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A Systematic Literature Review on Station Area Integrating Micromobility in Europe: A 21st Century Transit-Oriented Development

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Abstract

The increasing popularity of the bicycle, coupled with the emerging new micromobility solutions, such as personal electric micro-vehicles or sharing systems, call 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. 19 of the 3,955 articles recorded met the inclusion criteria specified in the methodology protocol. The analysed scientific papers clearly highlight TOD boundaries extended to about three kilometres, suggesting the redistribution of variables towards residential and cycling-friendly areas beyond the first walking kilometre. 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 neighbourhoods, and the application of qualitative research methods.

Keywords: Catchment Area; Micromobility; Systematic Literature Review; Transit-Oriented Development

1 Introduction

1.1 Conceptualising 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, in particular in the United States (Papa and Luca Bertolini 2015, p. 70). Closely connected with Smart Growth and New Urbanism movements, TOD as formalised promotes urban development along 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 and Ohland 2012, p. 5): European and Asian planners consider that TOD is an innovative instrument but not an invention (Jamme et al. 2019, p. 411), although the origins 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 and Luca Bertolini 2015, p. 77). Internationally formulated, TOD has the potential to fundamentally rethink about multiscale communities are built (Dittmar and Ohland 2012, p. 19), even if most theories on how to design successful TOD projects have been developed in the United States (Poiani and 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 in order to reduce the vehicular traffic congestion (Nasri and Zhang 2014, p. 172). TOD's key 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 travelled (VMT) and encourage transit use.

Additional D-requirements also complete the list of factors coordinating and integrating planning and transportation issues, including the '6Ds': 3Ds variables supplemented by Distance to Transit - central to the paper - Destination Accessibility, and Demand Management (Ewing and Cervero 2010, p. 274). Being a critical dimension in the TOD equation, the Distance to Transit variable is very crucial to measure the proximity and accessibility of a transit station and to make decisions on land development, while Destination Accessibility is based on the logic of providing greater mobility by moving people around the city more swiftly, and Demand Management can be considered as actions that are implemented at specific sites or strategies that are implemented at an area-wide level (Ogra and Ndebele 2014, p. 541). Black, Tara, and Pakzad (2016, p. 7) define elements that structure a Smart City, of which accessibility along public transport nodes.

One-half mile has become the accepted distance for gauging a transit station's catchment area in the United States (Guerra, Cervero, and Tischler 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 metres by walk or bike (Cervero, Murphy, et al. 2004, p. 238). The conventional TOD approach is based on the development of dense commercial and employment areas in proximity to a station, followed by residential zones with densities gradually decreasing (600 metres 'Primary Area') (Calthorpe 1993, pp. 43, 87). However, this standardized rule is likely to evolve and change the model by revisiting the stations' service area.

1.2 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

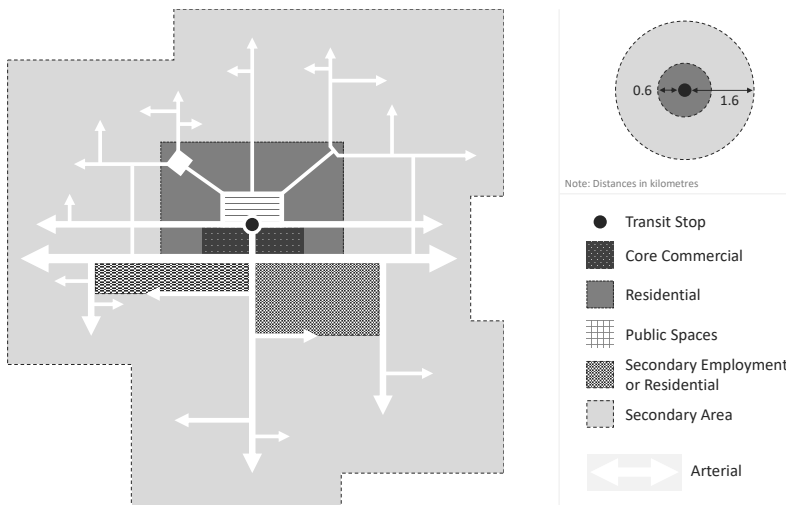


Fig. 1 Spatial Configuration of TOD at Station Level (redesigned from Calthorpe (1993, p. 60))

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limit of 500-800 metres (Pojani and Stead 2015, p. 133), while the second one is interested in mobility feeder solutions inviting to integrate first- and last-mile connections to public transport (Park, Farb, and Chen 2021, p. 38). Both approaches converge on a common critique of this distance threshold and suggest a broader view of TOD neighbourhoods 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, this 1.6-kilometre adjacent perimeter is characterised by lower density and auto-oriented urban systems (Ibraeva et al. 2020; Banai 1998, p. 112).

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, as well as the boundaries of a TOD district do not have to be confined to 1 kilometre (Ker and 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 published, but generally do not explicitly mention the urban planning vision of an extended TOD perimeter. Among the modes analysed that require a new understanding to TOD are bikes (Lee, Choi, and Leem 2016, p. 979), buses and personal rapid transit (J. B. Schneider 1992, p. 151), as well as shared and digitised mobility solutions (Knowles, Ferbrache, and Nikitas 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. While E-TOD assumes a network of Feeder-Distributor-Circulator (J. Schneider 2012) similar to Personal Rapid Transit (PRT), whose deployment strategy has evolved (J. B.

Schneider 1992, p. 152); B-TOD, which is part of the common thought of an extension of the TOD, focuses on the contribution of individual light modes and in particular of the bicycle.

In combination with the re-evaluation of the walking accessibility to and from a public transport station, secondary modes which 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. With the renewed popularity of the bicycle in Europe (Héran 2015, p. 142), rising development of bike and e-scooter schemes, but also the rapid adoption of emerging Personal Mobility Devices (PMDs) such as the standing scooter which play a positive role in public transport patronage (Kostrzevska and Macikowski 2017, p. 2), this paper focuses on this category of devices qualified as micromobility. The originality of this research is to link two approaches: the association of micromobility and public transport in connection with TOD areas.

