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A Node-Place-Accessibility-Ridership-per-Time Model to Evaluate Micromobility-friendly Transit-Oriented Development Potential in the Hauts-de-France Region

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Abstract

Introduction

This study investigates the development potential of station areas in the Hauts-de-France region through an extended version of the Node-Place Model (NPM), aiming to support micromobility-friendly Transit-Oriented Development (TOD) strategies.

Methodology

We introduce the Node-Place-Accessibility-Ridership-Time (NPART) model, a multi-criteria framework that captures the interplay between public transport provision and the socio-economic, spatial, and functional characteristics of station environments. The model incorporates advanced geostatistical analysis and machine learning tools.

Key Innovations

NPART advances the original NPM framework through four major extensions: (i) a novel application in a polycentric and under-researched region; (ii) the integration of design quality and dynamic ridership data; (iii) a differentiated analysis of walk-and-ride and bike-and-ride station areas; and (iv) the development of a spatial typology based on accessibility and intermodal potential.

Results

Our findings highlight the ability of the model to reveal hidden development opportunities, especially in intermediate station areas. A typology of rail-served zones was established, distinguishing three classes: rail-oriented, adjacent activity, and car-centered areas. Half of the stations fall into the intermediate category, showing promising potential for M-TOD initiatives supported by walking and cycling.

Implications

The NPART model demonstrates strong potential as a planning support tool for regional authorities. By identifying spatial disparities in multimodal accessibility, it provides actionable insights for refining TOD strategies and prioritizing investment. This contribution is particularly relevant in the French context, where quantitative TOD and M-TOD assessments remain rare despite pressing sustainability goals.

Keywords: Transit-Oriented Development; Node-Place Model; Urban Planning; Data Science; Bike-and-ride; Station Areas; Classification; Predictive Modeling; Machine Learning

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—1 Introduction

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Transit-Oriented Development is strongly considered a strategic lever for sustainable urban planning, offering a response to the challenges posed by the car-centric policies that continue to shape urban development (Sebban, 2003, p. 14). Overall, the theoretical and operational framework of TOD provides a robust and relevant foundation for addressing current environmental and socio-economic challenges, both at regional and local scales. The objective is not merely to promote better public transport provision—although this remains a necessary condition—but rather to embed this provision within a broader logic of interaction with territorial structure (Bernier, 2023, p. 9). The primary appeal of a network of TOD neighborhoods does not lie solely in their ability to attract new users to public transport, but also in their capacity to create urban environments that are pleasant to live in and visit, marked by high density and conviviality (Bentayou, 2015, p. 40). In other words, only a deep overhaul of territorial organization will make it possible to “wrench the car from the city” (Ducharme, 2021, p. 184).

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The integration of micromobility within the TOD framework supports a strategic positioning that complements the transit network, thereby enhancing the overall efficiency of the alternative mobility system and contributing to the emergence of a “post-carbon city” (Schultz and Grisot, 2019, p. 2). Driven by the rise of new types of vehicles, by electromobility, and by the development of shared mobility services, micromobility addresses emerging mobility needs that transcend the traditional dichotomy between personal vehicles and mass transit. It emerges as a practical and flexible solution. It is thus important to recall that TOD remains a flexible model, whose application varies according to specific contexts and challenges. Its guiding principles do not constitute a rigid framework, but rather an *ethos*, as emphasized by Calthorpe (1993, p. 11). In this regard, it has been observed that *Transit Metropolises* have evolved over the past decades by incorporating hybrid approaches, combining interventions on both mobility supply and demand (Cervero, 2020, pp. 137–143).

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Bike-and-ride potential is particularly evident within the modal chain of travel, where it strengthens the efficiency of public transport while offering a fluid and adaptable alternative to meet mobility needs (Molino et al., 2015, p. 4). This “hybrid” model—efficient, flexible, and competitive with the private car (R. Wang and Chen Liu, 2013, p. 107)—promotes a diversified “mobility bouquet” that helps break the “car reflex” and supports a transition toward more sustainable modes (Bertolini, 2017, p. 81; 6t-Bureau de recherche, 2019, p. 42). In this perspective, Amar (2016, p. 225) stresses the need to build bridges and synergies between new forms of mobility and emerging urban planning models, an approach developed by J. Lee et al. (2016, p. 979) through their conceptualisation of a *Bicycle-based Transit-Oriented Development*.

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One of the recent evolutions of the TOD explored in this chapter concerns the integration of micromobility, such as electric scooters. These modes complement traditional transport infrastructures by offering effective first- and last-mile solutions. However, knowledge about this form of intermodality—particularly regarding its articulation with urban form—remains limited. This gap is even more pronounced when it comes to the emerging mobilities within this category, whose interactions with TOD are still largely

unexplored. This deficiency is also highlighted by Kang (2020, p. 90), who notes the limited number of studies focusing on the combination between new micromobility services and public transport, despite their widely reported intermodal potential (Richer, 2021). Conducting rigorous empirical studies on these forms of intermodality appears crucial to assess and understand behaviours related to bike-and-ride and scoot-and-ride practices (Bortoli and Christoforou, 2020, p. 13). Based on this assessment, we have chosen to study what we refer to as an *Micromobility-friendly TOD* (Moïnse, 2025b)¹.

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The Node-Place Model (NPM) constitutes both an analytical and operational framework within the broader field of research on TOD. It is based on the assumption that transit infrastructures, when integrated into their urban environment, can foster compact, accessible, and economically dynamic forms of development. This perspective invites us to consider stations as catalysts for local development, depending on their connectivity and the intensity of the activities organized around them. The analytical framework relies on two fundamental axes: the *node* index and the *place* index, whose “balance” ensures the integrated development of station neighborhoods (Bertolini, 1999, p. 202). This systemic approach makes it possible to grasp the complexity of interactions between networks and territories—in other words, the urban integration of stations—on the basis of functional and structural indicators (Albertelli, 2024, p. 25), within a quantitative evaluation framework (Chorus and Bertolini, 2011, p. 47).

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—1 .1 A Methodological Framework to Assess the Coordination Between the Node and the Place

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Understanding the potential of station areas to support sustainable urban development remains a critical challenge in transport and land-use planning. In this context, NPM offer a structured, empirical approach for evaluating the articulation between transport provision and urban form. Their flexibility and replicability have made them popular across diverse contexts, particularly for supporting TOD strategies. This study applies an extended NPM—named Node-Place-Accessibility-Ridership-Time (NPART)—to the Hauts-de-France region, a polycentric and under-studied area in northern France where TOD remains marginal in planning practice. The region’s high car dependency and strong spatial disparities in public transport access present specific challenges that justify the use of a detailed, spatially-explicit model. The goal is to go beyond generic recommendations

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¹In this way, this work is based on the Moïnse (2025b, p. 621)’s PhD thesis that demonstrated that the integration of micromobility into the conceptualization of an M-TOD is not a mere improvement of the TOD, but rather a structural transformation of the rail-oriented urbanism model. By adopting a multi-level approach, his work laid the foundations for an M-TOD, integrating walk-and-ride and intermodal practices, in order to redefine the functional proximities of station neighborhoods. Theoretically, this research follows two main lines of thought: on one hand, it extends the reflections on “network urbanism” (Dupuy, 1991); on the other hand, it contributes to the discussions around the “mobility turn”, repositioning urban planning around renewed proximities (Sheller and Urry, 2006; Sheller and Urry, 2016, p. 8; Randell, 2020, p. 13). In this perspective, stations should no longer be seen as mere functional connection points, but rather as strategic intermodal spaces, located at the interface of the regional urban system. They are accessibility hubs, where cycling plays a fundamental role in the network and expansion of accessible territories. These new mobility practices offer the opportunity to move beyond a segmented, mode-based, and strictly infrastructure-focused view of public transport, by improving the “relational capacity of networks” (Richer, Meissonnier, et al., 2016, p. 15) through a systemic “door-to-door” approach. From this point of view, “altermobility” becomes inseparable from multimodality and intermodality (Vincent-Geslin, 2012, pp. 91–92), fostering a contextualized approach to TOD. A shift in reference frameworks is necessary, moving from an attractiveness logic to a territorial “hospitality” (Talandier, 2023, p. 2), which calls for a reconfiguration of urban strategies based on proximity relationships and quality of life expectations, paving the way for a new way of conceiving the interactions between urbanism and mobility.

and provide operational insights for local planning actors.

The methodology adopted to analyze the station–neighborhood pair is based on the characterization of the *node* and its surrounding *place*, using two composite indicators (Bertolini, 1996, p. 343; Bertolini, 1999, p. 199). The articulation of these two dimensions allows us to address the still underexplored multiscalar interaction between public transport network nodes (*nodes of networks*) and urban places (*places in the city*), as conceptualized by Bertolini (1996, p. 344). This model is primarily understood as an “an analytical tool to help identify the potential for public transport-oriented urban-regional development.” (Bertolini, 1999, pp. 199–201). Based on a feedback-loop model, this analytical framework examines how land use reflects and benefits from the advantages of public transport, and vice versa (Chorus and Bertolini, 2011, p. 47). NPM relies on the idea that improved public transport provision creates favorable conditions for urban development, which in turn increases mobility demand, thereby supporting the development of the mobility system itself (Chorus and Bertolini, 2011, p. 47). Exploring the interrelations among these various factors can then support public policy by promoting TOD and offering a classification that helps guide investment more effectively according to the type of station neighborhood.

NPM is fundamentally designed to address the concept of accessibility, examining the combined effects of transport networks (*network science*) and urban environmental characteristics (*spatial science*)—an approach that echoes the perspectives outlined by Ducruet and Beauguitte (2014, p. 300). Indeed, the model draws on the notion of accessibility² based on the premise that an accessible node also requires an accessible place—and vice versa (Bertolini, 1999, p. 203). This approach strategically positions the public transport station at the heart of the network to which it belongs, emphasizing the mobility opportunities and accessible functions it enables (Amini Pishro, Q. Yang, et al., 2022, p. 3). This vision aligns with the paradigm shift driven by TOD (Banister, 2008, p. 75), promoting a transition from *planning for mobility* to *planning for accessibility*, in which the model is firmly anchored (Caset, Vale, et al., 2018, p. 496). This comparative perspective on accessibility is also supported by Caset, Vale, et al. (2018, p. 521), who argue that the NPM effectively highlights the development potential of stations in terms of urban planning and mobility, by articulating transport networks with territorial dynamics. In doing so, the NPM proves to be a powerful analytical tool for guiding public policies and urban planning strategies by placing accessibility at the core of transport infrastructure planning and urban development.

The analytical framework of the NPM relies primarily on the development of a node typology, structured around the creation of a spatial index designed to evaluate levels of urban development and mobility systems within a region. The classification exercise proposed by the model thus proves to be an effective tool for identifying and addressing barriers to the implementation of TOD (Kamruzzaman et al., 2014, p. 55). Moreover, classifying stations into typological categories simplifies the understanding of territorial configurations, facilitating comparisons and the formulation of cross-cutting strategies that benefit urban planners, transport authorities, and both public and private actors involved in urban production (Kamruzzaman et al., 2014, p. 55). The growing interest in developing “normative TOD typologies” of nodes reflects a desire to provide public policy with a practical tool to inform and guide regional planning (Higgins and Kanaroglou, 2016, p. 307). This typology aims

²It is important to specify that the model focuses specifically on the notion of “relative accessibility” (Dalvi and Martin, 1976, p. 27).

to evaluate a set of station neighborhoods at the regional scale, allowing for comparison between stations that do not share the same territorial development potential nor the same intervention needs (IAU, 2017, p. 2).

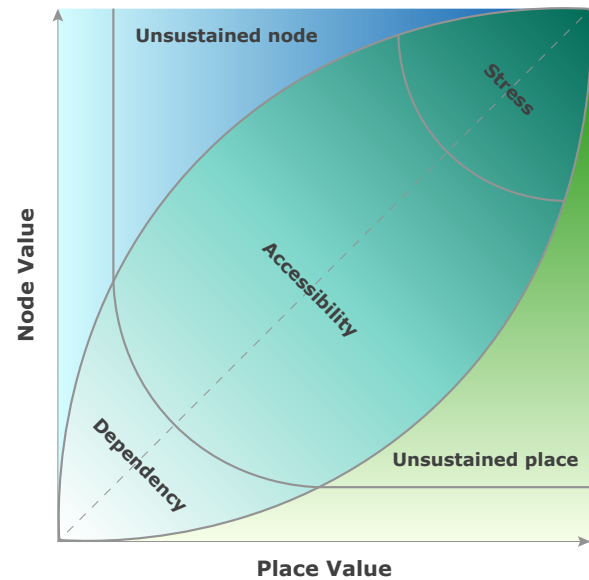


Fig. 1. Two-Dimensional Diagram of the Node–Place Model.

Authors: Moïnse, L’Hostis, Amini Pishro, Cissé, Lehmann, Zhang, Theureau, Adjeroud, Yuetong, and Xiao (2025)

NPM proposes a diagrammatic and two-dimensional framework for classifying public transport nodes based on observed characteristics both at the level of the physical stops and their surrounding environments. In this diagram, initially developed by Bertolini (1996, p. 344), the intensity of land use around the station is represented along the horizontal axis, while the vertical axis measures the accessibility of the node. This schematic allows for the identification of five distinct typological configurations (see Fig. 1, p. 2):

- The “balance zone” lies along the central diagonal of the diagram, indicating a relative equivalence between node-related and place-related values³;
- The “stress zone” describes a context in which both transport provision and the diversity of human activities are intense, generating maximum interactions;
- The “dependence zone” characterizes station neighborhoods where both node and place values are coherent but remain underutilized;
- The “unbalanced node zone” is identified when transport infrastructure and services exceed the surrounding land use;
- The “unbalanced place zone” refers to the opposite situation, where activities outpace the available public transport supply.

