individual light modes and, in particular, of the bicycle. In combination with the re-evaluation of walking accessibility to and from a public transport station, secondary modes that complement the public transport network can also play a role in the TOD model.

Feeder services to mass transit are superimposed on the pedestrian bubble, significantly widening the catchment area of the stations and thereby increasing potential ridership. In addition, new mobility solutions are emerging to enhance the attractiveness of public transport systems and thus improve the accessibility of stations. The renewed popularity of the bicycle in Europe (Héran, 2015, p. 142), rising development of bike and e-scooter schemes, and the rapid adoption of emerging Personal Mobility Devices (PMDs), such as the standing scooter, play a positive role in public transport patronage (Kostrzewska & Macikowski, 2017, p. 2). This research focuses on this category of devices qualified as micromobility, with the aim of linking two approaches: the association of micromobility and public transport in connection with TOD areas.

2 Materials and Methods

2.1 Study Selection Procedure

Given the relatively recent and extensive existing documentation related to the integration of micromobility and public transport supporting the TOD, a systematic literature review (SLR) was undertaken to reflect recent trends toward new personal and shared mobility embodied in the micromobility system. A review earns the adjective “systematic” when the questions are clearly formulated, studies are relevantly identified, quality is appraised and finally, methodology is summarized. According to Transportation Research Board of the National Academies (2015, p. 2), the benefits of an (1) SLR are to uncover a solution to a problem; (2) identify concurrent or previous work on the same topic; (3) validate a particular method; (4) provide a focus for investigations; and (5) confirm that further research is needed.

The aim of this study is to determine the state of knowledge about the range of TOD catchment areas extended by the use of micromobility on a European scale to identify similarities, differences, and research gaps. In a reflexive way, the point is to apprehend a renewal or a redefinition of the TOD with regard to the emergence of microvehicles supplementing the accessibility stations. This main objective is based on four questions underlying the systematic literature review:

1. Which approaches and parameters are used to assess the accessibility of station neighborhoods regarding micromobility?
2. Do academic studies on the size of station areas address the principles of TOD?
3. Are the estimated micromobility ranges close to a common threshold across European cases?

The choice to focus on an enlarged vision of B-TOD to analyze the literature on the integration of private and shared microvehicles with transit is then explained by their increasing mode split in Europe, which raises interesting issues in the making of sustainable and smart territories. This choice is also in line with the design guidelines made by Calthorpe (1993, pp. 54–60) regarding the promotion of “walk-and-ride” and “bike-and-ride” with bicycle connections to transit stops rather than “park-and-ride.” Indeed, the bicycle has the potential to expand the TOD boundaries from 4 to 25 times (Cottrell, 2007, p. 118) for less physical energy (Sebban, 2003, p. 50), with stations being connected to considerably more households, substantially increasing the potential number of users, services, and facilities (Jonkeren & Kager, 2021, p. 455). In parallel, this association is presented as the most efficient intermodal integration with walk-and-ride (Yang et al., 2013, p. 714), environmentally friendly (Cervero, 2001, p. 17), and fair (Cervero et al., 2013, p. 85), three objectives put forward by TOD.

A geographical lens is also applied to this research, with the deliberate selection of European case studies to exclude results from other parts of the world that might differ, as shown by the relative range of the walk. This geographic scope is motivated by the intention to supplement the systematic literature review on bike-and-ride published by Oeschger et al. (2020), which provides a solid and extensive overview of the subject. This chapter’s contribution is therefore to update studies available since the publication of this scientific article, while giving a more specific insight into this region: among the 48 articles analyzed by the authors, 14 have a European country or city as a study area, representing one-third of the sample.

Methods for reviewing research systematically are still emerging, and there is much ongoing development and debate. This SLR method was developed following the thematic synthesis described Thomas and Harden (2008) and adapted by the Transportation Research Board of the National Academies (2015) in the mobility area, as systematic reviews differ between disciplines (Padeiro et al., 2019, p. 738). Thus, the review protocol selected is derived from TOD and micromobility SLR published by Bozzi and Aguilera (2021, p. 4); Neilson et al. (2019, p. 36); Oeschger et al. (2020, p. 4); Padeiro et al. (2019, p. 738); Pritchard (2018, p. 2); Şengül and Mostofi (2021, p. 2). The selection procedure under the SLR involves four main steps (Jain et al., 2020, p. 2544):

1. Keywords and omission criteria
2. Reading titles and omission criteria
3. Reading abstracts and metadata
4. Reading full papers and snowballing

2.2 Search Strategy and Data Sources

Relevant academic papers were identified with the Scopus™ and Web of Science™ (WoS) search databases using an expression based on three categories: Public Transport (1) + Micromobility (2) + TOD Perimeter (3), detailed in Table 1. The

Table 1 SEARCH A: Keyword phrase for the systematic search

Category	Keywords and Boolean operators
Public transport	ALL = (“Transit-Oriented Development” OR “Public Transport” OR “Transit” OR “Train” OR “Rail” OR “Metro” OR “Tram” OR “Bus” OR “Rail”) AND
Micromobility	ALL = (“Micromobility” OR “Bicycle” OR “Bike” OR “Bike-and-Ride” OR “Cycling” OR “Scooter” OR “Device” OR “Transfer Mode” OR “Intermodal”) AND
Geographical area	ALL = (“Catchment” OR “Isochrone” OR “Buffer” OR “Service Coverage” OR “Shed” OR “Station Area” OR “Access Distance” OR “Last-Mile” OR “Perimeter”)

Source: Author elaboration

Boolean operators AND and OR were used to select only papers containing the three required keyword categories, depending on term variations. Each category’s terms are synonyms and have been incorporated within the phrase, requiring at least one word from each category for the article to appear in the search. The choice of synonyms was made possible and enriched with the help of a preliminary reading period, which made it possible to highlight the most important keywords.

Consultation of these electronic databases relies on different filters, starting with the publication period that has been widened to cover all collections, with English as the written language, and by type of resource, defined as scientific articles, proceedings, and book chapters available on these two search portals. The online search was executed and saved on December 3, 2021 for both Scopus™ and WoS, resulting in 2920 entries.

In addition to these two academic search engines, search strategy was drawn from the top-rated academic journals according to their H-index, an author-level metric that measures both the productivity and citation impact of the publications. To this end, search B relies on the classification drawn up by the SCImago Journal Rank™ (SJR) website in 2020, using the top 10 journals in “Transport,” on the one hand, and in “Urban Studies,” on the other (Table 2). This second direct source of data reflects an approach adopted by Padeiro et al. (2019, p. 738), who manually searched issues through a selection of journals from among the top 40 rankings. The electronic database was collected on February 8, 2022 and has 1354 scientific papers.

2.3 Inclusion and Exclusion Criteria

Once the preliminary list of papers has been obtained and the duplicates have been removed, i.e., altogether 3955 unique articles were identified, and the next step was to create an all-inclusive search with preset criteria. Studies were considered eligible if they satisfied a set of inclusion criteria (Fig. 2):

1. Academic paper is printed in English

Table 2 SEARCH B: List of refereed journals queried in transportation and urban planning

Rank	ID	Journal
TOP 10 Transportation Journals (2020)		
1	SMG ^{T1}	<i>Tourism Management</i>
2	SMG ^{T2}	<i>Transportation Research, Series B: Methodological</i>
3	SMG ^{T3}	<i>Transportation Research, Part A: Policy and Practice</i>
4	SMG ^{T4}	<i>Transportation Research Part C: Emerging Technologies</i>
5	SMG ^{T5}	<i>Transportation Research, Part E: Logistics and Transportation Review</i>
6	SMG ^{T6}	<i>Journal of Transport Geography</i>
7	SMG ^{T7}	<i>Transportation Research, Part D: Transport and Environment</i>
8	SMG ^{T8}	<i>Transport Policy</i>
9	SMG ^{T9}	<i>Transportation Research Part F: Traffic Psychology and Behavior</i>
10	SMG ^{T10}	<i>Journal of Air Transport Management</i>
Top 10 Urban Planning Journals (2020)		
1	SMG ^{U1}	<i>Urban Studies</i>
2	SMG ^{U2}	<i>International Journal of Urban and Regional Research</i>
3	SMG ^{U3}	<i>Journal of Urban Economics</i>
4	SMG ^{U4}	<i>Journal of the American Planning Association</i>
5	SMG ^{U5}	<i>Computers, Environment and Urban Systems</i>
6	SMG ^{U6}	<i>Journal of Urban Health</i>
7	SMG ^{U7}	<i>Cities</i>
8	SMG ^{U8}	<i>Environment and Planning B: Urban Analytics and City Science</i>
9	SMG ^{U9}	<i>Regional Science and Urban Economics</i>
10	SMG ^{U10}	<i>Habitat International</i>