1.3 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 takes 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?

In order to collect, analyse 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 the 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 paper is organised as follows: [Section 2](#) describes the methodological protocol adopted to select the scientific paper corpus, to analyse and discuss the results obtained in [Section 3](#), and to consider avenues for future research on a TOD integrating micromobility in [Section 4](#).

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 towards 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 SLR are to Uncover a solution to a problem (1); Identify concurrent or previous work on the same topic (2); Validate a particular method (3); Provide a focus for investigations (4); and Confirm that further research is needed (5).

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, in order 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 micro-vehicles 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 neighbourhoods 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 analyse the existing scientific literature on the integration of private and shared micro-vehicles 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), stations being connected to considerably more households, substantially increasing the potential number of users, services and facilities (Jonkeren and Roland 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 social (Cervero, Caldwell, and Cuellar 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 in order 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, Carroll, and Caulfield (2020), which provide 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, whilst giving a more specific insight into this region: among the 48 articles analysed 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 by 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, Louro, and Costa 2019, p. 738). Thus, the review protocol selected is derived from TOD and micromobility SLR published by Oeschger, Carroll, and Caulfield (2020, p. 4), Padeiro, Louro, and Costa (2019, p. 738), Pritchard (2018, p. 2), Sengül and Mostofi (2021, p. 3), Neilson et al. (2019, p. 36), and Bozzi and Aguilera (2021, p. 4). The selection procedure under the SLR involves four main steps (Jain, Singh, and Ashtt 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 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 which 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 3 December 2021 for both Scopus™ and WoS, resulting in a total of 2,920 entries.

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')

Realisation: Moïnse, 2022

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, Louro, and Costa (2019, p. 738) who manually searched issues through a selection of journals from among the top 40 rankings. The electronic database was collected on 8 February 2022 and has a total of 1,354 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 3,955 unique articles identified, the next step is 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
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, 1,777 of the 3,955 articles recorded were discarded because they did not deal with urban or transport-related issues. 1,599 of them do not deal with 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

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 Behaviour</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

Inclusive Criteria:

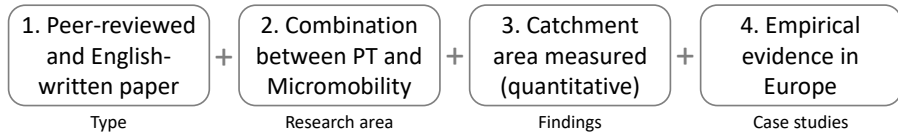


Fig. 2 Conditions for Inclusion in the Research Protocol

Realisation: Moinsé, 2022

unavailability of the full content. As a result, 243 articles were identified as discussing micromobility in combination with public transport (Fig. 3).

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. Lastly, 58 of the 74 empirical articles related to transit catchment area by micromobility were not included, as they covered on other regions. The selection process via the reading of abstracts revealed 16 scientific articles, as shown in Figure 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, Singh,

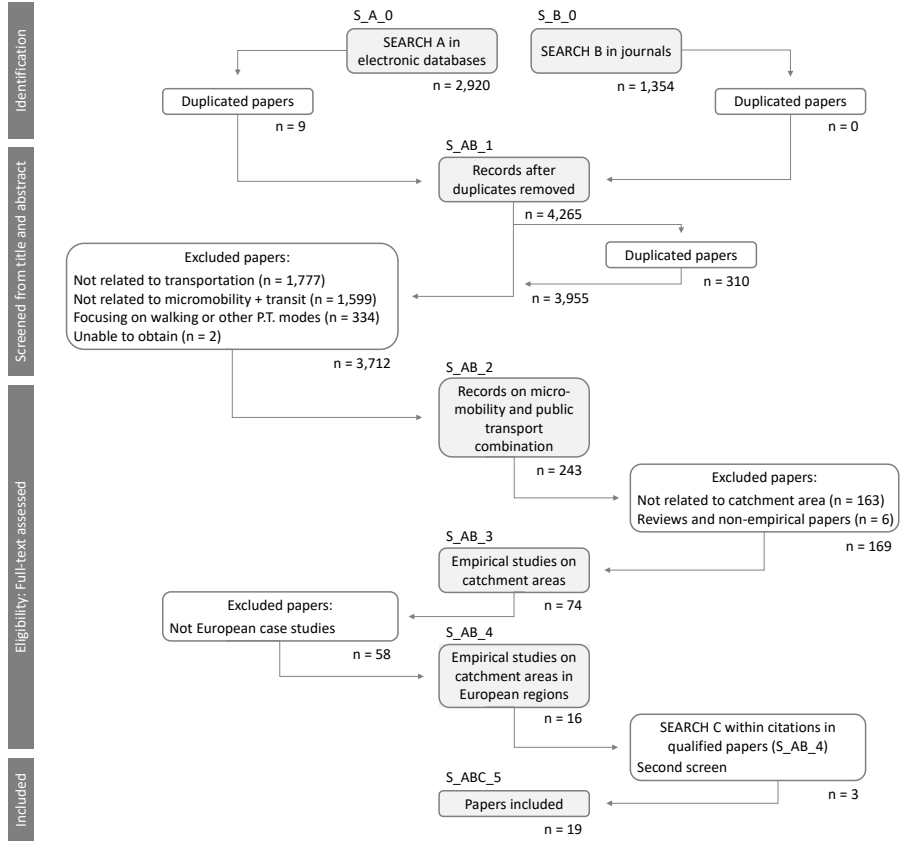


Fig. 3 Flow Diagram Representing the Selection and Review Process

Realisation: Moïnse, 2022

and Ashtt 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 four criteria above were added, resulting in a final body size of 19 articles.