A model like the NPM provides an empirical framework to explore diverse urban patterns, challenging the notion of a

³The definition of this zone has been debated in the scientific literature, with L. Yang and Song (2021, p. 243) instead referring to it as an “accessible zone,” combining mobility and urban environment considerations. When classifying stations in Brisbane, Kamruzzaman et al. (2014, p. 55) argued that nodes should be classified independently of the concept of balance. The authors illustrate this point by presenting two stations identified as having “TOD potential,” one of which is balanced while the other is not. Furthermore, according to Reusser et al. (2008, p. 194), if a balance—such as defined by Bertolini (1999, p. 202)—is to be considered, it should be contextualized according to station size, to better account for local specificities.

3.210 “one-size-fits-all” approach—particularly in the
 3.211 implementation of TOD principles. The need to tailor
 3.212 recommendations in order to effectively guide public policies
 3.213 requires a thorough analysis of the territorial context
 3.214 surrounding public transport stations (Zemp et al., 2011,
 3.215 pp. 678–679). Conversely, excessive
 3.216 simplification—neglecting the specific context in which each
 3.217 station operates—can lead to misjudgments, as questioned
 3.218 by Cao et al. (2020, p. 2). The NPM modelling framework
 3.219 emphasizes the local specificities of each site for a given type
 3.220 of TOD, rather than addressing the binary question of general
 3.221 suitability, as argued by Kamruzzaman et al. (2014, p. 55).
 3.222 The model’s ability to adjust and better reflect the complexity
 3.223 of the urban environments in which transport stations are
 3.224 embedded is thus validated by the scientific literature,
 3.225 demonstrating its applicability across a wide range of urban
 3.226 contexts.

and more generally on integrated station area typologies,
 intermodal accessibility, and the role of micromobility in TOD
 frameworks. The review was conducted using major
 academic search engines and bibliographic databases,
 including *Google Scholar*, *Scopus*, *Web of Science*, and
ResearchGate. References were organized using *Zotero* and
 synthesized in an *Excel* matrix, allowing for thematic
 comparison across methodological approaches, indicator
 sets, key findings, and prospective insights.

As part of the literature review conducted on the NPM, we
 identified a total of 79 bibliographic references explicitly
 applying this approach. These contributions were published
 between 1996—the year marking the conceptualization of the
 model—and early 2024, when the literature search was
 carried out. The corpus thus includes 69 journal articles, book
 chapters, and conference proceedings, as well as 5 technical
 reports, and 3 Master and 2 PhD theses. This initial
 chronological analysis confirms a growing interest in the NPM
 starting in 2014, with a particularly marked acceleration
 between 2020 and 2024, during which the number of
 publications doubled compared to the period spanning 1996
 to 2019 (see Fig. 2, p. 3). Moreover, this progression is part
 of a broader trend of increasing studies focusing on TOD
 (Moïnse, 2023, p. 185).

–1 .2 State of the Art of the Node-Place: An Advanced and Gradually Enhanced Model

3.231 Since 2007, the number of studies dedicated to this approach
 3.232 has continued to grow significantly. This trend is highlighted
 3.233 in the systematic literature review published by Ibrahim,
 3.234 Ayad, and Saadallah (2022, p. 383). Over the past two
 3.235 decades, the model has been implemented in a variety of
 3.236 geographical contexts—primarily in East and South Asia as
 3.237 well as Northern Europe (Caset, Blainey, et al., 2020,
 3.238 p. 1)—and has been adapted to different application scales,
 3.239 ranging from railway corridors to regional and even national
 3.240 levels. The NPM has been developed both by academic
 3.241 communities and various planning authorities, thus
 3.242 demonstrating its transcontinental flexibility (Caset, Blainey,
 3.243 et al., 2020, p. 1).

An Underutilized Method in the French Context

3.272 Studies reveal significant disparities in the application of the
 3.273 NPM depending on geographical contexts. Among the 63
 3.274 study areas identified, contributions are concentrated in
 3.275 China (11 references) and the Netherlands (8 references). In
 3.276 contrast, the United States—with only 2 studies—are almost
 3.277 entirely absent from this overview. Asia thus emerges as the
 3.278 leading continent in the development of this quantitative tool
 3.279 (see Fig. 3, p. 4). Furthermore, no scientific publication
 3.280 employing this model has been identified in France, apart
 3.281 from a study conducted by the *Institut Paris Region* (IAU,
 3.282 2017, p. 2).

An Assessment at a Limited Geographical Scale

3.284 Very few studies focus on the application of the NPM in
 3.285 regions that are not part of an international metropolitan
 3.286 area. This observation is consistent with that of Nigro et al.
 3.287 (2019, p. 111), who highlight the scarcity of research
 3.288 addressing the coordination between public transport and
 3.289 land use in low- or medium-density areas, economically
 3.290 declining territories, or those integrated into high-speed rail
 3.291 networks, due to their extensive coverage and associated
 3.292 constraints.

3.293 Another demonstration of the model’s flexibility lies in the
 3.294 diversity of public transport network sizes examined, ranging
 3.295 from 3 to 1,700 stations within a defined study area⁴. This
 3.296 quantitative approach generally covers regional railway or
 3.297 metro systems, with an average of 189 and a median of 63
 3.298 nodes. Indeed, half of the studies applying the NPM to metro
 3.299 systems examine fewer than 52 stops, while those focused
 3.300 on railway networks encompass around 103 nodes.

3.301 The adaptability of the model to various geographical
 3.302 contexts and to different forms of public transport systems
 3.303 illustrates its flexibility and its capacity to evolve in line with
 3.304 both theoretical and empirical developments since its initial
 3.305 formulation. This ongoing enrichment is also reflected in the

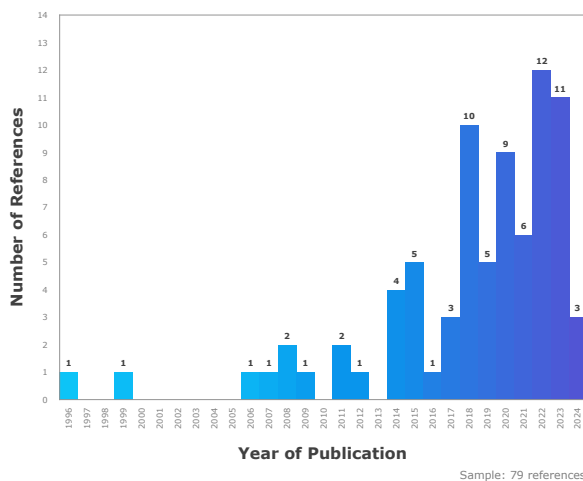


Fig. 2. Chronological Evolution of Studies on the Node-Place Model.

Authors: Moïnse, L’Hostis, Amini Pishro, Cissé, Lehmann, Zhang, Theureau, Adjerroud, Yuetong, and Xiao (2025)

3.244 The literature review was conducted through a targeted
 3.245 search of peer-reviewed articles and planning documents
 3.246 published between 1996 and 2025, focusing on the NPM tool,

⁴It is worth noting that two national-level Swiss studies successfully adapted the model to a network of approximately 1,700 stations (Reusser et al., 2008, p. 194; Zemp et al., 2011, p. 672).

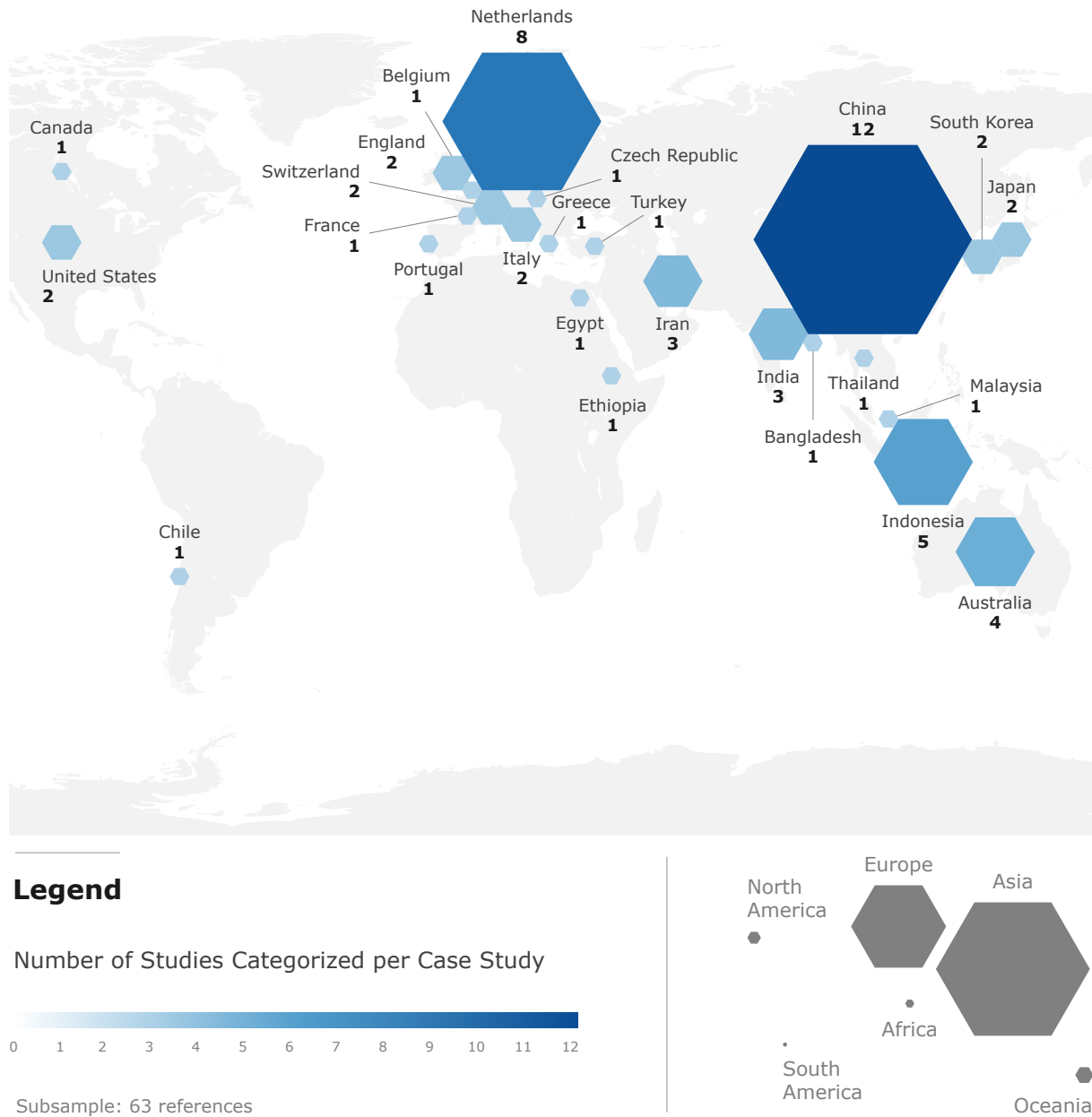


Fig. 3. Geographic Distribution of Studies Employing the Node-Place Model.

Authors: Moïnse, L’Hostis, Amini Pishro, Cissé, Lehmann, Zhang, Theureau, Adjeroud, Yuetong, and Xiao (2025)

4.306 diversity of composite indicators used to define it, as
4.307 presented in the following section.