Source: SCImago Journal Rank™, 2020

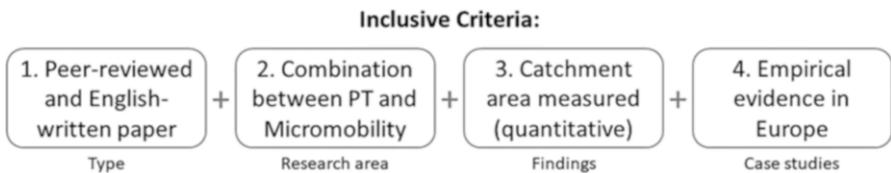


Fig. 2 Conditions for inclusion in the research protocol. (Source: Author elaboration)

2. The manuscript aims to investigate intermodality, and more specifically the combination of one or more types of micromobility with public transport
3. The paper production includes distance measures in relation to the influence area of the studied station(s)
4. The research field is in Europe, regardless of the scale of analysis.

The selection is made by reading the abstracts and contents of each document, excluding those that do not meet one of the four established criteria. For each scientific paper, preliminary relevance was determined by reading the title and abstract. The systematic selection was accompanied by the reason why the article displayed was listed or rejected.

More specifically, 1777 of the 3955 articles recorded were discarded because they did not address urban or transport-related issues. A total of 1599 of them did not address intermodality, while 334 articles addressing intermodality were rejected because they were not concerned with micromobility. Two articles could not be included in the final sample due to the unavailability of the full content. As a result, 243 articles were identified as discussing micromobility in combination with public transport (Fig. 3).

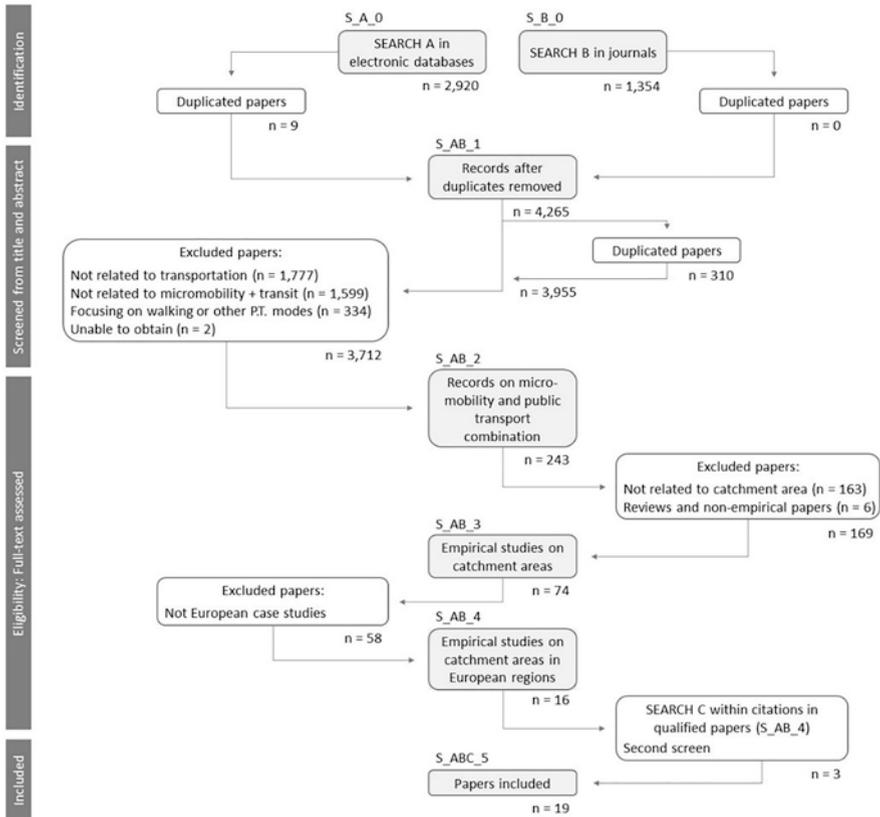


Fig. 3 Flow diagram representing the selection and review process. (Source: Author elaboration)

2.4 Verification and Snowballing Stage

Following the initial screening, the record's contents were examined to control and evaluate the selection process (Neilson et al., 2019, p. 36). Some 169 of them were removed, as they did not rely on distance measures. Finally, 58 of the 74 empirical articles related to transit catchment area by micromobility were not included, as they covered other regions. The selection process via the reading of abstracts revealed 16 scientific articles, as shown in Fig. 3.

At the same time, the references cited by papers and Google Scholar™ search were checked by the same reviewer to verify whether any other articles address the subject (Jain et al., 2020, p. 2545). To make sure to have not missed works, the snowballing phase was further supplemented by making use of the Connected Papers™ science mapping software tool. Overall, 3 scientific articles fulfilling the 4 criteria above were added, resulting in a final body size of 19 articles.

2.5 Aspects Considered

This systematic literature review will pay attention to the dimensions characterizing TOD in conjunction with the intermodal approach. Similar to Bertolini et al. (2012, p. 31), this work aims to review the factors driving revisited TOD areas in Europe as follows:

- Type of Integration
- Case Study Areas
- Methods
- D-variables: density, diversity, design, distance to transit, destination accessibility, and demand management

3 Results and Discussion

3.1 Research Publications on Micromobility and Transit-Oriented Development

By searching on Clarivate Analytics' WoS platform, it can be noted that the number of scientific publications has grown significantly since 2010 for "Transit-Oriented Development" and more recently since 2019 for "Micromobility" (Fig. 4).

In addition to the chart, a bibliometric search over the same period with the terms "Micromobility," "Bicycle," and "Bike" shows a similar trend starting in 2010. Consequently, there seems to be a significant and growing interest in these two subjects related to mobility and urban planning, as Jain et al. (2020, p. 2545) also observed on TOD based on the Google Trends platform. Figure 4 reveals the

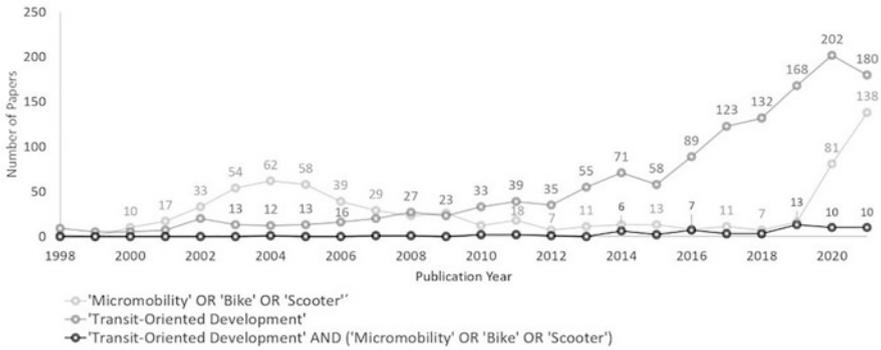


Fig. 4 Year-wise publication of bibliometric papers related to micromobility and/or TOD (March 16, 2022). (Source: Web of Science™ database)

gradual but still modest emergence of scientific studies across these subjects, with up to 7–13 papers published each year since 2019. The features of this recent pattern drive this chapter.

When looking at the geographical distribution of papers by author location, it clearly appears that one-third of the works on “Micromobility” since 1998 originate from Europe and North America each and one-quarter from Asia (Fig. 5a). France (9%), England (8%), Italy (7%), and Germany (6%) are the main contributors in Europe (36%); the United States (26%) and Canada (7%) in North America (33%); and South Korea (10%) and China (8%) in Asia (28%). This relatively wide distribution of a range of countries becomes more limited when focusing on “transit-oriented development.” Research is highly specialized in North America (39%), particularly in the United States (34%) and Asia (38%), with China (24%) in the lead (Fig. 5b). This is further strengthened when crossing the two concepts, with most of the work coming from the United States (55%) and China (32%). Nevertheless, it should be noted that works from European countries account for 15% of this emerging literature. It should be mentioned that developed countries are at the top of the rankings, although the query is biased by English-only keywords (Fig. 5c).