2.5 Aspects Considered

Through this systematic literature review, attention will be paid to the dimensions characterising TOD in conjunction with the intermodal approach. Similarly to Luca Bertolini, Curtis, and Renne (2012, p. 31), this work aims to review 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 the Clarivate Analytics’s WoS platform, it can be noted that the amount 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 term '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, Singh, and Ashtt (2020, p. 2545) also observed on TOD based on the Google Trends platform. Figure 4 reveals the gradual but still modest emergence of scientific studies crossing these subjects, up to 7 to 13 papers published each year since 2019. It is particularly the features of this recent pattern that drive this chapter.

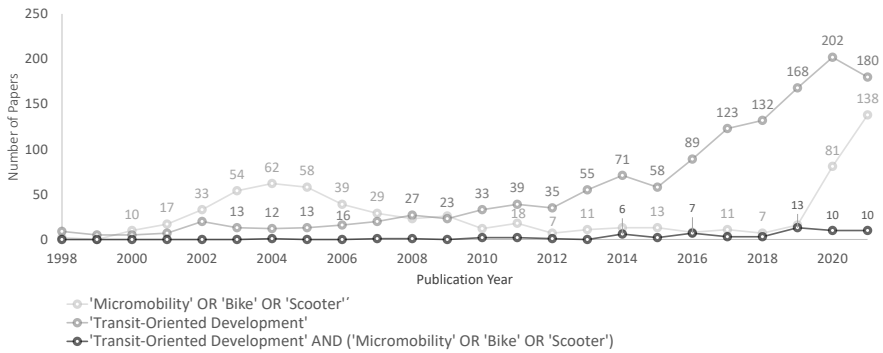


Fig. 4 Year Wise Publication of Bibliometric Papers related to Micromobility or/and TOD (16 March, 2022)

Source: Web of Science™ database, Realisation: Moinse, 2022

When looking at the geographical distribution of papers by author location, it clearly appears that one third of the works on 'Micromobility' since 1998 originates from Europe and North America each, and one quarter from Asia (Fig. 5, a). France (9%), England (8%), Italy (7%), and Germany (6%) are in the main contributors in Europe (36%); the United States (26%), and Canada (7%) in North America (33%); South Korea (10%), and China (8%) in Asia (28%). This relatively wide distribution of a range of countries becomes more limited when focusing on the 'Transit-Oriented Development'. Research is highly specialized in North America (39%), particularly in the United States (34%), and in Asia (38%), with China (24%) in the lead (Fig. 5, b). This is further strengthened when crossing the two concepts, with most of the work coming from 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. 5, c).

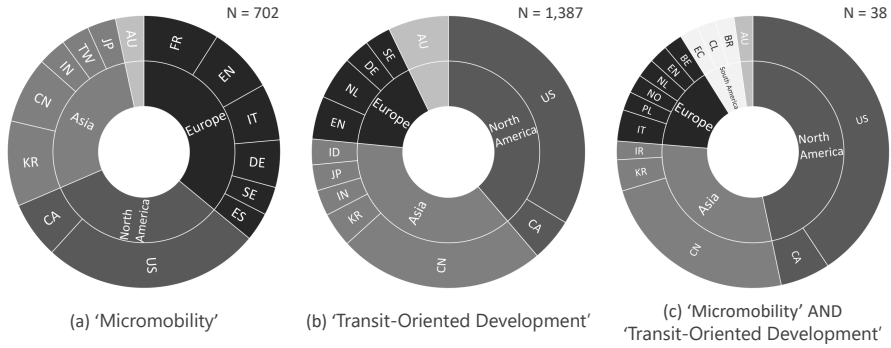


Fig. 5 Evolution of Scientific Production on Micromobility or/and TOD (16 March, 2022)
Source: Web of Science™ database, Realisation: Moïnse, 2022

3.2 Current State of International Studies on the Cycling and Transit Coordination

As explained in Figure 3, 74 articles were identified in the international literature on the subject of micromobility and PT integration, with a specific consideration and measure 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 analysed by browsing both keywords covered by this chapter: the three continents that contribute most strongly to the knowledge regarding station area by micromobility can be found in Figure 6.

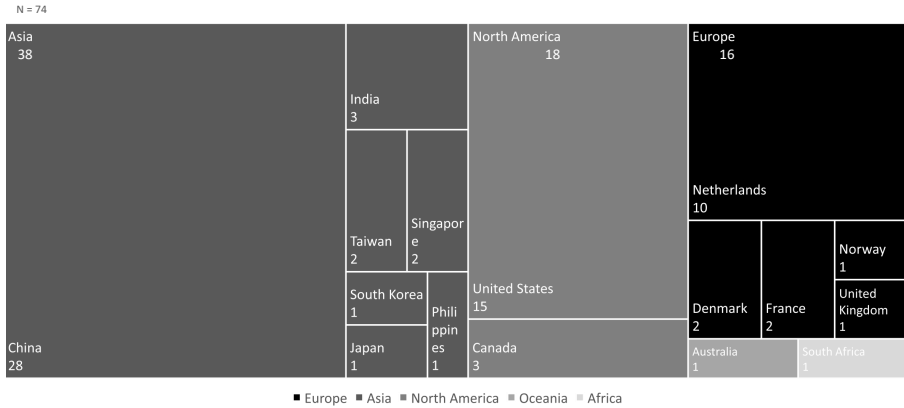


Fig. 6 Geographical Distribution of International References addressing Combined Transit and Micromobility
Realisation: Moïnse, 2022

By distinguishing the different types of micromobility investigated by this international database, the private and non-electric bicycle occupies a prominent place (47/74), which can be notably attributed to the seniority and global availability of this mode. 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 2 papers dealing exclusively with free-floating services, while one article focuses on pedicabs, a small pedal-operated vehicle serving as a taxi.

Regarding the 16 European papers in the sample, 14 of them address a personal micro-vehicle: 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 (PMD), 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 analysed in depth in the next section.