4.308 **A Model Gaining Precision Through Iterative Refinement**
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4.310 At present, there is no consensus regarding the selection of
4.311 indicators to assess the functionality of nodes and places in
4.312 public transport stations (Chen and Lin, 2015, p. 446;
4.313 Reusser et al., 2008, p. 194). Several adaptations of the
4.314 original NPM model have been introduced (J. B. Lee and

Salih, 2024, p. 2; Lukman and Singh, 2014, p. 20). According
to these authors, the ideal indicators for this model should
meet five key principles:

- Relevance and significance to TOD, by capturing differences across public transport stations;
- Practicality, meaning that the indicator should be measurable and applicable;
- Clarity of interpretation;
- Efficiency, with respect to data availability and measurement method;
- Reproducibility, allowing for general use across contexts

5.326	beyond the original study area.	
5.327	At the early stage of the analytical model's development,	
5.328	Bertolini (1999, pp. 202–203) proposed the integration of a	
5.329	set of synthetic indicators, classified according to the	
5.330	dimensions of the "node" and the "place." For its part, the	
5.331	<i>Transportation Research Board</i> emphasized the need to rely	
5.332	on the most quantifiable aspects of TOD to aggregate them	
5.333	into indices (Transportation Research Board of the National	
5.334	Academies, 2007): the most relevant indicators for	
5.335	calibrating the NPM model are namely public transport	
5.336	ridership, density, quality of public space design, amount of	
5.337	mixed-use structures, pedestrian activity, property value	
5.338	increases, public perception, intermodal connectivity, and	
5.339	parking layout configurations.	
5.340	However, the model was soon enriched with new indicators to	
5.341	address certain limitations identified in the scientific	
5.342	literature. First, M. Zhang and J. B. Lee (2023, pp. 4–5)	
5.343	argued that the current model fails to optimally identify the	
5.344	functional connections between the urban environment and	
5.345	the node. They point to a persistent confusion in	
5.346	distinguishing between a TOD-type environment and a	
5.347	Transit-Adjacent Development (TAD) ⁵ . To address this	
5.348	confusion, Z. Li et al. (2019, p. 271) propose integrating a	
5.349	new dimension related to place connectivity and extending	
5.350	the NPM by adding a third dimension focused on the notion of	
5.351	design.	
5.352	In parallel, research has steered the model towards	
5.353	integrating public transport station ridership—an aspect	
5.354	paradoxically overlooked despite being one of the pillars of	
5.355	TOD. Cao et al. (2020, p. 2) and Amini Pishro, Q. Yang, et al.	
5.356	(2022, p. 3) emphasize that previous studies have rarely	
5.357	considered ridership as a key dimension of the NPM. Yet	
5.358	ridership reflects how passengers actually use transit	
5.359	infrastructure and how this usage is influenced by the quality	
5.360	of the urban environment. The aim of such an extension of	
5.361	the model is therefore to systematically integrate mobility	
5.362	demand, as advocated by Liao and Scheuer (2022, p. 2).	
5.363	Among the 57 studies detailing the parameters defined in the	
5.364	development of their NPM, we identified 49 indicators used at	
5.365	least twice, which we grouped into four dimensions: "public	
5.366	transport service," "urban development," "local accessibility,"	
5.367	and "socio-demographic characteristics of the population."f	
5.368	In total, 421 occurrences of indicators were recorded,	
5.369	corresponding to an average of 9 indicators selected per	
5.370	model. More specifically, 13 variables are included in the first	
5.371	dimension, accounting for 131 occurrences; 12 variables in	
5.372	the second, accounting for 143 occurrences; 15 variables in	
5.373	the third, with 132 occurrences; and 7 variables in the last	
5.374	dimension, totaling 15 occurrences (see Fig. 4, p. 6). This	
5.375	analysis highlights a tripartite distribution of indicators across	
5.376	dimensions related to public transport supply, the degree of	
5.377	urban development, and the quality of public spaces	
5.378	combined with local accessibility. This finding aligns with the	
5.379	analysis of Lyu et al. (2016, p. 42), who identified, based on	
5.380	a systematic literature review, a total of 94 indicators,	
5.381	including 24 focusing on "transport," 53 on "urban	
5.382	development," and 17 on "design."	
5.383	The most frequently used criteria include population density	
5.384	(31 occurrences) and employment density (28 occurrences),	
5.385	functional diversity (28 occurrences), the provision of urban	
5.386	public transport (23 occurrences), service frequency (22	
5.387	occurrences), service coverage in terms of stations accessible	
	within a given time-distance threshold (22 occurrences), car	5.388
	parking availability (22 occurrences), and network	5.389
	connectivity, expressed as the number of directions	5.390
	accessible from a given station (20 occurrences). By	5.391
	examining the intensity of the links between these indicators,	5.392
	we observe that the most frequent connections appear, on	5.393
	the one hand, between population density and, on the other	5.394
	hand, employment density (26 links), functional diversity (23	5.395
	links), car parking availability (21 links), and the presence of	5.396
	urban public transport systems (21 links), as well as between	5.397
	employment density and functional diversity (20 links).	5.398
	Despite the identification of a wide range of models adapted	5.399
	to specific research objectives and geographical contexts,	5.400
	Ibrahim, Ayad, and Saadallah (2022, p. 394) argue that the	5.401
	literature reveals a gap in the quantitative measurement of	5.402
	TOD potential. Furthermore, Olaru et al. (2019, pp. 10–12)	5.403
	recommend integrating mobility solutions related to the first	5.404
	and last mile (FLM), which have received insufficient	5.405
	attention in existing NPM models. They also suggest	5.406
	broadening the scope of analysis to encompass an expanded	5.407
	station area, as mentioned by Z. Li et al. (2019, p. 280). For	5.408
	their part, Robillard et al. (2024, p. 80), as well as Nigro	5.409
	et al. (2019, p. 120), emphasize the importance of	5.410
	distinguishing between the pedestrian and cycling	5.411
	environments around stations, noting that the latter remains	5.412
	largely overlooked in both the model and the broader TOD	5.413
	literature. Following these recommendations, along with	5.414
	those of Motieyan and Mesgari (2018, p. 9), who advocate for	5.415
	the development of a model that incorporates spatiotemporal	5.416
	dynamics, we developed an NPM model enriched by insights	5.417
	from previous studies, while refocusing our core research	5.418
	question. We therefore chose to calculate an extended model,	5.419
	aiming to cover the entire railway network to ensure internal	5.420
	consistency, as recommended by Chorus and Bertolini (2011,	5.421
	p. 58), and at a broad regional scale, in line with the	5.422
	recommendations of Wei and L. Wang (2023, p. 643).	5.423
	The Hauts-de-France region presents a particularly relevant	5.424
	case for applying and extending the NPM. As a structurally	5.425
	polycentric and socio-spatially fragmented territory, it	5.426
	combines dense urban cores such as Lille with a majority of	5.427
	medium-sized cities, peripheral areas, and rural zones, many	5.428
	of which are marked by economic vulnerability and reduced	5.429
	access to services. Public transport provision is	5.430
	heterogeneous, with major disparities in frequency,	5.431
	coverage, and modal integration. In this context, developing	5.432
	a nuanced station area classification is critical to identifying	5.433
	zones with latent redevelopment potential and to reorienting	5.434
	planning priorities. The proposed model addresses this	5.435
	challenge by linking transport accessibility with urban form	5.436
	and ridership patterns, thereby supporting a more strategic	5.437
	approach to TOD. Beyond its regional application, the model	5.438
	offers a transferable framework to inform integrated urban	5.439
	and transport policies in contexts facing similar accessibility	5.440
	and equity concerns.	5.441
	–2 Study Area	5.442
	As presented in this section, the choice of a regional	5.443
	geographic perimeter for our research topic, rather than	5.444
	more narrowly defined intervention levels, is justified by the	5.445
	desire to adopt a systemic view of the interactions between	5.446
	mobility systems and territorial dynamics. This approach	5.447
	provides the opportunity to examine strategic areas	5.448
	associated with railway corridors, as defined by the concept	5.449
	of "Urban Corridors" (L. Liu, 2016, p. 63), while covering a	5.450
	variety of urban contexts. This orientation is also explained	5.451

⁵Using the San Francisco Bay Area as a case study, Renne (2009, p. 3) conceptualizes *Transit-Adjacent Development*, describing real estate or urban development projects located near public transport stations but not designed to maximize ridership. Although adjacent to stations, these projects promote car use through low density, a spatial predominance of car parks, limited access to active modes, and a lack of functional diversity. Unlike TOD, TAD is neither morphologically nor functionally integrated into public transport infrastructures.

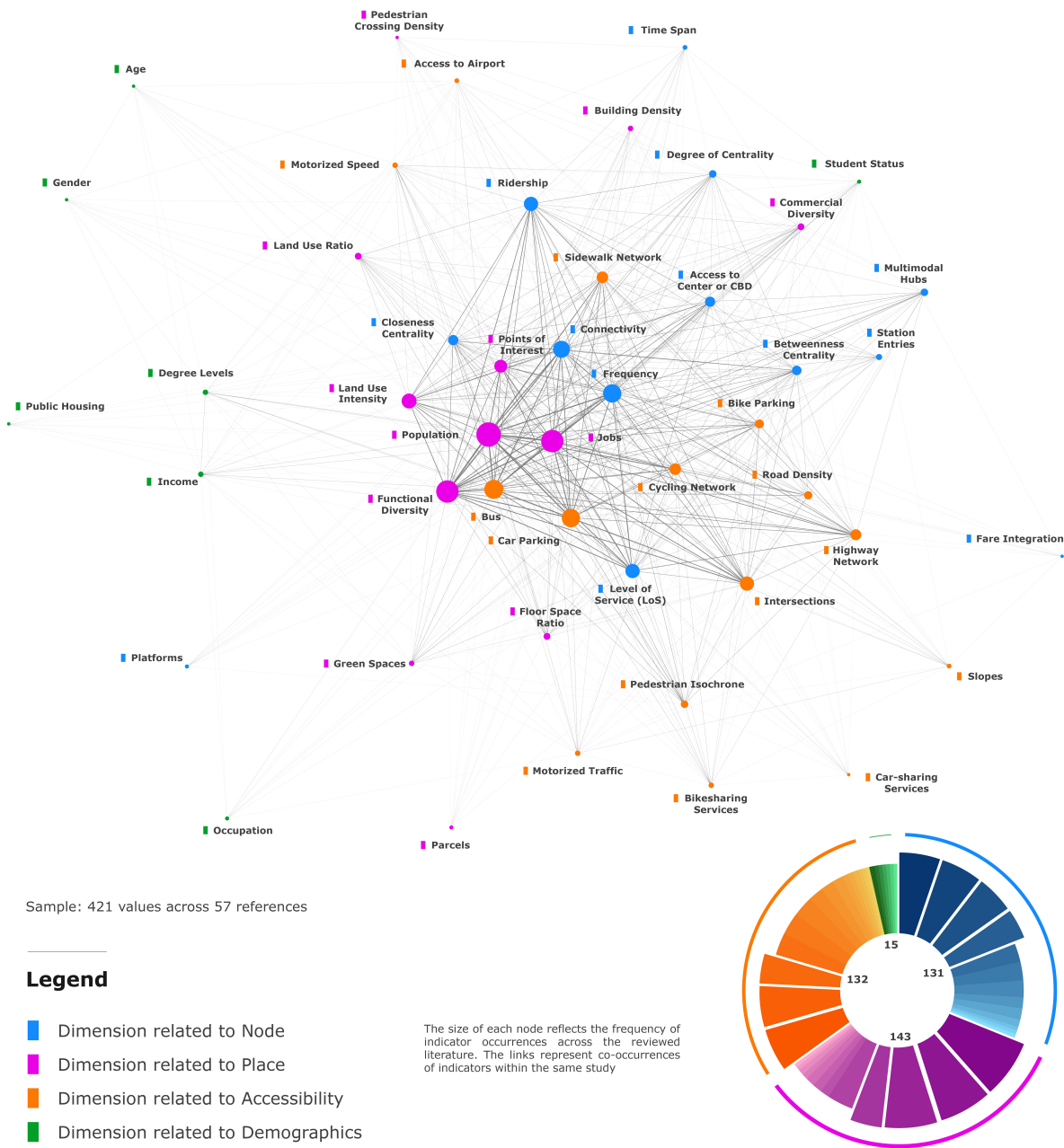


Fig. 4. Network Analysis of the Indicators Selected in Node-Place Models in Literature.

Authors: Moïnse, L'Hostis, Amini Pishro, Cissé, Lehmann, Zhang, Theureau, Adjeroud, Yuetong, and Xiao (2025)

6.452 by the alignment between the regional scale and
 6.453 transportation planning competencies, allowing us to
 6.454 integrate institutional issues and policy levers. With a
 6.455 multiscale perspective, we focus on station districts as
 6.456 spatial units, linked with the scales of corridors and the rail
 6.457 network, and embedded within a regional framework. The
 6.458 Hauts-de-France region, resulting from a recent
 6.459 administrative merger⁶, offers a polycentric laboratory suited

to studying the applicability of a revisited TOD. 6.460

In France, the region is an appropriate level for deploying a 6.461
 TOD strategy, due to its diverse competencies, reinforced by 6.462
 a legal framework for transport and planning. Its primary 6.463
 virtue is to create a project territory by uniting, within a 6.464
 common reference framework, initiatives that were 6.465

⁶Following the law of January 16, 2015, regarding the delineation of regions, regional and departmental elections, and the modification of the electoral calendar, the Nord-

Pas-de-Calais Picardie region, now known as Hauts-de-France, was born from the merger of the former regions of Nord-Pas-de-Calais and Picardie. The city of Lille became the regional capital, where the regional council is seated, by a decree from the Council of State issued on September 28, 2016.

previously conducted separately. For example, the “contracts of axis” allow for overcoming the “counter” logic that has long characterized the relationships between regions and municipalities (Bentayou et al., 2015, p. 118). It is since the enactment of the first legislative instrument positioning the region at the center of transport policies, the *Loi d’orientation des transports intérieurs* (LOTI)⁷ which established the principle of shared responsibilities between the state and local authorities. But it is especially the *Loi relative à la solidarité et au renouvellement urbains* (SRU) of December 13, 2000⁸, which enshrines the region as the “organizer of collective public transport of general interest”, excluding Île-de-France and Corsica (Commission nationale du débat public, 2024). Act III of decentralization is materialized by the *loi de modernisation de l’action publique territoriale et d’affirmation des métropoles* (MAPTAM) of January 27, 2014, which includes the *loi portant sur la Nouvelle Organisation Territoriale de la République* (NOTRe) of August 7, 2015⁹ which establishes the region as the “leader of intermodality and complementarity between transport modes” (GART, 2024). Recently, its intervention framework has been reinforced by the *loi d’orientation des mobilités* (LOM) of December 24, 2019¹⁰ which makes it responsible for strategic planning and coordination of intermodality and spatial planning policies (Barone and Thébert, 2020; Sajous et al., 2020, p. 174). Thus, the region, with its integrated approach, benefits from considerable decision-making power, significant investment resources, and a long-term strategic vision. We can even assert that, supported by a territorial narrative, transport policies at this political level help legitimize their recent merger (Revelli, 2019, pp. 260, 575–577).