3.2 Current State of International Studies on Cycling and Transit Coordination

As explained in Fig. 3, 74 articles were identified in the international literature on the subject of micromobility and PT integration, with specific consideration and measurement of the size of station areas. Taking a closer examination of this document collection, it can be observed that most articles come from Asia (38/74) and particularly from China (28/74), followed by the United States (18/74) and the Netherlands (10/74). These preliminary results are in line with the trend analyzed by browsing both keywords covered by this chapter: the three continents that

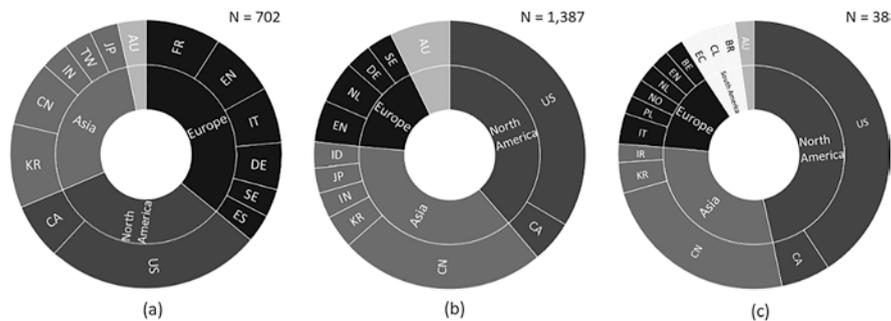


Fig. 5 Evolution of scientific production on micromobility and/or TOD (March 16, 2022). (a) “Micromobility,” (b) “Transit-oriented development,” (c) “Micromobility” and “transit-oriented development.” (Source: Author calculation using Web of Science™ database)

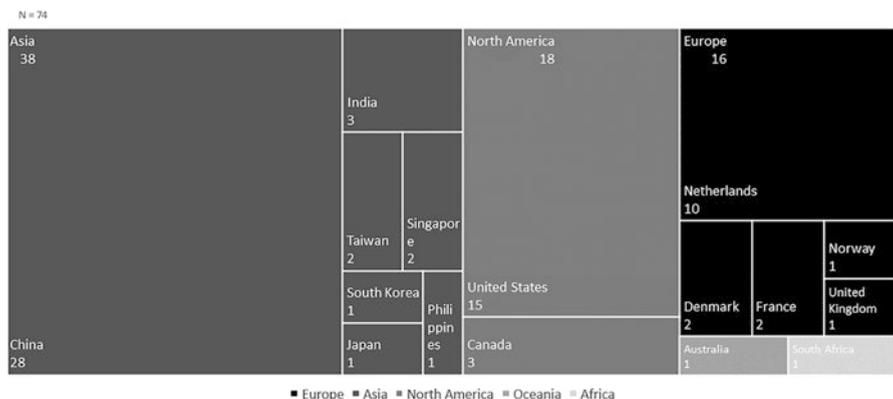


Fig. 6 Geographical distribution of international references addressing combined transit and micromobility. (Source: Author elaboration)

contribute most strongly to the knowledge regarding station area by micromobility can be found in Fig. 6.

By distinguishing the different types of micromobility investigated by this international database, private and nonelectric bicycles occupy a prominent place (47/74), which can be notably attributed to this mode’s seniority and global availability. Accordingly, the first bar shows all the regions identified in the body (Fig. 7). Interestingly, shared micromobility embodies 27 of the 74 available items, being split between Asia-led dockless bike systems (13/74) and public bike-sharing systems (11/74). The electric scooter springs with two papers dealing exclusively with free-floating services, while one article focuses on pedicabs.¹

¹Pedicabs are a small pedal-operated vehicle serving as a taxi.

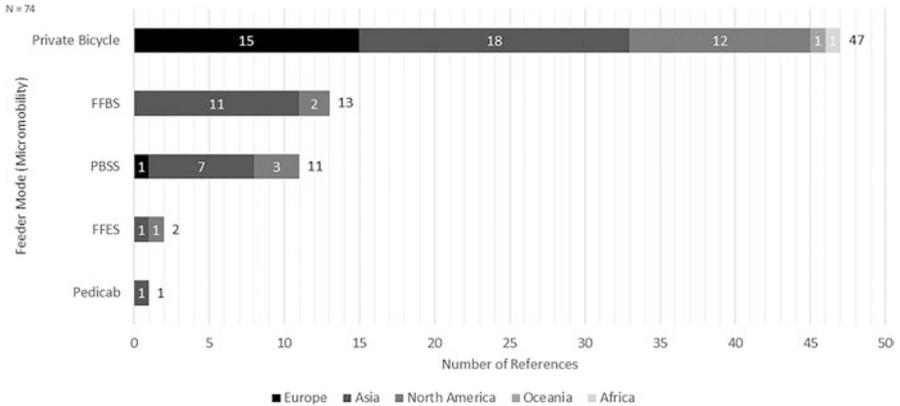


Fig. 7 Studied micromobility types across international references on intermodality. Note: FFBS: free-floating bike service; PBSS: public bike-share system; FFES: free-floating e-scooter service. (Source: Author elaboration)

Regarding the 16 European papers in the sample, 14 address a personal microvehicle: the bicycle. As a result, a literature gap may be detected with respect to the integration of shared micromobility schemes with public transport in relation to the scale of relevance around stations. Globally, no papers relating to the access distance of personal mobility devices (PMDs), such as standing scooters, to public transport are reported in the academic sphere. It should be noted that this corpus of documents does not include articles subsequently integrated through the snowball method. Thus, the geographical distribution of the literature indicated a modest emergence on the European side, with a hegemony of the Netherlands, which will have to be analyzed in depth in the next section.

3.3 Description of European Studies

3.3.1 Type of Integration Recorded

With further attention to the 16 European articles coupled with the 3 papers listed afterward, it is noteworthy that 17 out of 19 are oriented toward a private mode and particularly toward conventional cycling (16/19), as shown above. More specifically, this includes the combination of the personal bicycle and the train, which is highlighted in 13 works. Urban public transport is involved in 8 out of 19 papers, bus (5) and metro (4) in particular (Table 3). Only two publications deal with public bike-sharing systems (Adnan et al., 2019; Böcker et al., 2020), whereas a single one discusses electric bikes (Midenet et al., 2018) and another about electric standing scooters (Moinse et al., 2022). All four articles were published less than 4 years ago due to the recent spread of these microvehicles and the more difficult access to data.

Table 3 Academic articles included in the systematic literature review

ID	Authors (publication year)	System	Type of Integration
SLR ¹	Adnan et al. (2019)	Shared	PBSS+Rail
SLR ²	Böcker et al. (2020)	Shared	PBSS+Metro/Rail
SLR ³	Brand et al. (2017)	Private	Bike+Bus/BRT
SLR ⁴	Debrezion et al. (2009)	Private	Bike+Rail
SLR ⁵	Djurhuus et al. (2016)	Private	Bike+PT
SLR ⁶	Geurs et al. (2016)	Private	Bike+Rail
SLR ⁷	Hasiak (2019)	Private	Bike+Rail
SLR ⁸	Heinen and Bohte (2014)	Private	Bike+PT
SLR ⁹	Kager et al. (2016)	Private	Bike+Rail
SLR ¹⁰	Keijer and Rietveld (2000)	Private	Bike+Rail
SLR ¹¹	Martens (2004)	Private	Bike+PT
SLR ¹²	Midenet et al. (2018)	Private	(E-)Bike+Rail
SLR ¹³	Moinse et al. (2022)	Private	(E-)Scooter+Rail
SLR ¹⁴	Nielsen and Skov-Petersen (2018)	Private	Bike+Rail/Bus
SLR ¹⁵	Nigro et al. (2019)	Private	Bike+Rail
SLR ¹⁶	Rietveld (2000)	Private	Bike+Rail
SLR ¹⁷	Rijsman et al. (2019)	Private	Bike+Tram
SLR ¹⁸	Sherwin et al. (2011)	Private	Bike+Rail
SLR ¹⁹	Ton et al. (2020)	Private	Bike+Tram

Note: Only microvehicles are considered in the Type of Integration category. “PBSS” stands for Public Bike-Sharing System, “BRT” for Bus Rapid Transit, and “PT” comprises Railway, Metro, Tramway, Bus, or/and Ferry

3.3.2 Case Studies and Publication Periods

Within the literature corpus, there is not only a variety of geographical scales and types of urban forms among the case studies but also a clear clustering in Northern Europe.