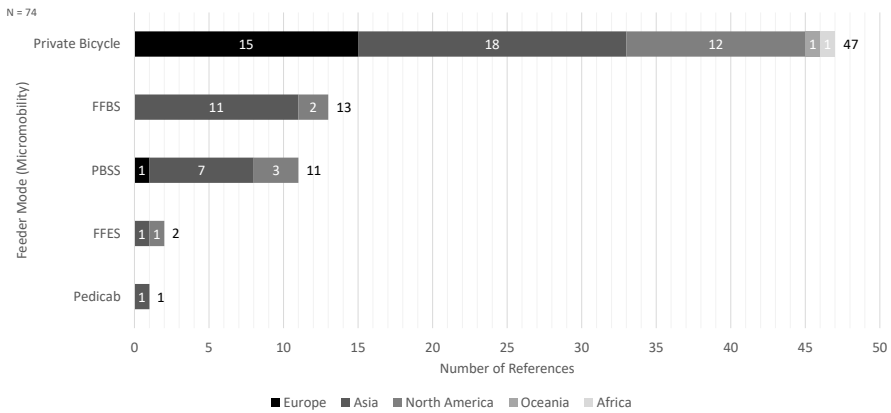


Fig. 7 Studied Micromobility Types across International References on Intermodality
 Note: FFBS: Free-Floating Bike Service; PBSS: Public Bike-Share System; FFES: Free-Floating E-Scooter Service

3.3 Description of European Papers

Type of Integration Recorded

With further attention to the 16 European articles coupled with the 3 papers listed afterwards, it is noteworthy that 17 out of 19 are oriented towards a private mode and particularly towards 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, Côme, and Papon 2018) and another about electric standing scooters (Moinse et al. 2022). All four articles were published less than four years ago, due to the recent spread of these micro-vehicles 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, Pels, and Piet Rietveld (2009)	Private	Bike+Rail
SLR ⁵	Djurhuus et al. (2016)	Private	Bike+PT
SLR ⁶	Geurs, La Paix, and Van Weperen (2016)	Private	Bike+Rail
SLR ⁷	Hasiak (2019)	Private	Bike+Rail
SLR ⁸	Heinen and Bohte (2014)	Private	Bike+PT
SLR ⁹	R. Kager, L. Bertolini, and Te Brömmelstroet (2016)	Private	Bike+Rail
SLR ¹⁰	Keijer and P. Rietveld (2000)	Private	Bike+Rail
SLR ¹¹	Martens (2004)	Private	Bike+PT
SLR ¹²	Midenet, Côme, and Papon (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, Luca Bertolini, and Moccia (2019)	Private	Bike+Rail
SLR ¹⁶	Piet 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 micro-vehicles are considered into 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.

Case Studies and Publication Periods

Within the literature corpus, there is 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 and Bohte 2014); while four articles are set in urban areas and regions such as Belgian cities (Adnan et al. 2019), Randstad South (Geurs, La Paix, and Van Weperen 2016), medium-sized train stations in Provence-Alpes-Côte d'Azur (Moinse et al. 2022), and Campania Region (Nigro, Luca Bertolini, and Moccia 2019). For their part, three works focus on medium-sized areas as in French local cities (Hasiak 2019), Amboise (Midenet, Côme, and Papon 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, Pels, and Piet Rietveld 2009; R. Kager, L. Bertolini, and Te Brömmelstroet 2016; Keijer and P. Rietveld 2000; Piet Rietveld 2000), with Germany and the United Kingdom (Martens 2004), and Denmark (Nielsen and Skov-Petersen 2018). The geographical distribution of the studied areas among the selected items clearly shows a spatial concentration around Western and Northern Europe Figure 8.

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 (Keijer and P. Rietveld 2000; Piet Rietveld 2000; Martens 2004; Debrezion, Pels, and Piet Rietveld 2009; Sherwin et al. 2011; Heinen and Bohte 2014), 13 of the papers were published from 2016 onwards and at least three quarters of them after 2019, supporting the hypothesis of a very recent literature.

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, Pels, and Piet Rietveld (2009)	The Netherlands	-
Djurhuus et al. (2016)	Denmark	Copenhagen
Geurs, La Paix, and Van Weperen (2016)	The Netherlands	Randstad South (Rotterdam-The Hague)
Hasiak (2019)	France	Local stations
Heinen and Bohte (2014)	The Netherlands	Delft, Zwolle, and surroundings
R. Kager, L. Bertolini, and Te Brömmelstroet (2016)	The Netherlands	-
Keijer and P. Rietveld (2000)	The Netherlands	-
Martens (2004)	Germany, the Netherlands, and the United Kingdom	-
Midenet, Côme, and Papon (2018)	France	Amboise
Moinse et al. (2022)	France	Provence-Alpes-Côte d’Azur region
Nielsen and Skov-Petersen (2018)	Denmark	-
Nigro, Luca Bertolini, and Moccia (2019)	Italy	Campania region
Piet 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 micro-vehicles are considered into the Type of Integration category. ‘PBSS’ stands for Public Bike-Sharing System and ‘PT’ comprises Railway, Metro, Tramway, Bus, or/and Ferry.