⁷ Following an initial experiment on the regionalization of railways conducted in the former Nord-Pas-de-Calais region (as part as Hauts-de-France region nowadays) in 1978 (Chauvineau, 2001, pp. 1–3; Passavant-Guion, 2016, p. 424), the LOTI of December 30, 1982, initiated a decentralization process by establishing a new distribution of responsibilities between the state and local authorities. This law opened the door to the regionalization of “rail links of regional interest” through agreements between the regions and the SNCF (Deimon, 2024, p. 4). The beginning of this long process, initiated as early as 1974 with regional transport plans, culminated in the launch of regional railways (TER networks) in 1987. However, the decentralization of rail services remains optional (Commission nationale du débat public, 2024). Following the enactment of the *loi d’orientation pour l’aménagement et le développement du territoire* (LOADT) of February 4, 1995, later adopted and modified by the *d’orientation pour l’aménagement et le développement durable du territoire* (LOADDT) of June 25, 1999, seven regions, including Nord-Pas-de-Calais, applied starting in 1997 to experiment with the management of regional rail transport (Burlando and Guihéry, 2004, p. 132).

⁸ The generalization of railway regionalization was scheduled for 2002, in light of the provisions applied by the SRU and the publication of the decree on “transfer of competencies in regional collective transport” on November 27, 2001 (Burlando and Guihéry, 2004, p. 132). The law then planned the development of cooperation between the region and urban authorities to organize intermodality: the creation of public transport partner committees thus aims to improve the continuity between the rail system and urban transport systems. It is within this framework that the regional level tends to assert itself as the leading authority on “intermodal transport and the complementarity between transport modes” (Chauvineau, 2001, pp. 1–18).

⁹ With the MAPTAM, the regional level is tasked with coordinating its actions with those of other mobility organizing authorities while defining general rules related to intermodality between transit services, as part of the *schéma régional de l’intermodalité* (SRI) (GART, 2024). Furthermore, the law redraws the boundaries of certain French regions, including Nord-Pas-de-Calais and Picardie, by merging them. These changes present an opportunity for the newly merged regions to rethink their transport systems offerings and policies within their expanded territories (Cerema, 2017). Simultaneously, the NOTRe law strengthens this competency transfer aspect by creating a planning tool at the regional level, the *schéma régional d’aménagement, de développement durable et d’égalité des territoires* (SRADDET).

¹⁰ Forty years after the foundational text organizing public transport services (LOTI), the LOM seeks to establish a distribution of responsibilities between the 1,200 local authorities, called AOM, and the 12 regional *autorité organisatrice de la mobilité* (AOM) responsible for TER and intercity buses (Richer, Pitout, et al., 2024, p. 29). In the decentralization movement, the region remains a relatively young actor whose political weight is steadily increasing as territorial reforms grant it new competencies: today, the region is becoming “the all-encompassing actor in mobility” (Richer, Pitout, et al., 2024, p. 34). Thus, the LOM promotes a “right to mobility”, referring to the previous “right to transport” established by the LOTI, as it aims to reduce “the strict boundary, once clear, between individual mobility and public transport” (Izembard, 2020, p. 283).

—2 .1 Defining the Geographic Scope: The Hauts-de-France Region

Located in the northern part of France, the Hauts-de-France region spans approximately 32,000 square kilometers and is home to 6,000,000 inhabitants, representing 9.2% of the metropolitan population according to the latest population census (see Fig. 5, p. 8). The population is distributed across five departments: Aisne, Nord, Oise, Pas-de-Calais, and Somme. This makes it the fifth most populous region in the country, with the Nord department alone concentrating nearly half of the regional population, thus making it the most populous department in France. The Lille metropolitan area, with a population of 1,520,000, ranks fourth nationally. The second largest metropolitan area in the region is that of Paris, on the Picardy side, with a population of 513,000 inhabitants (Leroux and Tieng-Majcherczak, 2023).

The Hauts-de-France region is characterized by dense urbanization, supported by a network of key hubs and a fabric of medium-sized and small towns. Firstly, the European Metropolis of Lille is marked by “a relatively *balanced quadracentric form*” in terms of urban structures (Mignot et al., 2007, p. 37), although the “Capital of French Flanders” is gradually asserting itself under the effects of ongoing metropolization. In addition to major urban areas such as Lille, Amiens, Arras, Calais, and Dunkirk, the region is structured by a conurbation forming a dense industrial arc, a legacy of its mining past. This “banana-shaped” area (Mission Bassin Minier Nord-Pas-de-Calais, 2024) stretches from Béthune to Valenciennes, passing through Lens, Hénin-Beaumont, and Douai. Although each of these cities has fewer than 50,000 inhabitants, their organization into a dense multipolar urban network brings together a population approaching that of Lille agglomeration, nearly one million residents. A comparable urban organization, though on a smaller scale, can be found in the Oise Valley, between Creil and Compiègne, considered an extension of the Parisian suburbs (see Fig. 5, p. 8).

The Lille metropolitan area appears to have the capacity to transmit its growth to surrounding territories through a high degree of polarization. It occupies a central position in a polycentric regional system where secondary hubs act as relays for Lille and Parisian activity, relying on cross-functional relationships that structure the territorial network (ADULM and Cattani, 2016, pp. 43, 46). The regional objectives are thus oriented towards a balanced functional specialization of the territory, promoting a logic that is both multifunctional and multipolar, in order to surpass the consolidation of the monocentric character of metropolises (Lo Feudo, 2014, p. 144). The significant regional endowment in railway infrastructure constitutes a key resource for fostering a truly multicentric territorial functioning. However, despite the density of the regional network, mobility practices remain heavily reliant on the automobile. Indeed, 77% of the trips made by employed individuals are done by private car, compared to only 4% by public transport. This proportion even rises to 83% in the Bassin Minier, despite its well-developed railway services (Michel and Werquin, 2016). To better understand the underlying reasons for automobile dependence (Motte-Baumvol et al., 2014, p. 74; Gallez, 2018, p. 4), despite the density of the railway network, we will delve into the mobility and urban planning issues in the Hauts-de-France region, closely tied to our research topic.

The railway network in Hauts-de-France is one of the most dense in France, representing nearly 10% of the national rail network, with approximately 2,900 kilometers of track (Région Hauts-de-France, 2024a, p. 11; CESER

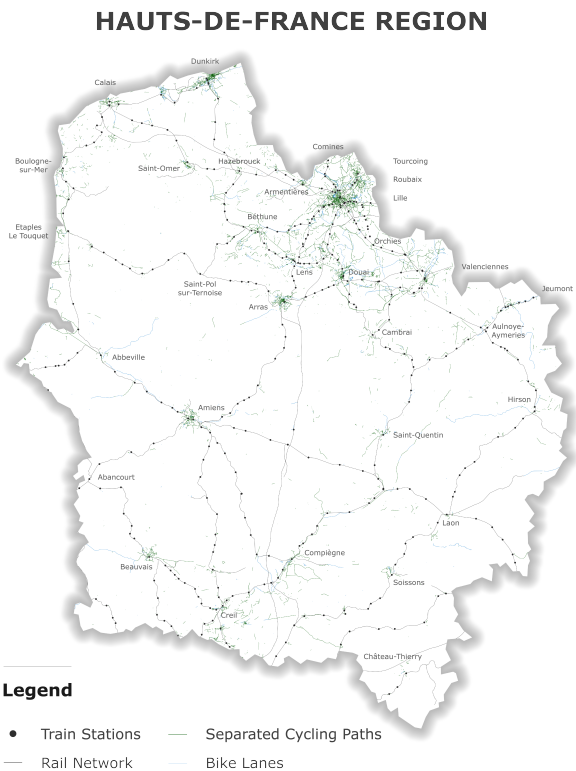


Fig. 5. Mapping of the Rail and Cycling Networks in the Hauts-de-France Region.

Authors: Moïnse, L’Hostis, Amini Pishro, Cissé, Lehmann, Zhang, Theureaux, Adjeroud, Yuetong, and Xiao (2025)

8.565 Hauts-de-France, 2021, p. 51). This extensive network
 8.566 includes 363 stations and stops, as well as coverage of 74
 8.567 commercial commuting lines (SNCF Réseau, 2024). This
 8.568 network is further enhanced by high-speed lines, with
 8.569 sections crossing the region, connecting Paris to Lille and
 8.570 extending directly to Brussels, London via the Channel
 8.571 Tunnel, and other French and European destinations.

8.572 Today, the density of the regional rail network allows 96% of
 8.573 the regional population to be within 10 kilometers of a rail
 8.574 stop, although the 15 largest regional stations account for
 8.575 55% of the network’s ridership (CESER Hauts-de-France,
 8.576 2021, p. 58). However, this picture of a region well-equipped
 8.577 with rail infrastructure contrasts with observed mobility
 8.578 patterns that indicate intensive car usage. Today, 10,400,000
 8.579 daily car trips, of which 5,200,000 are characterized by
 8.580 spatial distances of less than 5 kilometers, with an average
 8.581 vehicle occupancy rate of 1.1 (Région Hauts-de-France,
 8.582 2024b, p. 171). However, only 150,000 motorized trips are
 8.583 potentially transferable to train or bus, regardless of the level
 8.584 of service within the regional territory, emphasizing that the
 8.585 monomodal solution of the train alone is insufficient
 8.586 (Observatoire des territoires, 2019, pp. 7–8). This finding
 8.587 calls for the consideration of intermodal alternatives and a
 8.588 reevaluation of territorial organization.

8.589 Cycling remains marginal in the Hauts-de-France region,
 8.590 accounting for only 2.2% of all trips. This proportion varies
 8.591 by department, ranging from 1.1% in the Oise to 2.7% in the
 8.592 Nord (Insee, 2023). This regard, the region boasts a cycling
 8.593 network of over 3,107 kilometers in 2022, far from the

66,000 kilometers of roads in the administrative area. These
 8.594 dedicated facilities mainly consist in bike routes extending
 8.595 over 1,562 kilometers, 22% of which have been completed
 8.596 so far, in line with the objectives set in its 2024-2028 Bicycle
 8.597 Plan, with 57% being on dedicated lanes, totaling 861
 8.598 kilometers of bike paths (Vélo & Territoires, 2023). In
 8.599 comparison, France as a whole had over 76,500 kilometers of
 8.600 cycling infrastructure in the same year, including 37,000
 8.601 kilometers of bike lanes, 23,000 kilometers of greenways,
 8.602 and 15,000 kilometers of cycle tracks (Geovelo, 2024).
 8.603

In parallel with the individual use of bicycles, several areas in
 8.604 the Hauts-de-France region offer bikesharing systems. In
 8.605 2024, five municipal areas benefit from these mobility
 8.606 services: 20 communes around Lille with 260 stations¹¹, 5
 8.607 communes around Calais with 41 stations, the city of Amiens
 8.608 equipped with 25 stations, 5 communes around Soissons with
 8.609 15 stations, and the city of Laon with 11 stations (Région
 8.610 Hauts-de-France, 2023, p. 41). Additionally, 44 communes in
 8.611 the Lille agglomeration offer an electric-assisted bikesharing
 8.612 service, while 20 of these communes also provide e-scooter
 8.613 schemes, mainly operated by Lime, which manages a fleet of
 8.614 approximately 2,000 vehicles. Similarly, in the Valenciennois
 8.615 agglomeration, the local start-up Urban Labs Technology
 8.616 provides 200 shared e-scooters under the Jerico brand.
 8.617

8.618 — 2 .2 Representing Station Areas 8.619 Accessible by Walking and 8.620 Cycling

The interactions between urban fabric and the deployment of
 8.621 modal chains are explored from the perspective of spatial
 8.622 references associated with the *station-system*, understood
 8.623 through the concept of *station neighborhoods* nested within
 8.624 different patterns and scales (Menerault and Barré, 2001,
 8.625 p. 14). Defining and delimiting what constitutes a station
 8.626 area, within the context of its urban integration, represents a
 8.627 methodological milestone in this research. Stations, both
 8.628 *junction nodes* and *threshold spaces* (Serviant, 2015, p. 40),
 8.629 require special attention to outline the contours of their
 8.630 spatial footprint in relation to our research topic. The
 8.631 established boundaries serve as the foundation for
 8.632 constructing our empirical studies. Therefore, in this section,
 8.633 we focus on the parameters influencing the size and shape of
 8.634 station neighborhoods, as well as the nature of the data
 8.635 utilized (Forsch and Haunert, 2023, p. 383).
 8.636

8.637 Station Catchment Areas

The first challenge guiding the spatialization of the station
 8.638 neighborhood network in the region focuses on their size. By
 8.639 “station neighborhoods,” we refer here to two configurations:
 8.640 walk-and-ride for the pedestrian level (*P*) and bike-and-ride
 8.641 for the cycling level (*C*). These areas are further
 8.642 differentiated based on their type of transit service. We find
 8.643 pedestrian and cycling station neighborhoods around
 8.644 multimodal exchange hubs, high-speed rail stations, and
 8.645 regional commuting stops. Additionally, to prevent excessive
 8.646 overlaps, especially in areas where the distances between
 8.647 stations are short, we have defined a theoretical maximum
 8.648 radius for the station neighborhoods, using a geometric
 8.649

¹¹ *V’Lille* system, launched in 2011, is a major component of the cycling policy in the Lille metropolitan area, with 2,600 public bicycles. It has seen a 20% increase in usage over the past 10 years (Métropole Européenne de Lille, 2021, p. 1). With a core of 15,700 annual subscribers and 302,000 occasional users in 2023, the service averages 9,700 rentals per weekday (Bergès, 2023). This corresponds to a usage rate of 4 rentals per bike per day, a figure that rises to 6 daily uses in Lille, but drops to 0.5 in Roubaix and Tourcoing.