Five publications refer to metropolitan scales such as Oslo (Böcker et al., 2020), Amsterdam (Brand et al., 2017), the Capital Region of Denmark (Djurhuus et al., 2016), The Hague (Ton et al., 2020), and Delft, Zwolle, Midden-Delfland, and Pijnacker-Nootdorp (Heinen & Bohte, 2014). Four articles are set in urban areas and regions such as Belgian cities (Adnan et al., 2019), Randstad South (Geurs et al., 2016), medium-sized train stations in Provence-Alpes-Côte d’Azur (Moinse et al., 2022), and Campania Region (Nigro et al., 2019). For their part, three works focus on medium-sized areas as in French local cities (Hasiak, 2019), Amboise (Midenet et al., 2018), and Bristol (Sherwin et al., 2011). Table 4 further displays six scientific studies over 20 covering a national scale as described in the Netherlands (Debrezion et al., 2009; Kager et al., 2016; Keijer & Rietveld, 2000; Rietveld, 2000), with Germany and the United Kingdom (Martens, 2004), and Denmark (Nielsen & Skov-Petersen, 2018). The geographical distribution of the studied areas among the selected items clearly shows a spatial concentration around Western and Northern Europe in Fig. 8.

Table 4 Case studies of selected papers

Authors (Publication year)	Country	Geographical area
Adnan et al. (2019)	Belgium	30 small and medium cities
Böcker et al. (2020)	Norway	Oslo
Brand et al. (2017)	The Netherlands	Amsterdam
Debrezion et al. (2009)	The Netherlands	–
Djurhuus et al. (2016)	Denmark	Copenhagen
Geurs et al. (2016)	The Netherlands	Randstad South (Rotterdam-The Hague)
Hasiak (2019)	France	Local stations
Heinen and Bohte (2014)	The Netherlands	Delft, Zwolle, and surroundings
Kager et al. (2016)	The Netherlands	–
Keijer and Rietveld (2000)	The Netherlands	–
Martens (2004)	Germany, the Netherlands, and the United Kingdom	–
Midenet et al. (2018)	France	Amboise
Moinse et al. (2022)	France	Provence-Alpes-Côte d'Azur region
Nielsen and Skov-Petersen (2018)	Denmark	–
Nigro et al. (2019)	Italy	Campania region
Rietveld (2000)	The Netherlands	–
Rijsman et al. (2019)	The Netherlands	The Hague
Sherwin et al. (2011)	The United Kingdom	Bristol
Ton et al. (2020)	The Netherlands	The Hague

Note: Only microvehicles are considered in the Type of Integration category. “PBSS” stands for Public Bike-Sharing System, “BRT” for Bus Rapid Transit, and “PT” comprises Railway, Metro, Tramway, Bus, or/and Ferry

Beyond the geographical level, Table 4 draws a chronological scale, with a median set at the year 2018. While some publications are dated between 2000 and 2014 (Debrezion et al., 2009; Heinen & Bohte, 2014; Keijer & Rietveld, 2000; Martens, 2004; Rietveld, 2000; Sherwin et al., 2011), 13 of the papers were published from 2016 onward and at least three quarters of them after 2019, supporting the hypothesis of a very recent literature.

3.3.3 Research Methods

This SLR analyzed specific methods used among the 19 scientific works to study micromobility and public transport integration (Table 5). As identified by Oeschger et al. (2020, p. 8), the most common and the easiest method is the conduct and/or analysis of surveys to gain insight into practices and users' characteristics and

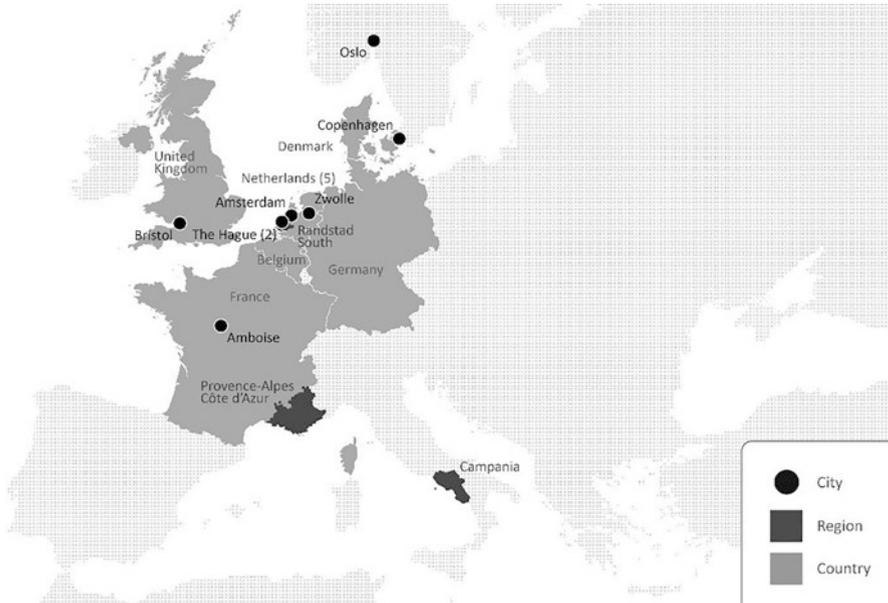


Fig. 8 Geographical distribution of areas investigated by the reviewed papers. (Source: Author elaboration)

Table 5 Methods used

Authors (publication year)	Methodology
Adnan et al. (2019)	Survey-based Hybrid Choice Model
Böcker et al. (2020)	Big Data with GIS-based Analysis
Brand et al. (2017)	Transit Model of VENOM
Debrezion et al. (2009)	Railway Station Quality Index (RSQI)
Djurhuus et al. (2016)	Multimodal Network Model and GIS Analysis
Geurs et al. (2016)	Multimodal Network Model and GIS Analysis
Hasiak (2019)	Survey's Analysis
Heinen and Bohte (2014)	Survey-based Analysis of Variance (ANOVA)
Kager et al. (2016)	System Perspective and Conceptual Analysis
Keijer and Rietveld (2000)	Survey-based Modal Choice
Martens (2004)	Surveys' Analysis
Midenet et al. (2018)	Access Mode Model
Moinse et al. (2022)	Survey's GIS-based Analysis
Nielsen and Skov-Petersen (2018)	Survey's GIS-based Analysis
Nigro et al. (2019)	Node-Place Model and GIS-based Analysis Piet
Rietveld (2000)	Survey's Analysis
Rijsman et al. (2019)	Survey-based Discrete Choice Models
Sherwin et al. (2011)	Monitoring of flow and Survey's Analysis
Ton et al. (2020)	Survey-based Discrete Choice and Access Mode Model

Note: GIS for a geographic information system

preferences. Various authors have appropriated national or regional survey results with an initial broader focus on mobility issues. The challenge lies in the identification of the relevant sample of research subjects. Keijer and Rietveld (2000, p. 231) and Rietveld (2000) undertook a statistical analysis based on the Dutch National Travel Survey from 1994. In the same way, Hasiak (2019, p. 12) analyzed 25 household travel surveys (HTS) carried out on different French urban areas and regions between 2009 and 2016 by using econometric methods, while Moïnse et al. (2022, p. 10) analyzed the French national public rail network manager SNCF Réseau's survey data. Nielsen and Skov-Petersen (2018, p. 38) realized a regression analysis of the urban structure and cycling trips based on the Danish National Travel Survey. Martens (2004, p. 282) captures a multitude of multiscale surveys and papers from Germany, the Netherlands, and the United Kingdom but faces challenges due to the collection data methods focusing on the primary transport mode, which neglects access and egress modes.

For their part, Sherwin et al. (2011, p. 192) conducted a mixed methodological approach in Bristol by undertaking counts in addition to surveys with 135 bike-rail uses in October 2007. Correspondingly, Heinen and Bohte (2014, p. 113) collected and examined data from a 2008 Internet survey in Delft, Zwolle, Midden-Delfland, and Pijnacker-Nootdorp by sending 3500 email invitations to employees and 22,000 others to addresses held by local authorities. A multitude of academic papers led to a series of stated preference (SP) surveys, i.e., how respondents might behave in new situations. To study shared bikes in 30 small- and medium-sized Belgian cities, Adnan et al. (2019, p. 10) used a web-based stated preference questionnaire to provide nine hypothetical scenarios for the last mile of a rail trip. Rijsman et al. (2019, p. 1) and Ton et al. (2020, p. 827) completed a regression model by collecting data with an on-board transit revealed preference approach among tramway travelers in The Hague. In the same way, Geurs et al. (2016, p. 7) investigated the effects of bike–train integration policies by conducting an SP survey, subsequently implemented in a multimodal network model, extended from the Dutch National Transport Model (NVM).