Research Methods

This SLR analysed specific methods used among the 19 scientific works to study micromobility and public transport integration Table 5. As identified by Oeschger, Carroll, and Caulfield (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 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 P. Rietveld (2000, p. 231) and Piet Rietveld (2000) undertook a statistical analysis based on the Dutch National Travel Survey from 1994. In the same way, Hasiak (2019, p. 12) and Moinse et al. (2022, p. 10) analysed 25 Households Travels



Fig. 8 Geographical Distribution of Areas Investigated by the Reviewed Papers
Realisation: Moïse, 2022

Surveys (HTS) carried out on different French urban areas and regions between 2009 and 2016 by using econometric methods, and the French national public rail network manager SNCF Réseau's survey data, respectively. Nielsen and Skov-Petersen (2018, p. 38) realised a regression analysis of 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 UK, but facing challenges due to the collect data methods focusing on the main transport mode which neglect 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 examine data from a 2008 Internet survey in Delft, Zwolle, Midden-Delfland, and Pijnacker-Nootdorp, by sending 3,500 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. Rijnsman et al. (2019) and Ton et al. (2020, pp. 1, 827) completed a regression model by collecting data with an on-board transit revealed preference approach among tramway travellers in The Hague. In the same way, (Geurs, La Paix, and Van Weperen 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 applied accessibility indicators with multimodal models to analyse the TOD and micromobility integration. Midenet, Côme, and Papon (2018, p. 11) analysed the station's catchment area with the use of 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 motorised 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, Luca Bertolini, and Moccia (2019, p. 116) determined the extent of catchment areas by using interconnectivity ratio and GIS analysis through the application of the network distance analysis. A railway quality index based on the Dutch National Railway Company was estimated by Debrezion, Pels, and Piet Rietveld (2009, p. 17) with a GIS analysis, while a VENOM transit model from the regional model of Stadsregio Amsterdam is 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 analysing the 2016-2017 records of 4.4 million trips by the Oslo public bike service, screening trips that start or end within 200 metres of a PT station, and conducting multivariate modelling techniques.

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, Pels, and Piet Rietveld (2009)	Railway Station Quality Index (RSQI)
Djurhuus et al. (2016)	Multimodal Network Model and GIS Analysis
Geurs, La Paix, and Van Weperen (2016)	Multimodal Network Model and GIS Analysis
Hasiak (2019)	Survey's Analysis
Heinen and Bohte (2014)	Survey-based Analysis of Variance (ANOVA)
R. Kager, L. Bertolini, and Te Brömmelstroet (2016)	System Perspective and Conceptual Analysis
Keijser and P. Rietveld (2000)	Survey-based Modal Choice
Martens (2004)	Survey's Analysis
Midenet, Côme, and Papon (2018)	Access Mode Model
Moinse et al. (2022)	Survey's GIS-based Analysis
Nielsen and Skov-Petersen (2018)	Survey's GIS-based Analysis
Nigro, Luca Bertolini, and Moccia (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.

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 analysed papers, micromobility distances measured in the first or last trip chain leg tend to converge towards on a cycling service area, in particular for railway stations, between one kilometre minimum (3.14 km²) and three (28.27 km²) to four kilometres (50.27 km²) maximum (see Fig. 9). The overall range of these micro-vehicles has the capacity to widen TOD limits from 9 to 16 times the 1-kilometre pedestrian pocket. In the Netherlands, cycling connects around 15 times as much people to main intercity stations and 4 times more people to local stations compared to walking (R. Kager, L. Bertolini, and Te Brömmelstroet 2016, p. 213). Moreover, walking distance is found to be weighted 2.1 times more negatively than cycling distance to access tramway 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 9 reviewed articles. Djurhuus et al. (2016, pp. 13, 16) choose to study all PT stops in Copenhagen within a 1-kilometre walking distance and within a 3-kilometre cycling distance from home in order to cover cycling trips to stops. The same observations in Denmark are given by Nielsen and

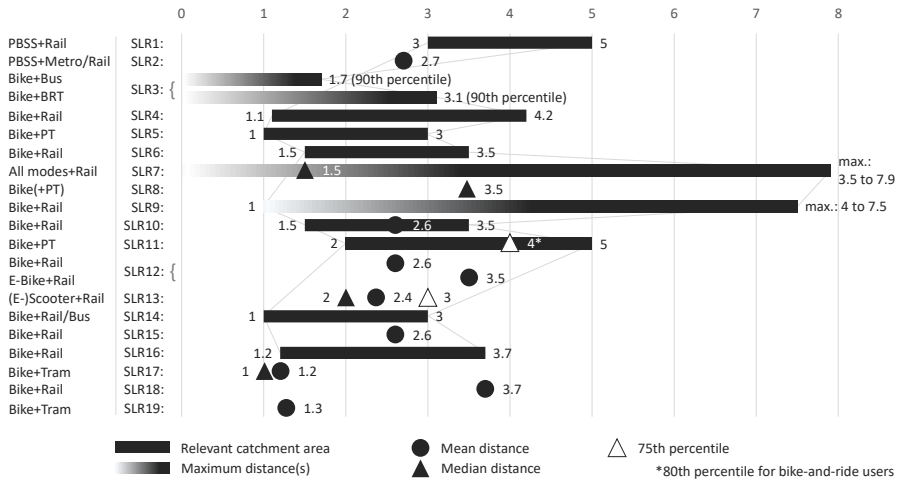


Fig. 9 Distances and influence areas in relation to public transport stations from the 19 reviewed articles

Realisation: Moinse, 2022

Skov-Petersen (2018, p. 42), the 3-kilometre distance band reflecting a convenient cycling range around a train station, whereas being less competitive than walking and PT within 1 kilometre. Debrezion, Pels, and Piet Rietveld (2009, p. 23) note that the bicycle is the most probable access mode choice for distances between 1.1 and 4.2 kilometres, but that this maximum distance will decrease to 3.6 kilometres if the frequency of urban public transport doubles in the Netherlands. Similarly, Keijer and P. Rietveld (2000, p. 234) determine that most people take the bike when the train station is situated between 1.5 and 3.5 kilometres 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 kilometres for residential areas (Keijer and P. Rietveld 2000; Piet Rietveld 2000; Geurs, La Paix, and Van Weperen 2016, pp. 233, 73, 9). Piet Rietveld (2000, p. 73) identifies an asymmetry for rail between access and egress trips, by distinguishing home-end segments where bike is dominant between 1.2 and 3.7 kilometres and activity-end segments where bike is not attractive when compared to walking (up to 2.2 kilometres) and urban transit. On average, cycling becomes more attractive than walking for distances of 1.31 kilometres or more to The Hague tramway stations (Ton et al. 2020, p. 832). In Germany, Netherlands and UK, Martens (2004, pp. 282, 289) reports 2- to 5-kilometre access trips by bike to PT stations, with longer distances (from 4 to 5 kilometres) for faster collective modes, and a 2-kilometre threshold seen for the metro. These outcomes are in line with Adnan et al. (2019, p. 9)’s works, who note that public-bike share is more optimal for distances between 3 and 5 kilometres in Belgium.