9.650 tessellation diagram that confines each area of influence
 9.651 within a cell specifically associated with it. This work on the
 9.652 spatial identification of station catchment areas builds on our
 9.653 previous scientific publication, based on the same research
 9.654 field, namely the Hauts-de-France region, with the
 9.655 determination of pedestrian and cycling zones (Moïnse and
 9.656 L'Hostis, 2024, pp. 3–9).

9.657 To determine the size of the station districts, we chose to use
 9.658 data from a questionnaire distributed to users, with the aim
 9.659 of analyzing their relationship to spatial-temporal distances.
 9.660 Our approach is thus user-centered, considering that the
 9.661 relevant geographical scale of the station influence areas is
 9.662 directly linked to the social acceptability of the users. This
 9.663 acceptability, in turn, results from observed mobility
 9.664 practices. The exercise consists in identifying the effective
 9.665 range of walk-and-ride and bike-and-ride, within the context
 9.666 of the Hauts-de-France region, in order to define station
 9.667 areas whose size is adjusted based on territorial realities and
 9.668 existing practices (Moïnse and L'Hostis, 2024, pp. 3–9). To
 9.669 do this, we relied on a commonly used threshold to measure
 9.670 the socially acceptable distance for access and egress stages
 9.671 (Wenxiang Li et al., 2021, p. 5): the 75th percentile and the
 9.672 85th percentile of the cumulative distribution of traveled
 9.673 distances, for walking and cycling respectively (J. Lee et al.,
 9.674 2016, p. 982)¹². This methodology allows the calibration of
 9.675 station area sizes based on empirical criteria derived from
 9.676 users' practices and perceptions, thus ensuring a better
 9.677 match between the defined areas and actual usage.

9.678 While the first distinction made between station areas is
 9.679 based on the scope of the transfer modes, we also took care
 9.680 to differentiate the catchment areas of the various public
 9.681 transportation systems. This approach aims to refine the
 9.682 precision of the delineation of these station neighborhoods,
 9.683 as transfer distances to the high-speed rail network (HSR)
 9.684 tend to be broader than those of conventional commuting rail
 9.685 networks. Hasiak and Bodard (2016, pp. 5–6) inquire about
 9.686 the factors influencing the geographic forms of periurban
 9.687 station areas in the Hauts-de-France region. The authors
 9.688 conclude that the area of these zones expands as rail
 9.689 frequency, PnR capacity, and distance to other stations
 9.690 increase. Thus, most traditional rail systems serve shorter
 9.691 distances, with influence zones typically limited to a regional
 9.692 or departmental territory. In contrast, HSR greatly extends
 9.693 the influence areas of the stations it serves. These stations
 9.694 become true regional, national, and even international hubs,
 9.695 attracting passenger flows over much larger distances.
 9.696 Taking these differences into account, the methodology
 9.697 allows for a more refined definition of station areas based on
 9.698 the actual reach of the transportation systems involved.

9.699 Furthermore, this approach incorporates an additional goal:
 9.700 the consideration of stations that, beyond being simple
 9.701 railway stops, benefit from enhanced connectivity through
 9.702 urban public transport networks on rail, such as metro and
 9.703 tramway systems. These complementary infrastructures tend
 9.704 to improve the accessibility and attractiveness of these
 9.705 stations, justifying a differentiated analysis of their influence
 9.706 areas. Aware that there is no standardized method for
 9.707 generating multimodal isochrones (Krismer, 2017, p. 5), we
 9.708 collected and utilized data from the GTFS format of the
 9.709 various public transport networks in the region, excluding bus

9.710 networks. This choice was motivated by algorithmic
 9.711 performance considerations, as integrating bus networks
 9.712 could significantly slow down the calculations. Our
 9.713 multimodal accessibility analysis is based on travel time,
 9.714 adopting a time propagation method. This method
 9.715 propagates travel times from a starting point to determine
 9.716 the zones that can be reached within a given time interval¹³.

9.717 To implement this approach, we used the multimodal buffer
 9.718 and isochrone generation tool from the open-source project
 9.719 *OpenTripPlanner* (OTP). This tool allows for the calculation of
 9.720 accessible areas from a given point, taking into account
 9.721 different modes of transport as well as possible combinations
 9.722 of these modes (Krismer, 2017, p. 15), with several
 9.723 adjustable parameters. By utilizing the *OTP Analyst* module,
 9.724 we were able to generate isochrones representing the station
 9.725 areas based on their multimodal connections. In total, 5
 9.726 stations in the region had their influence areas extended to
 9.727 encompass the entire multimodal approach due to their
 9.728 immediate proximity to metro or tramway stations:
 9.729 *Euraflandres*¹⁴, Lille CHR, Roubaix, Tourcoing, and
 9.730 Valenciennes. These multimodal exchange hubs were
 9.731 designated as *multimodal hubs*. In parallel, 13 other stations
 9.732 belong to a second category, associated with a HSR service,
 9.733 while a third category includes a total of 300 stations
 9.734 exclusively served by commuting rail.

9.735 Given the large number of nodes we are studying within the
 9.736 regional railway network, a legitimate concern arises
 9.737 regarding our approach to extending the walking and cycling
 9.738 catchment areas for the stations: the potential for territorial
 9.739 redundancy in spatial analyses, resulting from an excessive
 9.740 overlap of the catchment areas, especially in certain urban
 9.741 areas characterized by a high density of stations. While, in
 9.742 the case of a rail system, the inter-station distance is
 9.743 typically significant, the expansion of the catchment areas
 9.744 through the integration of cycling raises the legitimate
 9.745 question of an overabundance of overlapping areas. This
 9.746 problem is not only a matter of aesthetics or cartographic
 9.747 clarity but also concerns the risk of excessive analytical
 9.748 repetition of the same territorial configurations. In response
 9.749 to this issue, we propose combining the definition of the
 9.750 catchment areas—modulating their size based on the mode
 9.751 of transfer and the type of rail service—with a partition into
 9.752 polygonal patterns used to delimit each catchment area.

9.753 Assuming that intermodal cyclists, entering or leaving a train
 9.754 station, tend to choose the shortest path (Héran, 2009,
 9.755 p. 116), based on the results of our survey (Moïnse and
 9.756 L'Hostis, 2024, p. 8), we opted for a partitioning of the
 9.757 regional rail network to define the areas that are theoretically
 9.758 closest, from a geometric perspective, to each station. This
 9.759 division, based on a Euclidean plane, allows us to model and
 9.760 visualize the theoretical maximum coverage of each station's
 9.761 catchment area (Moïnse and L'Hostis, 2024, p. 8),
 9.762 represented by a cell derived from a standard Voronoi
 9.763 diagram (Mota et al., 2014, p. 479). This approach, which

¹³The time propagation method is used to determine the areas that can be accessed from a given point within a certain time, from a multimodal perspective. Starting from a point called the "source," various travel times are calculated based on the constraints of each mode of transportation, such as schedules, frequency, or speed. The modeling of the allotted time budget also considers transfer breaks, such as transfer and waiting times. In this way, the time propagation approach provides influence areas that are adapted to real-world conditions.

¹⁴We define the *Euraflandres* hub as a merger between the Lille Flandres and Lille Europe stations. These two hubs are located 500 meters apart from each other, thus forming a true "station orchestra" (Le Bot, 2019, pp. 415–416). This is a remarkable example of station-to-station cooperation, and this configuration could be described as the "Flandres hub," representing the "ultimate" evolution of metropolitan station expansion, beyond the mere scale of passenger buildings. This "hybrid" territorial configuration serves as a showcase for the agglomeration and the region (Heddebaut and Di Ciommo, 2018, p. 2). This configuration, described as having "international dimensions" (Bertolini, 1996, p. 334) is part of a larger urban project, including the pedestrianization of Place des Buisseries and the enhancement of Place François Mitterrand, now grouped under the name *Euraflandres*. This designation aims to characterize the functional and spatial links between the Lille Flandres and Lille Europe exchange hubs and the Euraille CBD (ADULM, 2017, p. 71).

¹²The scientific literature seems to agree on the threshold for the social acceptability of distances, placing this criterion at the 75th percentile for walking and at the 85th percentile for non-motorized and motorized vehicles. According to Zuo et al. (2018, p. 5), the distances to public transport stops deemed acceptable by users correspond to this threshold in relation to the intermodal use of bicycles. J. Lee et al. (2016, p. 982) argue that the influence of public transport nodes for cyclists should be considered from the 85th percentile of the observed distances, asserting that cycling behaviors are closer to those of car use than walking, traditionally evaluated at the 75th percentile (O'Sullivan and Morrall, 1996, p. 23). Many studies on M-TOD refer to this threshold to calibrate their analyses (Hu et al., 2022, p. 4; Wei Li and Joh, 2017, p. 3491; Ma et al., 2018, p. 64; Rabaud and Richer, 2022, p. 62; Moïnse and L'Hostis, 2024, p. 7).

10.764 avoids any form of overlap, is based on the assumption that
 10.765 each cell corresponds to a zone where all points are closer to
 10.766 the associated station than to any other, regardless of the
 10.767 hierarchical structure of the rail network (Lebedeva et al.,
 10.768 2018, p. 429).

10.769 Morphology and Boundaries of Station Neighborhoods

10.770 Even today, most NPM and more largely TOD
 10.771 studies—whether academic or operational—rely on the use of
 10.772 theoretical circles (buffers) to represent the catchment areas
 10.773 of public transport stations. These buffer zones are typically
 10.774 drawn as circles at a fixed distance, either spatial or
 10.775 temporal, around transport nodes, without taking into
 10.776 account surrounding networks or geographical obstacles. This
 10.777 method has the advantage of being simple to produce and
 10.778 easy to interpret, as it requires neither complex data nor
 10.779 advanced computations. However, this technique for
 10.780 delineating station neighborhoods faces major limitations. By
 10.781 relying on straight-line distance representations, it disregards
 10.782 both transport networks and the geographical constraints of
 10.783 the physical environment. As a result, buffer zones fail to
 10.784 reflect the actual accessibility of infrastructures. Such
 10.785 simplification may lead to inaccurate conclusions, especially
 10.786 in contexts where the configuration of networks and
 10.787 territorial features plays a decisive role in defining station
 10.788 neighborhoods.

10.789 From this perspective, isochrones are often considered a
 10.790 more realistic representation of accessible areas. Unlike
 10.791 buffer zones, they delineate the spaces that can be reached
 10.792 within a given time frame, from or to a station, while
 10.793 accounting for infrastructures and modes of transportation.
 10.794 By incorporating the road network and the specific
 10.795 characteristics of various modes of travel—primarily their
 10.796 range, speed, and the types of areas they are allowed to
 10.797 traverse—isochores offer a more accurate depiction of
 10.798 accessibility. Thanks to their ability to reflect actual spatial
 10.799 dynamics, isochrone modelling constitutes a precise tool for
 10.800 evaluating effectively accessible areas.

10.801 We favored the combined use of buffer zones and isochrones.
 10.802 Their integration within spatial analysis provides a
 10.803 comprehensive perspective on accessibility. By
 10.804 superimposing isochrones onto buffer zones, it becomes
 10.805 possible to assess accessibility differentials—that is, the gap
 10.806 between actual and theoretical accessibility (see Fig. 6,
 10.807 p. 11). This comparison also enables the calculation of a
 10.808 service coverage rate, which expresses the ratio between the
 10.809 area that is actually accessible and the area reachable in a
 10.810 straight line (Héran and Pouillaude, 2009, p. 13). The
 10.811 cartographic diagnosis of these various representations of
 10.812 station neighborhoods makes it possible to systematically
 10.813 identify the obstacles encountered by travellers.

10.814 Although the advantages of isochrones are widely
 10.815 acknowledged in research practices, their outputs often vary
 10.816 significantly and frequently lack transparency regarding the
 10.817 underlying modelling parameters. This opacity can be
 10.818 attributed to the fact that most isochrones are generated
 10.819 using online platforms that restrict control over modelling
 10.820 settings. In response to this issue, we developed our own
 10.821 station neighborhood delineations using a custom-made
 10.822 script, allowing us to define geographic boundaries tailored to
 10.823 our specific research objectives.

10.824 A thorough reflection is required to establish appropriate
 10.825 cartographic representation strategies for accessibility areas.
 10.826 This approach is not merely a matter of aesthetics or
 10.827 communication; it also aims to ensure both conceptual and
 10.828 visual control over the geographical foundations underpinning

the entire analysis. As a first step, it is essential to clarify the
 concepts involved, notably by identifying the parameters that
 influence the structure of these representations and the
 analytical interpretations that follow. Given the wide range of
 available tools for generating buffers and isochrones, we
 chose to carry out our analysis using the *Python*
 programming language. This decision is based not only on the
 richness of its available libraries, but also on the transparency
 afforded by this open-source environment, which allows for
 complete control over the defined parameters.