Several scientific studies have applied accessibility indicators with multimodal models to analyze TOD and micromobility integration. Midenet et al. (2018, p. 11) analyzed the station's catchment area using time-indexed modal potential through an access mode spatial model based on a central zone close to the Amboise stations and an external zone devoted to motorized modes. Djurhuus et al. (2016, p. 6) proposed a multimodal network model from the Danish Geodata Agency combined with a spatial analysis in Copenhagen. From the 2011 Italian National Census, Nigro et al. (2019, p. 116) determined the extent of catchment areas by using the interconnectivity ratio and GIS analysis through the application of network distance analysis. A railway quality index based on the Dutch National Railway Company was estimated by Debrezion et al. (2009, p. 17) with a GIS analysis, while a VENOM transit model from the regional model of Stadsregio Amsterdam was used by Brand et al. (2017, p. 3) to assess the characteristics of access and egress modes with bus services.

Böcker et al. (2020, p. 395) used big data by analyzing the 2016–2017 records of 4.4 million trips by the Oslo public bike service, screening trips that start or end within 200 m of a PT station, and conducting multivariate modeling techniques.

3.4 Review of Distances Measured in Europe

The catchment area of a transit station designates the geographic area where residents are likely to access and egress the station to use public transport services (Hochmair, 2015, p. 15). Through the 19 analyzed papers, micromobility distances measured in the first or last trip chain leg tend to converge toward a cycling service area, in particular for railway stations, between 1 km minimum (3.14 km²) and 3 (28.27 km²) to 4 km (50.27 km²) maximum (see Fig. 9). The overall range of these microvehicles has the capacity to widen TOD limits from 9 to 16 times the 1-km pedestrian pocket. In the Netherlands, cycling connects approximately 15 times as many people to main intercity stations and 4 times more people to local stations compared to walking (Kager et al., 2016, p. 213). Moreover, walking distance is found to be weighted 2.1 times more negatively than cycling distance to access tramways and bus stops due to the additional physical effort required for a lower speed (Ton et al., 2020, p. 832).

Distance intervals estimating the cycling subarea are computed by nine reviewed articles. Djurhuus et al. (2016, pp. 13–16) chose to study all PT stops in Copenhagen within a 1-km walking distance and within a 3-km cycling distance from home to cover cycling trips to stops. The same observations in Denmark are given by Nielsen and Skov-Petersen (2018, p. 42); the 3-km distance band reflects a convenient

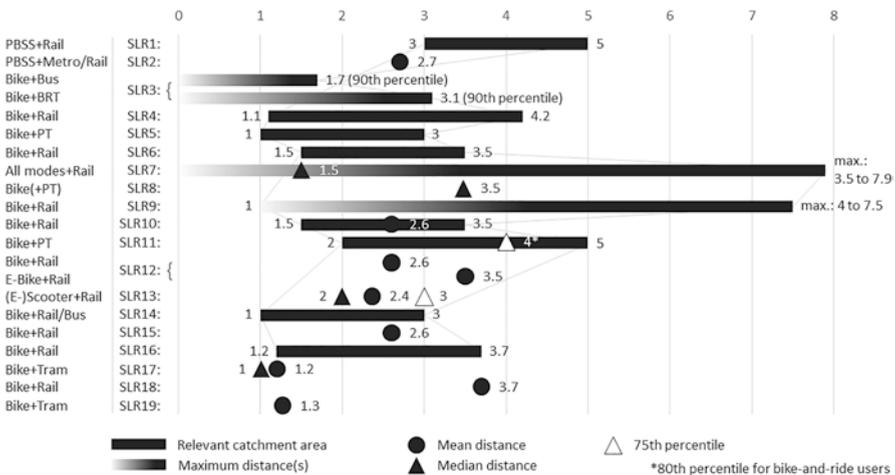


Fig. 9 Distances and influence areas in relation to public transport stations from the 19 reviewed articles. (Source: Author elaboration)

cycling range around a train station, whereas it is less competitive than walking and PT within 1 km. Debrezion et al. (2009, p. 23) note that the bicycle is the most likely access mode choice for distances between 1.1 and 4.2 km but that this maximum distance will decrease to 3.6 km if the frequency of urban public transport doubles in the Netherlands. Similarly, Keijer and Rietveld (2000, p. 234) determine that most people take the bike when the train station is situated between 1.5 and 3.5 km in the Netherlands, passengers opting for urban PT above this length. Furthermore, the rail patronage propensity remains relatively stable as long as the catchment area does not exceed 3.5 km for residential areas (Geurs et al., 2016, p. 9; Keijer & Rietveld, 2000, p. 233; Rietveld, 2000, p. 73). Rietveld (2000, p. 73) identifies an asymmetry for rail between access and egress trips by distinguishing home-end segments where the bike is dominant between 1.2 and 3.7 km and activity-end segments where bike is not attractive when compared to walking (up to 2.2 km) and urban transit. On average, cycling becomes more attractive than walking for distances of 1.31 km or more to The Hague tramway stations (Ton et al., 2020, p. 832). In Germany, the Netherlands, and the United Kingdom, Martens (2004, pp. 282–289) reports 2- to 5-km access trips by bike to PT stations, with longer distances (from 4 to 5 km) for faster collective modes and a 2-km threshold seen for the metro. These outcomes are in line with Adnan et al.'s (2019, p. 9) works, who note that the public-bike share is better for distances between 3 and 5 km in Belgium.

Four papers look at the maximum size of the catchment area delineation by estimating the 85th percentile key factor (Li et al., 2022, p. 14). In Germany, the Netherlands, and the United Kingdom, 20% of bike-and-bus users, mainly students, cycle more than 4 km (Martens, 2004, pp. 282–289), while 10% of cyclists travel more than 1.70 km by ComforNet² bus and 3.1 km by R-Net³ BRT in Amsterdam (Brand et al., 2017, p. 5). In some medium-sized rail stations in a French region, 25% of scooter-and-rail users cycle more than 3 km (Moinse et al., 2022, p. 21).

In general, the access distance to train stations covered by bike is 2.6 km long for a 12-minute isochrone area in the Campania region (Nigro et al., 2019, p. 120). Cycle trips to and from Bristol railway stations have an average length of 3.7 km (Sherwin et al., 2011, p. 192). Similarly, passengers combining trains and standing scooters have an access range of 2.4 km, while half of these trips are 2 km long (Moinse et al., 2022, p. 21). On average, passengers accessing or egressing stations in Amboise by conventional bicycle would travel 2.5 km, while e-bike users would make trips of 3.5 km in a 2025 scenario (Midenet et al., 2018, p. 29). The mean cycling feeder distance in The Hague is fixed at 1.2 km (a 1-km median) for the tramway network (Rijsman et al., 2019, p. 4).

²“ComforNet [correspond to] conventional bus lines, which are feeder lines to other, hierarchically higher, modes of transportation” (Brand et al., 2017, p. 752).

³“R-Net [correspond to] high quality, high speed bus services in the region around Amsterdam, connecting different cities, towns and villages in Amsterdam region, and connecting these areas with the city of Amsterdam” (Brand et al., 2017, p. 752).

3.5 Review of TOD Aspects Studied in Europe

To examine the integration of the commonly recognized TOD-defining attributes, the six main criteria of the urban model were investigated in the analysis of the 19 selected articles. The purpose is to identify and assess the recurrence and relevance of some TOD dimensions and, conversely, specific literature gaps. Table 6 summarizes the incorporation of these variables based on two single options: “+” indicates the presence of the “D” criterion, while “-” suggests an explicit absence of this criterion as interpreted by the author. The following analysis attempts to outline the other five Ds, the Distance to Transit D being discussed earlier.

3.5.1 Density

Density is studied in seven articles within the database, despite being a key component of TOD station development. This can be explained in particular by the common area of study relating to cycling modes supposed to meet the first- and last-kilometer issue, whereas increasing the density of a larger perimeter seems more complex.