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

In general, the access distance to train stations covered by bike is 2.6 kilometres long, for a 12-minute isochrone area in the Campania region (Nigro, Luca Bertolini, and Moccia 2019, p. 120). Cycle trips to and from Bristol railway stations has an average length of 3.7

kilometres (Sherwin et al. 2011, p. 192). Similarly, passengers combining train and standing scooter have an access range of 2.4 kilometres, while half of these trips are 2 kilometres long (Moïnse et al. 2022, p. 21). On average, passengers accessing or egressing stations in Amboise by conventional bicycle would travel 2.5 kilometres, while e-bike users would make trips of 3.5 kilometres in a 2025 scenario (Midenet, Côme, and Papon 2018, p. 29). The mean cycling feeder distance in The Hague is fixed at 1.159 kilometres (a 1.025-kilometre median) for the tramway network (Rijsman et al. 2019, p. 4).

3.5 Review of TOD Aspects Studied in Europe

In order to examine the integration of the commonly recognised TOD-defining attributes, the 6 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 summarises the incorporation of these variables based on two single options: '+' indicated 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.

Density

Density is studied in 7 articles within the database, despite being a key component of the 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-kilometre issue, whereas increasing the density of a larger perimeter seems more complex.

Martens (2004, p. 290) argues that bike-and-ride practices are significantly influenced by the location of transit stations in Germany, the Netherlands and the UK, by describing higher proportions in suburban neighbourhoods, due to the compactness of the centres with a greater density of stops, feeder transit services, and more opportunities to choose transport lines and stops close to their origin or destination. TOD in low-density areas needs to consider multiple feeder transport other than walking (Nigro, Luca Bertolini, and Moccia 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 kilometres median access distance to rail stations, Hasiak (2019, p. 27) calls for reconsidering the primacy of the 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 as having 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 (R. Kager, L. Bertolini, and Te Brömmelstroet 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 characterised from less dense areas, suggesting that the use of e-scooters in dense neighbourhoods may be explained by car parking and traffic constraints. From radar diagrams, Nigro, Luca Bertolini, and Moccia (2019, p. 119) point out the possibility of urban intensification, as long as it is accompanied simultaneously by improvement of accessibility, by either train and 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.

Diversity

Only 3 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 and P. Rietveld 2000, p. 234). Keijer and P. 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, and recommends priority for the construction of travel intensive activities near railway stations, such as offices, education, cultural, and shopping facilities. Piet Rietveld (2000, p. 75) supports this planning strategy, stating that residential areas can extend up to 3.5 kilometres around a railway station to match the access range of the bike. This is consistent with Böcker et al. (2020, p. 397)'s results, regarding the Oslo bike share system, who report that users' routes serve higher building use diversity areas, particularly at the destination.

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 kilometre of the residence, built environment close to home being the most important for accessing to train stations. In their 'ambitious' implemented scenario, Hasiak (2019, p. 26) set up a modal shift from car to walking within one kilometre and to bike from one to three kilometres. 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, La Paix, and Van Weperen (2016, p. 11) develop 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 PT is complex, as in the Campania Region, the quality of feeder networks is crucial (Nigro, Luca Bertolini, and Moccia 2019, p. 110). Moinse et al. (2022, p. 22) make recommendations for designing a cycling-friendly environment as an opportunity to strengthen TOD to benefit micromobility like bicycle and standing scooter. However, findings suggest a minimised role of cycle paths in intermodal use for exurban areas: segregated bike lanes 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 and P. Rietveld 2000, p. 234), the availability of bicycle stands having a positive effect on the choice of Dutch departure-railway stations accessed by bicycle (Debrezion, Pels, and Piet Rietveld 2009, p. 26). In The Hague, Rijsman et al. (2019, p. 5) identify insufficient and unsafe parking places as one of the main barriers for accessing a tramway stop by bike. They recommend providing lockers and cameras at stops in order to potentially rise 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 which profit more from bicycle parking improvements (Geurs, La Paix, and Van Weperen 2016, p. 13). 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 metres and by 334 meters for multimodal hubs (tramway and bus). Keijer and P. 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 favour 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) attract drivers (Debrezion, Pels, and Piet Rietveld 2009, p. 26), which raises issues about the integration of the car in TOD areas.

It seems necessary to rationalise 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 presence of car constraints like parking regulation. With multiples scenarios, in a French local case study, Midenet, Côme, and Papon (2018, p. 30) highlights 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 a 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).

Destination Accessibility

Destination Accessibility is studied in 7 academic works within the corpus. The transport quality aspects for trains tend to increase with distance travelled, whereas for micromobility, its qualities tend to decrease as distance increase (R. Kager, L. Bertolini, and Te Brömmelstroet 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 kilometres, and a regional scale which is up to 40 km in Denmark, while Heinen and Bohte (2014, p. 114) obtain an average of 36.45 kilometres distance home-work by bicycle and PT.

The complementarity of micromobility with PT provides a wider accessibility to destinations and consequently to resources, especially to employment areas. By accessing all PT stops within 1 kilometre walking and 3 kilometres cycling distances in 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, La Paix, and Van Weperen (2016, p. 11) provide a greater job accessibility than the increased frequency scenario, with significant accessibility improvements towards small and medium-sized stations in Randstad South.

The use of these micro-vehicle feeders in conjunction with PT turns out to be effective compared to the 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 kilometres. In their second scenario, characterised by ideal travel time and penalties, R. Kager, L. Bertolini, and Te Brömmelstroet (2016, p. 216) reveal that cycling is an average 10 minutes advantage over feeder transit services during a 10 to 80 kilometres train trip.