An initial parameter that challenges the geographical
 construction of station catchment areas lies in the
 directionality of flows. At first glance, it may seem intuitive to
 assume that, regardless of the flow direction—whether the
 trip involves approaching the station (inbound) or departing
 from it (outbound)—the station neighborhood would retain a
 similar size and shape. However, this assumption tends to
 overlook two key dimensions: road network connectivity,
 which is especially critical for cycling and governed by traffic
 regulations, and temporality. Indeed, an isochrone drawn
 toward or from a station does not necessarily hold the same
 validity depending on factors such as service frequency,
 operating hours, or served directions. In the context of our
 empirical material, we chose to consider that, by default,
 both buffers and atemporal isochrones are designed to
 analyze areas accessible *to* the station, rather than *from* it,
 which is more commonly the case. This choice is justified
 given that cycling, when used in connection with rail service,
 is far more frequently employed for access than for egress.

The issue of cartographic representation of
 isochrones—whether from an analytical or communicative
 perspective—also involves choices regarding which
 structuring elements should be emphasized. Should the focus
 be on a visual representation of the accessible versus
 non-accessible surface areas? Or would it be more relevant to
 highlight the street network, which materializes the
 connections used as the basis for isochrone computation?
 Another option would be to emphasize the built environment
 or the Points of Interest (POIs), which ultimately represent
 the destinations individuals seek to reach. These cartographic
 choices are not neutral, as they shape both the interpretation
 of the data and the way the results are communicated to
 various target audiences¹⁵.

From this perspective, we chose to combine the various
 forms of cartographic representation explored throughout our
 work by producing hybrid isochrones: primarily
 surface-based, yet whose shape is determined first and
 foremost by the street network, while also being influenced
 by the surrounding built environment (see Fig. 7, p. 12). This
 technique enabled us to generate cartographic
 representations with significantly more accurate contours
 than the approximations often observed in traditional
 isochrone outputs. In this approach, we relied on the
 innovative method developed by Butts (2017), based on the
 OSMnx tool, specifically designed for modelling street
 networks (Boeing, 2017, p. 132). This method aligns with the
 principle of an isochrone map built on the street network
 (*lines*), following a graph-based logic (*edges*), while
 incorporating a linear buffer zone around each accessible
 segment and intersection (*buffers*). This process thus makes
 it possible to integrate urban elements adjacent to the street

¹⁵ From a comparative perspective, isochrones traditionally represented as accessible surface areas offer the advantage of high visual clarity, generally require a limited amount of geographic data, and are well suited for broad-scale analyses. In contrast, representations based on the street network—although more precise—are geared toward more specific uses such as navigation, which are less relevant to our research objectives. Finally, representations focused on the built environment or on accessible facilities and services within a given area have the merit of being more user-centered. They are particularly appropriate for urban analyses, especially those concerning urban form and accessibility to targeted services. However, this type of cartographic representation is more demanding in terms of data requirements and involves higher mapping costs.

Pedestrian (PB) and Cycling Buffers (CB)

Pedestrian (PI) and Cycling Isochrones (CI)

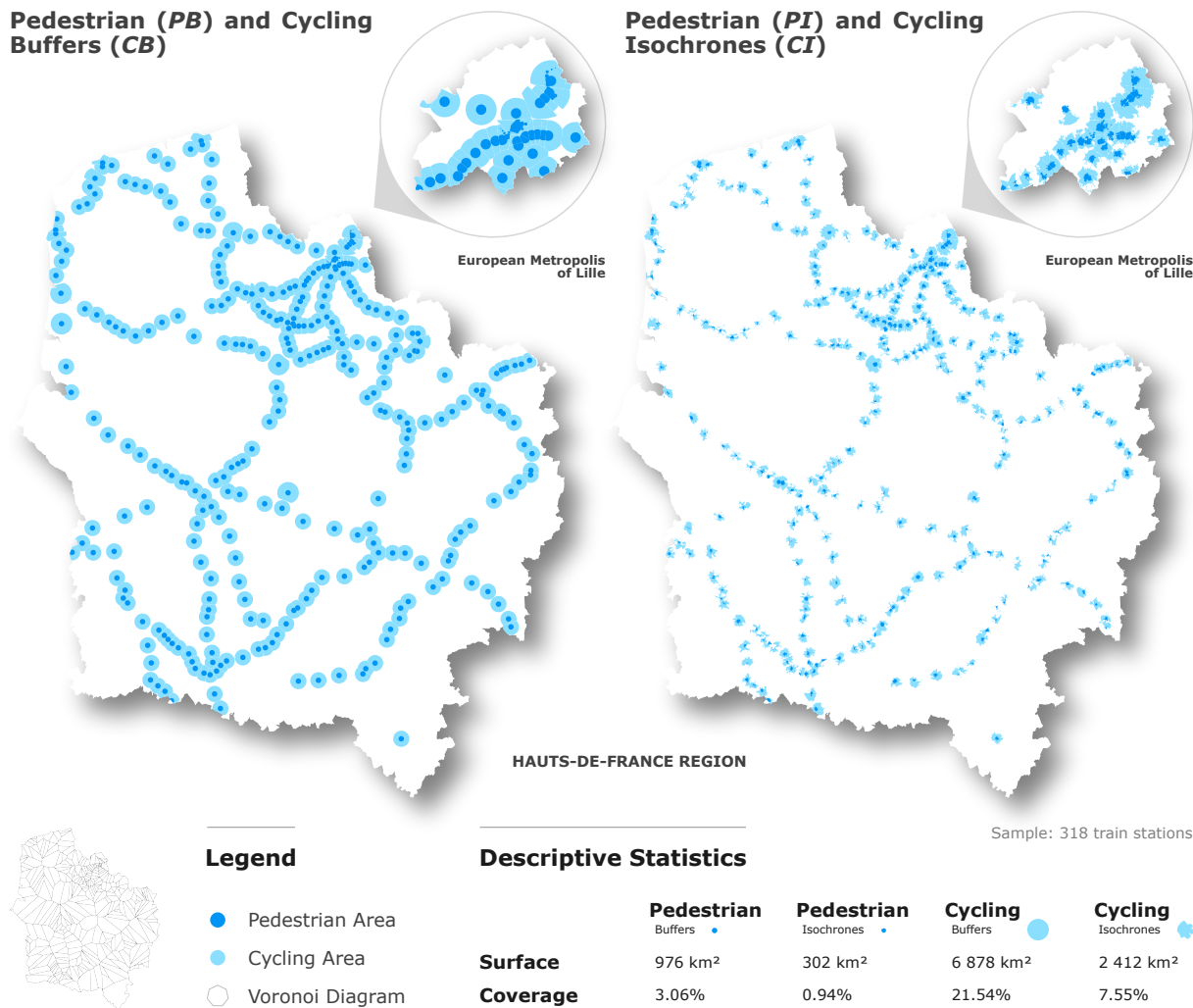


Fig. 6. Spatial Distribution of Station Areas Accessible by Walking and Cycling in the Hauts-de-France Region.

Authors: Moine, L'Hostis, Amini Pishro, Cissé, Lehmann, Zhang, Theureau, Adjeroud, Yuetong, and Xiao (2025)

11.890 network (Boeing, 2017, p. 135).

11.891 **—2 .3 Geostatistical Analysis of**
 11.892 **Mapped Station**
 11.893 **Neighborhoods**

11.894 The effort devoted to the geographical delineation of station
 11.895 neighborhoods with varying sizes and shapes would be
 11.896 meaningless if the integrated data were aggregated at overly
 11.897 broad scales, such as that of the municipality. Restricting
 11.898 analysis to such administrative boundaries would neither
 11.899 reflect the individuality of each station area nor capture
 11.900 distinctions between different types or internal variations. In
 11.901 response to this issue, we established a methodological rule
 11.902 to rely exclusively on disaggregated datasets, in the form of
 11.903 point, line, or polygon vectors, independent of any grids or
 11.904 administrative borders. However, due to the limited
 11.905 availability of open-access data—despite France's

11.906 advantageous position thanks to a strong data
 11.907 centralization—it is sometimes necessary to use aggregated
 11.908 data, particularly for anonymization purposes. Consequently,
 11.909 in a second phase, we propose a method for estimating
 11.910 values based on data aggregated at the scale of regular
 11.911 grids. This approach makes it possible to circumvent these
 11.912 limitations while maintaining sufficient analytical precision to
 11.913 meet the needs of our research.

11.914 **Desaggregated Geodata**

11.915 The importance of adopting a detailed reading of station
 11.916 neighborhoods—independent of municipal boundaries—has
 11.917 been widely emphasized (Moretti and Vacheret, 1999, p. 7).
 11.918 The data used in our study come from various official
 11.919 sources, combined to form a coherent dataset that can be
 11.920 processed within a GIS environment or through computer
 11.921 code to generate graphical outputs suitable for spatial
 11.922 analysis. In our case, geocoding refers to scripts written in
 11.923 *Python*. These sources include open-access data,

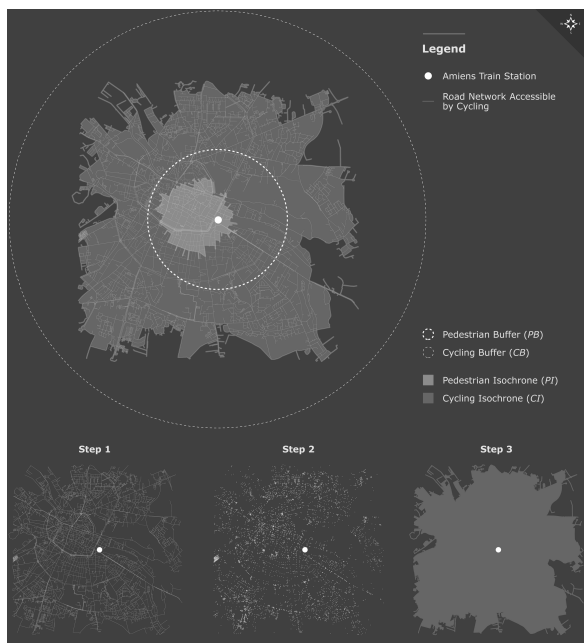


Fig. 7. Cartographic Representation of the Isochrone Accessible by Cycling to Amiens Station, Overlaid with the Road Network.

Authors: Moïnse, L'Hostis, Amini Pishro, Cissé, Lehmann, Zhang, Theureau, Adjeroud, Yuetong, and Xiao (2025)

12.924 disaggregated socio-economic databases, and cadastral
12.925 records. This data integration ensures a detailed and
12.926 contextualized representation of station neighborhoods.

12.927 Some data grids, although essential to this research, are
12.928 unfortunately not available in disaggregated form. To address
12.929 this limitation, we chose to rely on databases expressed
12.930 through standardized grids¹⁶.

12.931 **Integration of Regular Geographic Data Grids**

12.932 To reduce the approximations associated with applying data
12.933 grids, we implemented a calculation method aimed at
12.934 enhancing their accuracy and ensuring their relevance within
12.935 the framework of our study. We relied on a *ModelBuilder*¹⁷
12.936 developed in *ArcGIS*, as part of the SOFT research project
12.937 (Bonin et al., 2020, p. 123). This model generates buffers
12.938 while adjusting calculations based on the surface areas of the
12.939 grid cells, whether partially or fully contained within the
12.940 buffer. In practice, some cells may have only a fraction of
12.941 their area included in the buffer zone. The proposed method
12.942 then consists in estimating an adjusted value for each cell to
12.943 better reflect the reality of the catchment area, accounting
12.944 for the effective proportion of surface included. Following this

¹⁶Data grids come in several types, distinguished by their geometry and scale. Among the most common are regular rectangular or square grids, frequently used for demographic and climate datasets, as well as hexagonal grids (hexbins, H3), characterized by hexagon-shaped cells that offer more homogeneous territorial coverage due to their equidistant edges. Conversely, this research excludes the use of irregular grids, such as administrative or geodesic grids, as well as raster formats.

¹⁷A *ModelBuilder* is a visual tool designed for the creation, automation, and execution of geospatial processing chains. It functions as a graphical programming language, where users assemble tools and processes in the form of diagrams to create reproducible, adaptable, and editable workflows. This approach facilitates the standardization of analyses and streamlines complex operations while ensuring their traceability.

approach, we adapted and systematized the methodology
within our own scripts. This adaptation, applied automatically
to the buffers and isochrones generated, makes it possible to
refine calculations whenever a data grid is used.

—3 Materials and Methods

The exploration of the scientific literature on NPM highlights
how this quantitative approach has evolved as research
progresses. This technical framework, whose main goal is to
classify nodes and their surroundings to identify TOD
potential, continues to improve by progressively integrating
new dimensions related to the concept of urban planning,
enriched by increasingly in-depth knowledge. Even though
new indicators are proposed and integrated into the
developed models, our first section identified certain gaps.
These limitations concern, on one hand, the delineation of
restricted geographic perimeters around station areas, based
on a limited conception of walk-and-ride. This research
practice also supports the near-total absence of models
accounting for the contribution of cycling. On the other hand,
at a larger scale, the defined geographical areas are often
limited to a single municipality or agglomeration.
Furthermore, the lack of case studies based in France,
despite the wealth of open databases, calls for such an
investigation on this area, aiming to capture national or local
similarities or even specificities.