Table 6 Consideration of the conventional TOD 6Ds regarding micromobility and PT mix

Authors	Density	Diversity	Design	Destination	Demand	Distance
Adnan et al. (2019)	-	-	+	-	+	+
Böcker et al. (2020)	+	+	-	-	-	+
Brand et al. (2017)	-	-	+	-	+	+
Debrezion et al. (2009)	-	-	+	-	+	+
Djurhuus et al. (2016)	-	-	-	+	-	+
Geurs et al. (2016)	-	-	+	+	+	+
Hasiak (2019)	+	-	+	-	+	+
Heinen and Bohte (2014)	-	-	-	+	-	+
Kager et al. (2016)	+	-	-	+	-	+
Keijer and Rietveld (2000)	-	+	+	-	-	+
Martens (2004)	+	-	+	-	+	+
Midenet et al. (2018)	-	-	+	-	+	+
Moinse et al. (2022)	+	-	+	+	-	+
Nielsen and Skov-Petersen (2018)	-	-	+	+	-	+
Nigro et al. (2019)	+	-	+	-	-	+
Rietveld (2000)	-	+	-	+	+	+
Rijsman et al. (2019)	-	-	+	-	+	+
Sherwin et al. (2011)	+	-	+	-	-	+
Ton et al. (2020)	-	-	+	-	-	+
Total of “+”	7	3	14	7	9	19

Note: All articles in this table score the “Distance to Transit” heading since the empirical measurement of the catchment area for transit stations was one of the inclusion criteria for this systematic review

Martens (2004, p. 290) argue that bike-and-ride practices are significantly influenced by the location of transit stations in Germany, the Netherlands, and the United Kingdom by describing higher proportions in suburban neighborhoods. TOD in low-density areas needs to consider multiple feeder transports other than walking (Nigro et al., 2019, p. 119). Some authors address low-density locations in which improving the quality of urban PT services is challenging and for which micromobility is a suitable option. Sherwin et al. (2011, p. 191) focus on the Bristol Parkway rail station, located in a context of modern medium-density residential development and low-density office and retail development, where many access and egress trips exceed the walking range. Given the 1.5-km median access distance to rail stations, Hasiak (2019, p. 27) calls for reconsidering the primacy of car use to the benefit of walking and cycling in some French spread-out areas. Similarly, Böcker et al. (2020, p. 397) note that public bike-sharing near rail and metro correlates highly with lower job and population densities around the unconnected location in Oslo, suggesting that intermodal users move to low-density areas.

Other authors consider this intermodal approach to have effects on the densification of TOD areas and reciprocally. The synergy provided by this trip chain increases the urban densities of trip origin and destination locations, giving rise to a positive and reciprocal relationship between densities and proximity (Kager et al., 2016, p. 217). Moïnse et al. (2022, p. 17) locate e-scooter access trips to French train stations in relatively dense places, whereas bike-and-ride trips are characterized from less dense areas, suggesting that the use of e-scooters in dense neighborhoods may be explained by car parking and traffic constraints. From radar diagrams, Nigro et al. (2019, p. 119) point out the possibility of urban intensification, as long as it is accompanied simultaneously by improvement of accessibility by either train or feeder transport. It should be noted that these articles on urban density all deal with railway stations, revealing a lack of knowledge on the role of density in the combination of urban PT and micromobility.

3.5.2 Diversity

Only three articles were identified as contributing to the urban mixed-use factor. To encourage the use of intermodal trips, it is essential to coordinate urban policies with respect to land use and transportation policies (Keijer & Rietveld, 2000, p. 234). Keijer and Rietveld (2000, p. 234) find a well-documented asymmetry in feeder mode use between access and egress, which reveals that cycling is mainly used during the first segment of the trip chain due to the location of the home in the Netherlands. They recommend priority for the construction of travel-intensive activities near railway stations, such as offices, education, cultural, and shopping facilities. Rietveld (2000, p. 75) supports this planning strategy, stating that residential areas can extend up to 3.5 km around a railway station to match the access range of the bike. This is consistent with Böcker et al. (2020, p. 397) results regarding the Oslo bike-share system, who report that users' routes serve higher building use diversity areas, particularly at the destination.

3.5.3 Design

Unsurprisingly, the third D associated with design emerges from the analysis, with 14 papers on this aspect linked to planning and infrastructures promoting cycling and ride. Three types of design-related development stand out: continuous, pleasant, and safe cycle routes; quality micromobility parking; and at the same time, restrictions on car use.

Nielsen and Skov-Petersen (2018, p. 41) note a robust effect of bike paths within an estimated 1 km of the residence, with the built environment close to home being the most important for accessing train stations. In their “ambitious” implemented scenario, Hasiak (2019, p. 26) set up a modal shift from car to walking within 1 km and to bike from 1 to 3 km. In this situation, with a condition based on quality cycling infrastructure including a network of cycle paths and parking facilities, 33% of drivers and 38% of passengers became cyclists (Hasiak, 2019, p. 26). Likewise, Geurs et al. (2016, p. 11) developed a logit model in which perceived connectivity and cycling route improvements on access time have similar sized effects as the train frequency increase scenario, especially in small railway stations from Randstad South. For low-density and natural areas where densification around the PT is complex, as in the Campania Region, the quality of feeder networks is crucial (Nigro et al., 2019, p. 110). Moïnse et al. (2022, p. 22) make recommendations for designing a cycling-friendly environment as an opportunity to strengthen TOD to benefit micromobility, such as bicycles and standing scooters. However, findings suggest a minimized role of cycle paths in intermodal use for exurban areas: segregated bike lane availability is not significant in small-medium Belgian cities, due in part to the lower levels of traffic volume (Adnan et al., 2019, p. 8).

Bicycle parking facilities deserve more attention than they usually receive (Keijer & Rietveld, 2000, p. 234), and the availability of bicycle stands has a positive effect on the choice of Dutch departure railway stations accessed by bicycle (Debrezion et al., 2009, p. 26). In The Hague, Rijsman et al. (2019, p. 5) identify insufficient and unsafe parking places as one of the main barriers to accessing a tramway stop by bike. They recommend providing lockers and cameras at stops to potentially increase bike-and-ride users from 21.7% to 37.5%. Similar conclusions converge on high-quality bus systems, which would benefit from an increase in the share of users accessing a stop by bicycle with parking facilities (Brand et al., 2017, p. 7). This is also the case for railway stations, except that it is primarily large train stations that profit more from bicycle parking improvements (Geurs et al., 2016, p. 13). The impact of the installation of bicycle parking on the TOD perimeter is measured by Ton et al. (2020, p. 833), who show that these facilities increase the catchment area by 234 m and by 334 m for multimodal hubs (tramway and bus). Keijer and Rietveld (2000, p. 234) underline the role of bicycle parking facilities near rail stations for home-end segments in coordination with short walking distances at the activity end. The security of parked cycles at stations is an important aspect of TOD design, to the extent that the experience of theft and perceived poor security can encourage users to favor bicycles on board the train (Sherwin et al., 2011, p. 196). While it has

been seen that the provision of bicycle parking spaces attracts the expected users, it is also true that park-and-ride (P+Rs) attracts drivers (Debrezion et al., 2009, p. 26), which raises issues about the integration of cars in TOD areas.

It seems necessary to rationalize the car parking supply around PT sites by evaluating the demand to enhance the TOD area, as mentioned by Hasiak (2019, p. 26). By promoting bike-and-ride at the expense of P+R, the station area has no negative externalities related to servicing costs, floor space, and environmental impact. Furthermore, Moïnse et al. (2022, p. 20) illustrate that the e-scooter for access is competitive with car use only in the presence of car constraints such as parking regulations. With multiple scenarios, in a French local case study, Midenet et al. (2018, p. 30) highlight that the most significant initiative to stimulate a modal transfer from 53% of P+R users to bike or e-bike with PT lies in constraining the car parking size. The urban design approach should be considered as one of the solutions to promote lower carbon emission access to stations, as the modal shift from car to rail is significantly influenced by the connection quality to the station (Moïnse et al., 2022, p. 21).

3.5.4 Destination Accessibility

Destination accessibility is studied in seven academic works within the corpus. The transport quality aspects for trains tend to increase with distance traveled, whereas for micromobility, its qualities tend to decrease as distance increases (Kager et al., 2016, p. 212). According to Nielsen and Skov-Petersen (2018, p. 42), bikeability can be divided into a local scale, a more urban scale with a range up to 4 km, and a regional scale that is up to 40 km in Denmark, while Heinen and Bohte (2014, p. 114) obtain an average of 36.5 km distance home-work by bicycle and PT.