Demand Management

The TOD's last D in relation to demand management is included in 9 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 favour faster and higher quality types of PT like train and intercity bus, unlike tram or local bus. 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. Firstly, reduced travel time on PT has a positive impact on the choice of departure station (Debrezion, Pels, and Piet Rietveld 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

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

Authors (Publication Year)	Density	Diversity	Design	Destination Accessibility	Demand Management	Distance to PT
Adnan et al. (2019)	-	-	+	-	+	+
Böcker et al. (2020)	+	+	-	-	-	+
Brand et al. (2017)	-	-	+	-	+	+
Debrezion, Pels, and Piet Rietveld (2009)	-	-	+	-	+	+
Djurhuus et al. (2016)	-	-	-	+	-	+
Geurs, La Paix, and Van Weperen (2016)	-	-	+	+	+	+
Hasiak (2019)	+	-	+	-	+	+
Heinen and Bohte (2014)	-	-	-	+	-	+
R. Kager, L. Bertolini, and Te Brömmelstroet (2016)	+	-	-	+	-	+
Keijer and P. Rietveld (2000)	-	+	+	-	-	+
Martens (2004)	+	-	+	-	+	+
Midenet, Côme, and Papon (2018)	-	-	+	-	+	+
Moinse et al. (2022)	+	-	+	+	-	+
Nielsen and Skov-Petersen (2018)	-	-	+	+	-	+
Nigro, Luca Bertolini, and Moccia (2019)	+	-	+	-	-	+
Piet 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.

collective mode more efficient (Brand et al. 2017, p. 6). *A contrario*, transit frequency has also a moderate effect on the choice of departure stations by passengers accessing by micromobility. The Geurs, La Paix, and Van Weperen (2016, p. 11)' sixth scenario based on increased frequencies of local trains shows that rail-micromobility integration produces limited benefits. Moreover, when doubling the frequency of local PT, it leads to a decrease of distance for bike from 4.2 to 3.6 kilometres (Debrezion, Pels, and Piet Rietveld 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 two minutes from the

train platform generate beneficial effects around the site, users even highly willing to pay for improvement of these facilities (Geurs, La Paix, and Van Weperen 2016, p. 9). From a systematic perspective, these effects interact with car use and parking space management. Debzejon, Pels, and Piet Rietveld (2009, p. 24) evidence that a car ownership to 0.60 per person would involve the car domination over PT from 10 kilometres. Midenet, Côme, and Papon (2018, p. 30) advocate the implementation of pricing policies on P+R depending on the reverse of the distance from the client's residence to the train station, to encourage modal shift and optimisation of car park size. Considering the potential modal shift from car to walking within one kilometre and from cycling between one and three kilometres, Hasiak (2019, p. 27) demonstrates that a saving 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, Rijnsman 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 parking¹. 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 Piet 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 represent also 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 the 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 programmes for pedestrians and micromobility users (Hasiak 2019, p. 27).

4 Revisiting the TOD Concept

4.1 A Hybrid TOD Adaptable to Spatial Contexts

Transit-Oriented Development is a promising model for building sustainable, smart urbanization and mobility to the future (Cervero 1998, p. 3). The author identified and drew up 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 have accepted spread-out with low-density areas and have 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 conceptualisation given to the Transit Metropolises (TOD), which was written two decades ago and which should be renewed as Hybrid Transit Metropolises from a 21st 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, Choi, and Leem (2016, p. 983) introduce the concept of Bicycle-based Transit-Oriented Development (B-TOD) as an alternative to the walking-based TOD and

¹In 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.

shed light on the identification of the station impact area where bicycle is a main access mode and on a more or less relaxed density criteria (Fig. 10). This book chapter follows the revisited Transit Metropolis and B-TOD direction, highlighting 19 scientific papers that examine the role of feeder micromodes in strengthening hybrid TODs, bringing sustainable mobility and urban forms to strategic auto-centric areas, within enlarged transit catchment areas (Nigro, Luca Bertolini, and Moccia 2019, p. 119). Stránský (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 favouring 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.

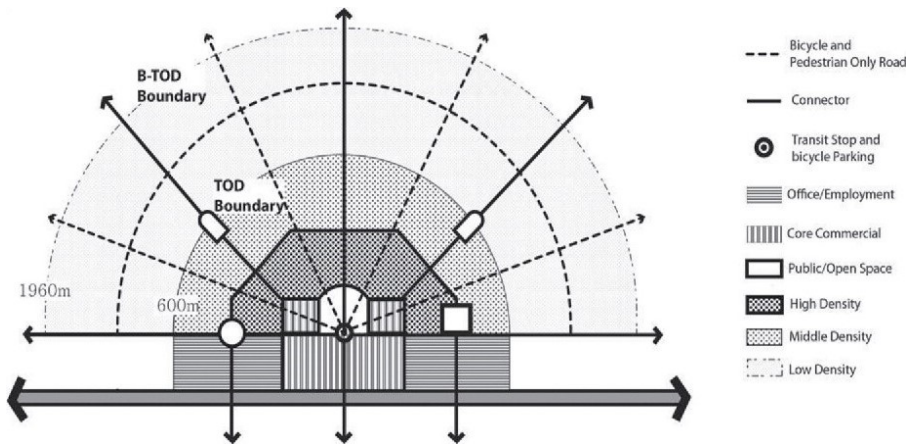


Fig. 10 Spatial context and configuration of B-TOD (adapted from Calthorpe (1993)
Source: Lee, Choi, and Leem (2016, p. 979)

4.2 15-Minute TOD-friendly Areas

Bike-and-ride, and more broadly micromobility combined to transit, offers a number of environmental, social, and economic benefits over the use of the private car (Martens 2004, p. 282), including reduction of the various forms of pollution, relative energy sobriety, better accessibility, or territorial and land use valorisation. 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 on 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: R. Kager, L. Bertolini, and Te Brömmelstroet (2016, p. 212) emphasise 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), allowing micromobility-and-ride to compete with auto, especially on congested roads. Recognising the comparative advantages of this intermodal system, Luca Bertolini (2017, p. 120) recommends to place interchange facilities as close as possible to the low-density and low-functional-mix areas, including bike- and park-and-ride.