Building on this observation, we opted for an innovative
approach by choosing to explore an uncharted territory, while
integrating the latest contributions related to NPM. This
includes a variety of indicators introduced in the most recent
models published, as well as original parameters focusing on
the still under-documented integration of cycling. In other
words, the modeling we adopted relies on a revised version of
NPM, incorporating the contribution of cycling. This approach
aims to determine whether nuances emerge in comparison to
walk-and-ride, within the expanded context of a region.

In this regard, the originality of our NPM lies in the
integration of two innovative dimensions. On one hand, we
ensured the inclusion of the links between the station object
and the urban object in the form of public spaces. On the
other hand, we aimed to connect these themes with the
mobility demand expressed through the dynamic ridership of
public transport stations. Thus, four dimensions structure the
modeling we have chosen to name NPART.

—3.1 Selection of Synthetic Indicators to Quantify and Characterize the Four Modeling Dimensions

Quality of Rail Service (N)

The first dimension, related to "quality of rail service,"
is divided into four categories: "level of service," "system
performance," "network metrics" from a graph perspective,
and "accessibility to centralities" in Lille and Paris (see
Table 1, p. 13). The aim of this first dimension, in line with
the original NPM, is to represent the rail service denoted by
N in the region, by examining its various aspects structured
around sixteen key indicators. It should be noted that, unlike

13.1002 the other three dimensions, the values for each of the
13.1003 synthetic indicators are similar across the four types of
13.1004 geographic perimeters studied (PI , PB , CI , and CB).

13.1005 This first category, part of the “*Transit*” component of
13.1006 *Transit-Oriented Development*, aims to comprehensively
13.1007 assess the quality of service offered by the rail infrastructure.
13.1008 It is established that the frequency of public transport
13.1009 networks significantly influences station ridership (Sung and
13.1010 Oh, 2011, p. 79). Similarly, Kashfi et al. (2015, p. 63)
13.1011 emphasize that the intensity and operating hours of services
13.1012 promote increased ridership. In our modeling, we quantified
13.1013 the service level by defining the frequency of high-speed and
13.1014 regional train networks (N_1 , N_2 , N_3 , and N_4), as well as the
13.1015 operating hours (N_5 and N_6). We also considered the system
13.1016 performance, including commercial speed (N_7), which
13.1017 influences passenger volumes (Vuchic, 2007, pp. 149–201)
13.1018 and the number of directions served (N_8), identified as a key
13.1019 indicator in various NPM models for station ridership (Cao
13.1020 et al., 2020, p. 9). We explored the network structure
13.1021 through graph analysis, evaluating aspects such as degree
13.1022 centrality¹⁸ (N_9) and closeness centrality¹⁹ (N_{11}), which,
13.1023 according to Shi et al. (2018, p. 14), play a crucial role in
13.1024 station attractiveness, as well as betweenness centrality²⁰
13.1025 (N_{10}), which is associated with an increase in the number of
13.1026 passengers (Jang and An, 2022, p. 339). Finally, the last
13.1027 branch examines accessibility to urban centers, focusing on
13.1028 distances to urban poles (N_{13} , N_{14} , N_{15} , and N_{16}), which are
13.1029 inversely correlated with station attractiveness (Chao Liu
13.1030 et al., 2016, p. 8; Kuby et al., 2004, p. 241).

13.1031 By proposing these sixteen indicators for the dimension
13.1032 related to rail service, our model draws inspiration from
13.1033 previous NPM models while refining them. This first
13.1034 dimension, focusing on regional mobility infrastructure and
13.1035 service, seeks to address the three major challenges faced by
13.1036 the development of public transport accessibility models:
13.1037 system performance, the configuration of the public transport
13.1038 network, and access to various destinations (Malekzadeh and
13.1039 Chung, 2020, p. 744).

13.1040 From the perspective of rail service quality, we first sought to
13.1041 broaden the temporal scope of statistical analysis by
13.1042 projecting more complex graphs that go beyond the simple
13.1043 consideration of a single time interval or a single day, as is
13.1044 the case in almost all the studies reviewed. Indeed, most of
13.1045 them calculate these variables based on a typical day, usually
13.1046 a Tuesday, or even just a single time slot, most often during
13.1047 peak hours. While frequency is among the most commonly
13.1048 used indicators, the originality of our model lies in the
13.1049 distinction between different public transport systems, as
13.1050 well as the separation between weekdays and weekends. This
13.1051 concern for differentiation is reminiscent of the models
13.1052 developed by Ivan et al. (2012, p. 149), who isolated the
13.1053 frequency of trains from that of suburban trains, trams, and
13.1054 buses, as well as by Nigro et al. (2019, p. 117), whose
13.1055 frequency was evaluated based on work and vacation
13.1056 periods.

13.1057 Similarly, the number of stations accessible within a given
13.1058 distance-time has been widely incorporated into NPM models.
13.1059 However, we chose to extend the time interval, which is
13.1060 regularly limited to twenty minutes and seems inadequate for
13.1061 a regional rail system. Regarding the time span between the

¹⁸ Degree centrality measures the number of direct connections a node has with other nodes in a network. The more connections a node has, the higher its degree centrality. By direct connections, we mean the number of stations reached by rail services, without transfers, from the starting station.

¹⁹ Closeness centrality measures how close a node is to all other nodes in a network. It is defined as the inverse of the sum of the shortest distances between a node and all other nodes.

²⁰ Betweenness centrality quantifies how often a node appears in the shortest paths between other nodes. A node with high betweenness centrality plays a crucial role as a mediator in a network.

13.1062 first and last trains in service, to the knowledge of the
13.1063 authors, only one model considers this aspect (Caset, 2019,
13.1064 p. 132). The issue of the commercial speed of trains was
13.1065 addressed by building on the work of Debrezion et al. (2009,
13.1066 p. 271) and Zheng and Austwick (2023, p. 6), who focused
13.1067 on the theoretical speed of trains. To this end, we chose to
13.1068 calculate the actual average operational speed on the
13.1069 commercial network, rather than using theoretical speed.

13.1070 While the quality of rail service is generally well accounted for
13.1071 in previous models, it appears that measures related to
13.1072 network configuration are rarely used appropriately (Papa
13.1073 and Bertolini, 2015, pp. 72–74). However, as demonstrated
13.1074 by Dou et al. (2021, p. 8), who introduced this concept in a
13.1075 third dimension called “*Node-Place-Network*” (NPN), it proves
13.1076 effective in better understanding the performance of the
13.1077 studied network. With this in mind, we integrated three
13.1078 indicators: degree of centrality, betweenness centrality, and
13.1079 closeness centrality, which, based on our observations, have
13.1080 not yet been jointly analyzed in existing studies.

ID Node Dimension

Level of Service

N_1	Daily frequency of high-speed rail on weekdays
N_2	Daily frequency of high-speed rail on weekends
N_3	Daily frequency of regional rail on weekdays
N_4	Daily frequency of regional rail on weekends
N_5	Operating hours on weekdays
N_6	Operating hours on weekends

System performance

N_7	Commercial speed
N_8	Number of directions served

Network metrics

N_9	Degree centrality
N_{10}	Betweenness centrality
N_{11}	Closeness centrality

Accessibility to centralities

N_{12}	Number of stations accessible within one hour
N_{13}	Number of stations to reach Lille’s urban core (Euralille hub)
N_{14}	Travel time to reach Lille’s urban core (Euralille hub)
N_{15}	Number of stations to reach Paris’s urban core (Châtelet hub)
N_{16}	Travel time to reach Paris’s urban core (Châtelet hub)

Table 1. Set of Indicators Grouped within the Dimension related to Node (*Transit*).

Authors: Moinsé, L’Hostis, Amini Pishro, Cissé, Lehmann, Zhang, Theureau, Adjeroud, Yuetong, and Xiao (2025)

Degree of Urban Development (P)

13.1081

13.1082 The second dimension, related to “degree of urban
13.1083 development,” is divided into five categories: “density,”
13.1084 “functional diversity,” “attraction sites,” “land value,” and
13.1085 “demographics,” (see Table 2, p. 14). The aim of this
13.1086 category, also in line with the original NPM, is to measure
13.1087 urban forms, facilities, and territorial attractiveness, as well
13.1088 as the sociological profile of resident populations, denoted by
13.1089 P , by examining its various aspects structured around
13.1090 thirteen key indicators.

13.1091 We incorporated and developed indicators already present in
13.1092 most NPM models, such as population and employment

14.1093 density, as well as the functional diversity of territories, in
 14.1094 addition to new variables. The use of POIs refers to relatively
 14.1095 few studies that have considered these urban elements
 14.1096 generating flows (Robillard et al., 2024, p. 82; Zhou et al.,
 14.1097 2023, p. 2). Furthermore, we chose to reflect the diversity of
 14.1098 POIs²¹, following the recommendations made by M. Zhang
 14.1099 and J. B. Lee (2023, p. 7).

14.1100 Although the Transportation Research Board of the National
 14.1101 Academies (2007) recognizes land value as one of the ten
 14.1102 key indicators in building an NPM model, few studies have
 14.1103 addressed this issue so far. Kim et al. (2018, p. 135) suggest
 14.1104 examining property values around stations to assess urban
 14.1105 dynamics, although obtaining these data presents certain
 14.1106 challenges. Ibrahim, Ayad, Turki, et al. (2023, p. 242) were
 14.1107 able to capture the land value-added resulting from private
 14.1108 investments in Alexandria. However, Singh et al. (2014,
 14.1109 p. 263) raise concerns about the need to improve the
 14.1110 accuracy of statistical data related to investments in order to
 14.1111 enrich such a model.

14.1112 In addition to these reflections, the issue of social housing
 14.1113 supply, in relation to land pressures, is raised (Singh, 2015,
 14.1114 p. 27). This socio-spatial dimension is largely
 14.1115 underrepresented in the literature, except for the model
 14.1116 undertaken by Zhou et al. (2023, p. 2). Finally, the
 14.1117 consideration of household economic resources, particularly
 14.1118 income, remains an underutilized indicator in this model,
 14.1119 despite being an important factor according to the results
 14.1120 derived from the modeling process of Cummings and
 14.1121 Mahmassani (2022, p. 3).

ID	Place Dimension
Density	
P ₁	Population density
P ₂	Employment density
Functional diversity	
P ₃	Residential land use
P ₄	Commercial and public services land use
P ₅	Office and industrial land use
P ₆	Green space land use
Points of interest	
P ₇	"Proximity" points of interest
P ₈	"Intermediate" points of interest
P ₉	"Superior" points of interest
Attraction sites	
P ₁₀	Land value of residential properties
P ₁₁	Land value of industrial, commercial, and office properties
Demographics	
P ₁₂	Share of social housing
P ₁₃	Average household income

Table 2. Set of Indicators Grouped within the Dimension related to Place (*Development*).

Authors: Moïnse, L'Hostis, Amini Pishrow, Cissé, Lehmann, Zhang, Theureau, Adjeroud, Yuetong, and Xiao (2025)

²¹ These POIs are taken from the *Base Permanente des Équipements* (BPE), a database that lists a wide range of facilities and services—both commercial and non-commercial—available to the public throughout France (Insee, 2021). Our classification of POIs into three levels of importance corresponds to the categories defined by the BPE. "These groupings make it possible to construct summary indicators that reflect the hierarchical organization of territories in terms of services available to the population". (Insee, 2021). From the 188 listed facilities in the BPE, we chose to exclude twelve categories that, in our view, are not relevant to our research topic: automobile and agricultural machinery repair (A301), automotive technical inspections (A302), professions of masonry (A401), plasterer, painter (A402), carpenter, locksmith (A403), plumber, roofer, heating technician (A404), and electrician (A405), as well as general building companies (A406), ambulances (D303), taxis, ride-hailing service (E101), train stations (E107, E108, and E109), and sports and health courses (F109).

Design and Public Space Management (A)

14.1122

The third dimension of this study, labeled "local accessibility and public space management" and falling under the "Oriented" component of *Transit-Oriented Development*, focuses on examining the interactions between urban development and the mobility system. It specifically explores link scale, investigating the quality of urban design and its contribution to the qualification of the built environment (Yushan Zhang et al., 2023, p. 294). This dimension encompasses the concepts of walkability, bikeability, and local connectivity in relation to urban public transport networks, as well as demand management, focusing on the space allocated to private car (see Table 3, p. 15). It should be noted that the last category is approached from the perspective of car competitiveness relative to public transport use, in line with TOD principles. Thus, the values assigned to the presence of cars in urban space are inverted in the modeling: the greater the importance given to cars, the lower the station area's ranking relative to others. Through this component, labeled *A*, eleven indicators have been integrated in total to assess the four defined geographic perimeters (*PI*, *PB*, *CI*, and *CB*).

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Existing documentation has revealed a substantial positive association between the indices related to the node, place, and design, thus highlighting the determining influence of place connectivity, which manifests through pedestrian and cycling links around mobility spaces and human activities (M. Zhang and J. B. Lee, 2023, pp. 4–5). The morphological and functional interrelationship between transport and land use is therefore fundamental in this model (Z. Li et al., 2019, p. 271), as this dynamic interaction within the station area must be considered as an independent variable (Peek et al., 2006, p. 20).