The complementarity of micromobility with PT provides wider accessibility to destinations and consequently to resources, especially to employment areas. By accessing all PT stops within 1 km walking and 3 km cycling distances in the Copenhagen city area, Djurhuus et al. (2016, p. 13) demonstrate that a larger accessibility area is drawn as opposed to only accessing the nearest stop. Reflecting the destination benefits of micromobility and transit mix, the bicycle–train integration policy scenarios developed by Geurs et al. (2016, p. 11) provide greater job accessibility than the increased frequency scenario, with significant accessibility improvements toward small and medium-sized stations in Randstad South.

The use of these microvehicle feeders in conjunction with PT turns out to be effective compared to access or regional trips by private car. By studying the combination of the e-scooter with the regional train, Moïnse et al. (2022, p. 17) note that the trip chain is time competitive with an unconstrained car scenario up to the threshold of 33 km. In their second scenario, characterized by ideal travel time and penalties, Kager et al. (2016, p. 216) reveal that cycling is an average 10-minute advantage over feeder transit services during a 10–80 km train trip.

3.5.5 Demand Management

The TOD's last D in relation to demand management is included in nine articles dealing with this aspect in various forms. The quality of the PT infrastructure and service is an important factor in attracting passengers, including micromobility riders.

Martens (2004, p. 292) states that bike-and-ride users are more inclined to favor faster and higher quality types of PT, such as train and intercity buses, unlike tram or local buses. However, while these elements may be necessary to build an attractive PT network, they appear to have different positive or modest effects in bringing in intermodal cyclists. First, reduced travel time on PT has a positive impact on the choice of departure station (Debrezion et al., 2009, p. 28). Although BRT stop distances do not influence the bicycle catchment area, their spatial spread affects the speed of the service, making the collective mode more efficient (Brand et al., 2017, p. 6). *In contrast*, transit frequency also has a moderate effect on the choice of departure stations by passengers accessing micromobility. The Geurs et al.'s (2016, p. 11) sixth scenario based on increased frequencies of local trains shows that rail-micromobility integration produces limited benefits. Moreover, doubling the frequency of local PT leads to a decrease in distance for bikes from 4.2 to 3.6 km (Debrezion et al., 2009, p. 28).

Managing the supply of parking spaces to influence demand around stations has a crucial role in the micromobility and PT mix. One of the most important attributes of bicycle access to the train station is the location of bicycle parking. In the Netherlands, providing free guarded bicycle parking and cycling spaces within 2 minutes from the train platform generates beneficial effects around the site, and users are even highly willing to pay for improvement of these facilities (Geurs et al., 2016, p. 9). From a systematic perspective, these effects interact with car use and parking space management. Debrezion et al. (2009, p. 24) evidence that car ownership of 0.60 per person would involve car domination over PT from 10 km. Midenet et al. (2018, p. 30) advocate the implementation of pricing policies on P+R depending on the reverse distance from the client's residence to the train station to encourage modal shift and optimization of car park size. Considering the potential modal shift from car to walking within 1 km and from cycling between 1 and 3 km, Hasiak (2019, p. 27) demonstrates that a savings of up to 40% in parking places emerges since the share of passengers reaching local rail stations by car would fall from 53% to 29%.

Demand management can also address specific challenges of micromobility-transit combination, such as the unavailability of bikes in access and egress. For instance, Rijsman et al. (2019, p. 3) recommend providing bicycle sharing schemes at tram stops in The Hague. This opportunity is arising and is being reinforced by the arrival of free-floating bicycle and scooter services and progressively by smart

parking.⁴ Brand et al. (2017, p. 7) focus more on the egress side, where riders are dependent on walking range, and call for providing bike-sharing and bike-renting opportunities. These statements follow the advice from Rietveld (2000, p. 75), which proposes services at the activity-end, such as bike renting, cycling facilities on board the train, or safe parking for second bikes. On-board folding micromobility solutions such as private e-scooters also represent an alternative for both access and egress sides, notably for exurban territories where the implementation of bike schemes seems complex (Moinse et al., 2022, p. 21). The articulation of the train with micromobility services is based on successful management and communication Mobility-as-a-Service (MaaS) applications (Adnan et al., 2019, p. 8). These guidelines can also be coupled with prevention and education programs for pedestrians and micromobility users (Hasiak, 2019, p. 27).

4 Revisiting the TOD Concept

4.1 A Hybrid and Smart TOD Adaptable to Spatial Contexts

Transit-oriented development is a promising model for building sustainable, smart urbanization, and mobility in the future (Cervero, 1998, p. 3). The author identified and identified four types of transit-oriented metropolises (Cervero, 1998, p. 7):

1. “Adaptive cities” that have invested in rail systems to guide urban growth
2. “Adaptive Transit” that has accepted spread-out with low-density areas and has adapted transit services to serve these regions
3. “Strong-core cities” that have integrated transit and development within a confined and central urban context
4. “Hybrid” adaptive cities and adaptive transit that are balanced between dense urbanization along transit corridors and suitable transit to serve suburbs

Recently, Cervero (2020, p. 131) sought to update the conceptualization given to the Transit Metropolises (TOD), which was written two decades ago and should be renewed as Hybrid Transit Metropolises from a twenty-first-century perspective. The dichotomy of adaptive cities and adaptive transit now gives way to a modern transit metropolis vision marrying well-designed TOD and flexible, door-to-door mobility options (Cervero, 2020, p. 144). Lee et al. (2016, p. 983) introduce the concept of bicycle-based transit-oriented development (B-TOD) as an alternative to walking-based TOD and shed light on the identification of the station impact area where bicycle is the primary access mode and on more or less relaxed density criteria (Fig. 10). This book chapter follows the revisited Transit Metropolis and B-TOD

⁴In response to deregulated micromobility operations, smart parking is considered as an urban management solution consisting of dedicated parking bays. Parking bays are a way to support and promote intermodal trips by creating shared micromobility hubs close to stations, when smart parking’s density is sufficient.

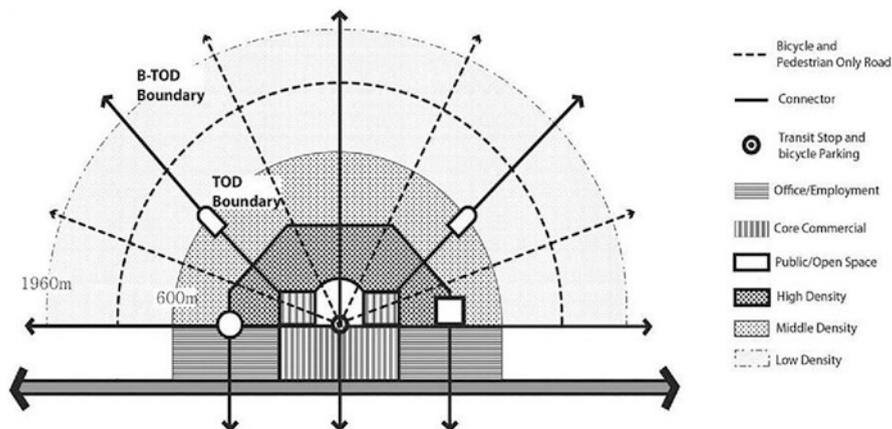


Fig. 10 Distances and influence areas in relation to public transport stations from the 19 reviewed articles. (Source: Author elaboration)

direction, highlighting 19 scientific papers that examine the role of feeder micro-modes in strengthening hybrid TODs, bringing sustainable mobility and urban forms to strategic auto-centric areas within enlarged transit catchment areas (Nigro et al., 2019, p. 38). Stransky (2019, p. 38) develops a simplified TOD framework for peri-urban locations around Paris, reinterpreting the 3Ds as “Walkability,” “Variety,” and “Treatment.” These context-specific TOD criteria illustrate the adaptability of the model, according to the author, by favoring the ability of the area to be easily walkable, the variety of supply, and the quality of the feeder routes for walking and cycling at different scales.