From this analysis, results suggest that two levels are integrated to the territorial system, when considering urban development around PT and especially railway station areas: the walking catchment area of up to 1 kilometre or 1.5 kilometres, covered by a 15-minute neighbourhood, and the acceptable cycling range estimated to 3 or 4 kilometres, also within

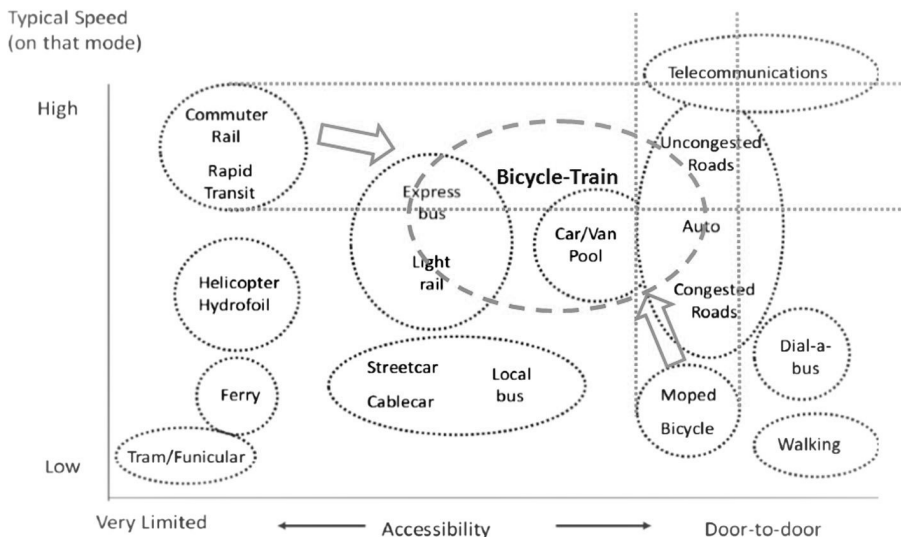


Fig. 11 Characterizing the bicycle–train mode according to speed and level of accessibility (indicative, adapted from Meyer and Miller (2013))

Source: R. Kager, L. Bertolini, and Te Brömmelstroet (2016, p. 212)

the scope of a 15-minute city, which are consistent with Brès (2014, p. 271)'s findings. Midenet, Côme, and Papon (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 and Bengtsson 2015; Stránský 2019, pp. 2531, 38). Extending the railway station areas by promoting micromobility could reflect the emerging concept of the '15-Minute City' (Duany and 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 and Hjelm 2021). For this, more multimodal planning that is able to invest as much in active and micromodes as would be spent on road and parking facilities for car is needed, in order to create a least-cost planning 15-minute neighbourhood (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 the benefit of emerging micromobility options is a way of reinforcing the TOD model by taking into account European urban patterns and new mobility solutions complementing the transit network, while bringing a more inclusive approach by appealing to more distant populations.

4.3 Knowledge Gaps Regarding Extended-TODs

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

While the quantitative methods employed by the scientific articles are diverse, varying from analyses of mobility surveys to modelling, qualitative methods are sorely lacking and prevent a better understanding of the experience and appropriation of users from secondary areas, to favour 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, Carroll, and Caulfield (2020, p. 17) through their 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. Though research in North America and Asia related to new mobility services is gradually emerging, as demonstrated in the Section 3, emerging shared and private PMDs integrated with transit are thus marginalised 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 being 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 towards rail, whereas some cases only exist for urban PT. Martens (2004, p. 292) notes that levels of bike-and-ride is much less clear for slower types of PT, shares in feeder 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 paid to comparing the characteristics that differ between neighbourhoods with high and low levels of services (LOS), as well as access and egress legs.

At the same time, it was seen that 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, Ferbrache, and Nikitas (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 design was regarded as one of the criteria privileged in the studies.

Lastly, 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, economic dynamics stimulated in territories as well as the energy balance in relation to modal shifts. As Oeschger, Carroll, and Caulfield (2020, p. 17) also pointed out, the economic aspect related to extended TOD is the most important missing analysis dimension in Europe.

4.4 Conclusions

Through the framework of this literature body in respect of the 6Ds, it was possible to review such factors in these extended perimeters. Firstly, it was possible to underline the critical place of 'Distance to Transit' with the emergence of micromobility devices and services, in order to support and accommodate the TOD application towards zones located 3 or even 4 kilometres 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 (Canepa 2007, p. 28). 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 kilometres. This chapter underlined the unclear role of compacity in these secondary areas, micromobility being a response to low-dense 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, like the presence of cycling infrastructure. Finally, 'Destination Accessibility' proved the effectiveness of micromobility

in providing a more inclusive connection to employment locations, guaranteeing a 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 (Oostendorp and Gebhardt 2018, p. 77). 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 kilometres with the assistance of micro-vehicles, especially the personal bicycle, as a strengthening of the 1.6-kilometre Secondary Area mentioned by Calthorpe (1993, p. 60). These access distances mirror what has been observed in European studies, showing that cycling is generally 1.7 kilometres, 3.2 kilometres for high quality transport networks and 4 kilometres for railway stations (Oort 2020). According to R. Kager, L. Bertolini, and Te Brömmelstroet (2016, p. 208), cycling and PT can have a symbiotic relationship, forming a hybrid and distinct transport mode, which should be reflected in transport planning. TOD can be redefined for the 21st century though game-changing mobility paradigms, such as smart and sustainable mobility (Knowles, Ferbrache, and Nikitas 2020, p. 7).

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