4.2 15-Minute TOD-Friendly Areas

Bike-and-ride, and more broadly micromobility combined with transit, offers a number of environmental, social, and economic benefits over the use of private cars (Martens, 2004, p. 282), including reduction of the various forms of pollution, relative energy sobriety, better accessibility, or territorial and land use valorization. The emergence of an extended version of TOD seems to be in line with the recommendations of (Jamme et al., 2019, p. 421), which are based on the urge of renewed TOD with the original goal of developing inclusive and sustainable communities. Figure 11 highlights the advantages of the combination of PMDs and PT over other travel modes, allowing micromobility-and-ride to compete with auto, especially on congested roads. Kager et al. (2016, p. 212) emphasize that this hybrid system ensures both a relatively high speed (efficiency allowed by the mobility service) and the possibility of making a door-to-door journey (flexibility of micromobility). Recognizing the comparative advantages of this intermodal system, Bertolini (2017,

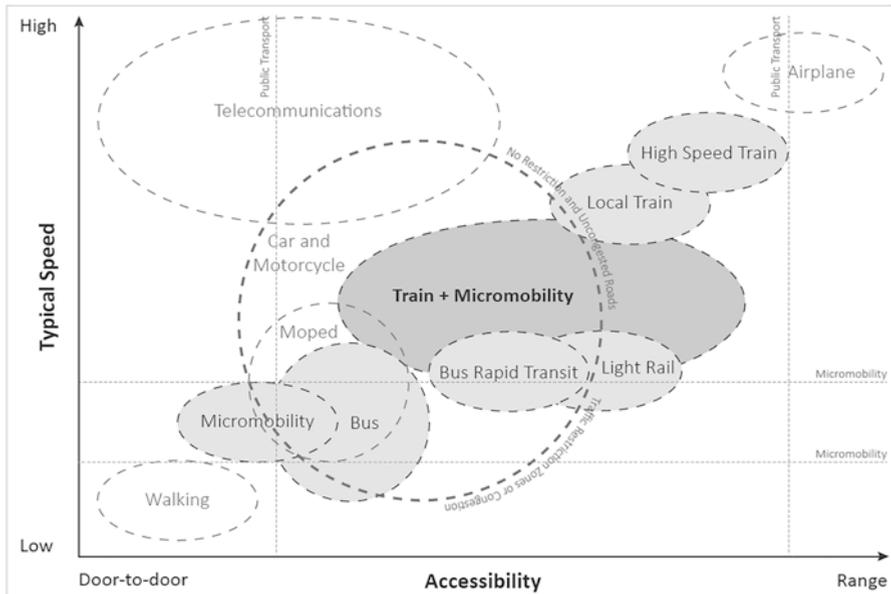


Fig. 11 Characterizing the bicycle train mode according to speed and level of accessibility (indicative, adapted from Meyer and Miller (2013)). (Source: Kager et al. (2016, p. 212))

p. 120) recommends placing interchange facilities as close as possible to the low-density and low-functional-mix areas, including bike- and park-and-ride areas.

From this analysis, the results suggest that two levels are integrated into the territorial system when considering urban development around PT and especially railway station areas. The walking catchment area of up to 1 or 1.5 km is covered by a 15-minute neighborhood, and the acceptable cycling range estimated to be 3 or 4 km is also within the scope of a 15-minute city, which is consistent with Brès (2014, p. 271) findings. Midenet et al. (2018, p. 29) further considers an access time by bicycle, with a cycling-friendly environment, set to 20 minutes. Nevertheless, this study follows the need for a site-specific conceptualization of TOD (Qvistrom & Bengtsson, 2015, p. 2531; Stransky, 2019, p. 38). Extending the railway station areas by promoting micromobility could reflect the emerging concept of the “15-Minute City” (Duany & Steuteville, 2021), where the combination of walking, cycling, scootering, and PT (Sadik-Kahn, 2021) would ensure that most commonly accessed services and activities can be reached within a 15-minute walk or cycling ride (Moreno & Hjelm, 2021). For this, more multimodal planning that can invest as much in active and micromodes, as would be spent on road and parking facilities for cars, is needed to create a least-cost planning 15-minute neighborhood (Litman, 2021, p. 34). From this broader point of view, the urban project oriented to structured PT, in particular the railway station, must simultaneously take advantage of a wide pedestrian zone appropriate to its real potential, as well as the micromobility and urban PT isochrones guaranteeing intermodality development (L’Hostis et al., 2009, p. 69).

Integrating auto-oriented Secondary Areas to benefit emerging micromobility options is a way of reinforcing the TOD model by considering European urban patterns and new mobility solutions complementing the transit network while bringing a more inclusive approach by appealing to populations that are more distant.

4.3 Knowledge Gaps Regarding Extended TODs

Existing gaps in the academic literature for European case studies were identified from this SLR and resulted in providing guidance for future research on extended TOD.

While the quantitative methods employed by scientific articles are diverse, varying from analyses of mobility surveys to modeling, qualitative methods are sorely lacking and prevent a better understanding of the experience and appropriation of users from secondary areas to favor policies adapted to an efficient modal shift. Moreover, the methods linked to the digital collection of big data are not very widespread in Europe (1/19), giving rise to a second gap.

As recognized by Oeschger et al. (2020, p. 17) through an international SLR on micromobility and PT, an evident gap is the lack of research focusing on new and electric micromodes in the context of integrated transit. Although research in North America and Asia related to new mobility services is gradually emerging, as demonstrated in Sect. 3, emerging shared and private PMDs integrated with transit are thus marginalized in the research. This can be explained by the novelty of these modes, such as electric bikes, scooters, skateboards, or folding bikes, as well as the difficulty of gathering data in specific contexts. Data are still scarce despite the establishment of open access platforms promoted by local authorities at different scales.

Regarding PT networks, gaps have also been identified with research mainly oriented toward rail, whereas some cases only exist for urban PT. Martens (2004, p. 292) notes that levels of bike-and-ride are much less clear for slower types of PT, shares in feeding trips to bus, tramway, or metro stops revealing to be poor partly because of a lack of policy attention for their integration.

This gap unfolds not only within micromodes or PT but also across case studies that are underrepresented in large parts of Europe, especially in Eastern and Southern Europe. Although research has focused on multiple types of urban patterns within metropolises, little attention has been given to comparing the characteristics that differ between neighborhoods with high and low levels of services (LOS), as well as access and egress legs.

At the same time, not all TOD criteria were treated equally, with some variables receiving little implicit or explicit consideration, including destination accessibility, urban diversity, and density. As identified by Knowles et al. (2020, p. 7), the reviewed subject devotes little space to the extended area effects on the founding

assumptions of TOD, namely, density, diversity, and design, even though the design was regarded as one of the criteria privileged in the studies.

Last, more research is needed on the impacts of micromobility and PT integration on station areas through economic, social, and environmental dimensions, i.e., the potential for modal shift, regional accessibility and social inclusion provided by the combination of economic dynamics stimulated in territories as well as the energy balance in relation to modal shifts. As Oeschger et al. (2020, p. 17) also pointed out, the economic aspect related to extended TOD is the most important missing analysis dimension in Europe.

5 Conclusions

Through the framework of this literature body with respect to the 6Ds, it was possible to review such factors in these extended perimeters. First, it was possible to underline the critical place of “Distance to Transit” with the emergence of micromobility devices and services to support and accommodate the TOD application toward zones located 3 or even 4 km away. This SLR highlighted the importance of “design” and, in particular, the quality of the cycling network and parking in the feeder area, which has the capacity to extend the acceptable distance for passengers, those factors being expanders or contractors of the TOD walking radius. This can only be effective as long as the place of the car is questioned in this strategic secondary area, transportation “demand management” taking the form of spatial and ownership of car restrictions, the implementation of reverse distance-based pricing for P+R, and the provision of mobility services near station areas. “Diversity” is relevant to the extent that it promotes intensive activity clustering around the station and housing in the walking and cycling surrounding area, up to 3–4 km. This chapter underlined the unclear role of compacity in these secondary areas, with micromobility being a response to low-density territories. While some studies highlighted the positive correlation between micromobility use as a feeder mode and medium urban density, other variables may influence these observations, such as the presence of cycling infrastructure. Finally, “destination accessibility” proved the effectiveness of micromobility in providing a more inclusive connection to employment locations, guaranteeing local, urban, and regional accessibility.

This work aimed to better understand the growing interest in the extended TOD perimeter, whereby the association of new micromobility forms and public transport is expected to become more relevant in the future. It has been seen, by reviewing 19 scientific papers, that the catchment area of European transit stations, in particular train stations, is easily extended to 3 km with the assistance of microvehicles, especially personal bicycles, as a strengthening of the 1.6-km secondary area. TOD can be redefined for the twenty-first century through game-changing mobility paradigms, such as smart and sustainable mobility.

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