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Although walkability is frequently integrated into NPM models, indicators related to bikeability are much rarer. Some research published by Reusser et al. (2008, p. 195), Lukman and Singh (2014, p. 26), Huang et al. (2018, p. 312), Maheshwari et al. (2022, p. 1.018), Arliani et al. (2023, p. 10), M. Zhang and J. B. Lee (2023, p. 6), and Robillard et al. (2024, p. 82) have explored this aspect by examining the length of cycling networks and the number of bike parking facilities.

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Furthermore, we chose to focus on the car system, particularly speed limits and car ownership rates, which have been scarcely addressed in previous studies, while considering all car parking areas within the territory, without limiting the study to park & ride. In this sense, we opt for an inversion of the values associated with car usage measurement, considering that the development of the car system contradicts the principles of TOD. This approach is supported by Maheshwari et al. (2022, p. 1.020), who demonstrated that car parking density is inversely proportional to metro ridership in Ahmedabad, India.

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Ridership per Time (RT)

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The fourth dimension of our study, labeled *RT*, models station ridership, an indicator directly linked to mobility demand. Based on the assumption that station classification only gains legitimacy when it is based on their size, i.e., their ridership, allowing for a comparison based on relative "accessibility," we opted for the innovative addition of this component (Reusser et al., 2008, p. 194). To assess the ridership of each station, we extracted data from SNCF (2024) open data. This database provides information on the number of passengers per year and per station. In order to

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ID Accessibility Dimension	
Walkability	
A ₁	Length of pedestrian network
A ₂	Intersection density
A ₃	Spatial efficiency rate (pedestrian and cycling isochrones)
Bikeability	
A ₄	Length of cycling network
A ₅	Capacity of bicycle parking facilities
A ₆	Public bikeshare fleet
Local connectivity	
A ₇	Metro and tramway stops
A ₈	BRT and bus stops
Travel demand management	
A ₉	Motorized speed limit
A ₁₀	Area of car parking facilities
A ₁₁	Household motorization rate

Table 3. Set of Indicators Grouped within the Dimension related to Accessibility (*Oriented*).

Authors: Moïnse, L'Hostis, Amini Pishro, Cissé, Lehmann, Zhang, Theureau, Adjeroud, Yuetong, and Xiao (2025)

make the model more precise and dynamic, the lack of real-time traffic data led us to estimate the passenger flow for each station at daily intervals and hourly slots. We chose to use the ridership data published by Google Maps (2024), known as GPT²² for the week of March 18 to March 24, 2024. Thus, we were able to determine the estimated ridership for each station at each hour over a typical week²³, unaffected by holidays, public holidays, or local or national disruptions.

We carried out the automated extraction and organization of data from this online site, concerning visits recorded by location and search type. To this end, we developed and implemented a *Python* script to collect the total flow by hour and by day for each station. Based on estimated trips, we segmented time into six distinct periods, applying a classification method that allowed us to group hourly ridership based on observed similarities.

The first five periods, from RT_1 to RT_5 , are dedicated to weekdays, while the RT_6 period is reserved for Saturday and Sunday. The periods of high ridership are designated RT_2 and RT_4 , while off-peak hours are identified as RT_1 , RT_3 , RT_5 , and RT_6 . This statistical method allows us to precisely characterize the ridership of each station according to these six time intervals. Thus, this dimension illustrates the mobility demand, which we treat, in this analytical framework, as dependent variables, influenced by the forty other indicators considered as independent. It should be noted that the values associated with the resulting time segments were normalized.

The determination of hourly ridership patterns for stations during a specific week provides a precise insight into the mobility behaviors of rail passengers. As shown in Fig. 8 (p. 16), weekday activity is strongly marked by commuting,

²²Given the scarcity of public data on this subject, this innovative method has certain limitations, notably that the recorded visits do not necessarily reflect the actual ridership at the station, which would ideally be measured by physical counters or validated tickets at the station. However, to validate this approach, we compared the results obtained with our regional quantitative observations ((Moïnse, 2025a)), finding a certain consistency between the two datasets.

²³In 2023, Vongvanich et al. (2023, p. 5) reused GPT data as innovative resources, available in many cities around the world. They used this real-time data to analyze and predict ridership in ten stations in Kyoto, Japan, and also explored the number of visits to surrounding services and businesses. To our knowledge, this is the only scientific publication that has used GPT data to determine ridership at public transport stations.

with significant peaks in ridership between 6:00 and 9:00 AM and between 3:00 and 7:00 PM. This trend results in generally higher ridership during these days. In contrast, weekend ridership profiles show more moderate variations, with secondary peaks at noon and between 4:00 and 7:00 PM on Saturday, and between 3:00 and 6:00 PM on Sunday²⁴.

Although station ridership is known for a specific week, this information remains both limited and static. To address this challenge, prediction allows us to go beyond this snapshot by anticipating the evolution of usage patterns and external contexts. The value of predicting station flows lies, from a statistical perspective, in the continuous improvement of the model, and from a planning perspective, in optimizing decision-making.

The prediction of passenger volumes primarily aims to anticipate flows in order to highlight potential levers for encouraging modal shift to public transport, while enhancing its management. The development of predictive models addresses the need to continuously improve these models and better predict fluctuations due to events, seasonal variations, or long-term trends. To this end, we applied several statistical techniques from Machine Learning by adopting an Ensemble Learning model²⁵, after normalizing the collected data:

- Multiple Linear Regression (MLR) models the linear relationship between explanatory variables and the target variable, i.e., the number of rail passengers;
- K-Nearest Neighbors (KNN) predicts ridership by identifying the k most similar moments in the past and calculating an average of the corresponding riderships;
- Artificial Neural Networks (ANN) capture complex and non-linear relationships between variables, inspired by the architecture of the human brain.

The evaluation of these models was carried out using metrics based on Mean Squared Error (MSE)²⁶ and Adjusted Prediction Error Reduction (APRE)²⁷. In both metrics, a low value indicates a performant model, capable of predicting real values accurately while minimizing relative errors.

The results obtained from these predictive models indicate that all three Ensemble Learning techniques significantly reduce APRE, suggesting an improvement in performance, particularly for stations with low ridership. While the KNN method shows satisfactory performance before the weighting of explanatory variables, both MLR and ANN models demonstrate notable improvements after this weighting is applied. We compared the evolution of MSE and APRE values across different geographic perimeters and periods. This analysis showed that KNN and the three Ensemble Learning-based predictive models provide a more accurate fit in predicting station ridership. It appears that these predictive models particularly benefit less frequented stations, for which the accuracy of the forecasts is improved.

²⁴Wednesday also stands out due to an intermediate peak between 10:00 AM and 12:00 PM, likely due to the afternoon traditionally given to children, while Friday records a more pronounced peak in ridership during the evening rush hour. The identification of an intermediate peak in our observations is supported by the distribution analysis of trips conducted by Munch (2017, p. 66) on the SNCF Transilien network for 126 stations in 2015.

²⁵Ensemble Learning involves combining multiple models, known as "weak learners," in order to improve accuracy over a single model. This Machine Learning approach enhances overall performance by reducing generalization error, i.e., the difference between performance on training data and new data (i), model variance by smoothing individual predictions (ii), and model bias (iii).

²⁶MSE is a commonly used metric for measuring the gap between observed values and predicted values by a Machine Learning model, particularly in regression models. One drawback of this measure is that it amplifies large errors due to squaring the differences, making the model more sensitive to outliers.

²⁷APRE quantifies the relative error between observed and predicted values, normalizing it by the actual values. This metric is particularly useful for evaluating the accuracy of prediction models when data exhibit significant variations in amplitude. Unlike MSE, APRE is less sensitive to outliers as it takes into account the scale of the actual values.

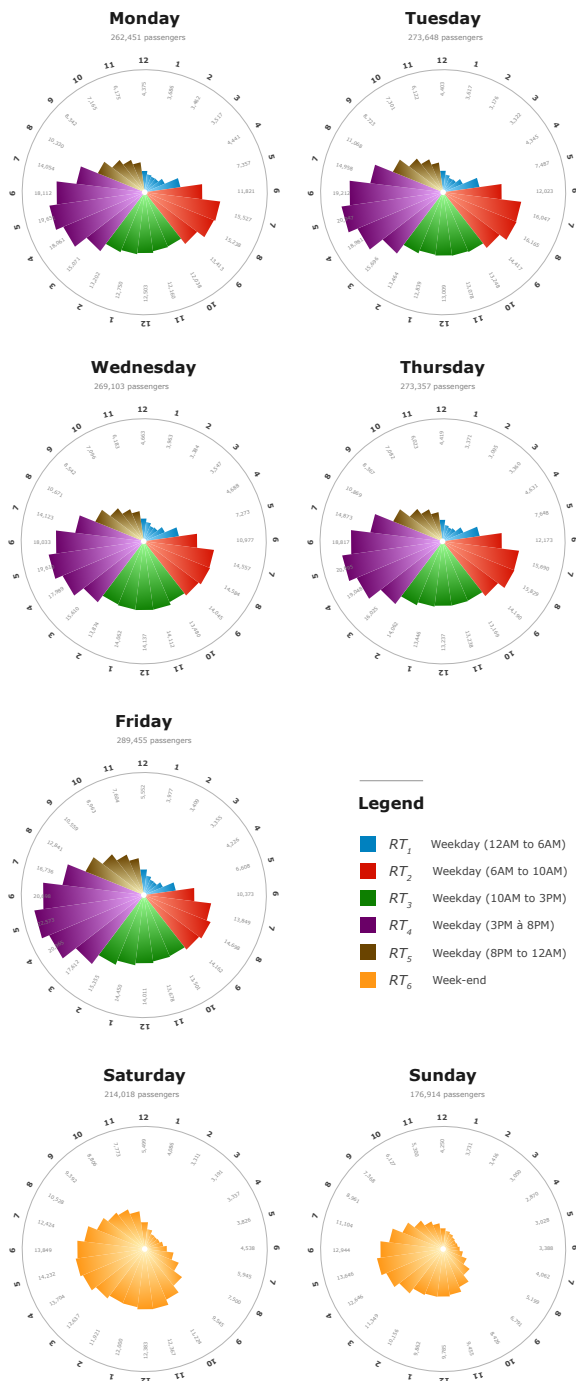


Fig. 8. Estimation of the Total Ridership for all the Stations Examined, by Hour and by Day, between March 18 and March 24, 2024.

Authors: Moïse, L’Hostis, Amini Pishro, Cissé, Lehmann, Zhang, Theureau, Adjeroud, Yuetong, and Xiao (2025)

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After defining the NPART based on a set of indicators organized around four key dimensions – the Node, Place, Accessibility, and Ridership – we focus on describing the steps involved in calibrating the model. The objective is to adjust and validate

the parameters of the tool used.

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–3 .2 Data Collection and Analysis Protocol

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The design of our NPART model is based on the selection of forty quantifiable explanatory indicators and six indicators related to station ridership. The goal is to classify and characterize the stations and their immediate environment within the framework of developing an M-TOD, for which a methodological protocol has been established. This includes data collection and geostatistical analysis. This analysis protocol led to the generation of 288 specific typologies, depending on several factors: the analyzed geographic area (*PI*, *PB*, *CI*, and *CB*), the periods studied (from RT_1 to RT_6), variable weighting strategies, and classification methods applied to the stations (see Fig 9, p. 17).

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Data Collection Techniques and Validation

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This sub-section describes the steps of collecting and analyzing statistical data related to stations as well as geographical information, in connection with the defined isochrones and buffers. The data preparation preceding the modeling work is primarily based on the search for disaggregated data sources, which are then transformed and scaled to ensure their consistency. Furthermore, the model validation is based on the analysis of interdependencies between the different indicators. Following this statistical analysis, we can adopt a classification approach based on various parameters outlined.

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Once the indicator grid was defined in detail, we proceeded with the spatial extraction of the available data. For each exchange point, we selected the defined station areas, integrating both isochrones and buffers for pedestrian (*PB* and *PI*) and cycling (*CB* and *CI*) areas. We deliberately restricted ourselves to the use of disaggregated geographic data to maximize the precision of the location of the determined variables, except the node-related values, which rely exclusively on GTFS data provided by institutions and mobility managers. Furthermore, this spatial granularity requirement led us to adopt data estimation methods when data is aggregated within spatial grids.

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In this regard, we chose to use the programming language *Python* exclusively, particularly its various libraries dedicated to geospatialization to extract and analyze the data. This choice is explained by several comparative advantages over the traditional use of GIS²⁸.

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The normalization of input data is a critical step before any modeling, *a fortiori* in the context of NPM. In this context, the data collected for each station must be homogenized to prevent the scale differences between variables from disproportionately influencing the model’s results. To this end, the Min-Max normalization method was applied before the training phase. This technique involves transforming the values of each variable so that they fall between 0 and 1.

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After the data collection and normalization, it is important to ensure that the transformed variables are ready to be integrated into the model. A key preparatory step before

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²⁸ First, *Python* offers greater flexibility in data processing, being both more adaptable and easily customizable. Additionally, it allows for the handling of large datasets and the automation of data extraction and transformation processes through the various scripts generated. Moreover, *Python* facilitates complex calculations, enabling the retrieval of required data, particularly when combinations of diverse datasets are needed. Finally, the analysis of GTFS data is greatly simplified, especially by allowing the modeling of complex networks and graph analysis.

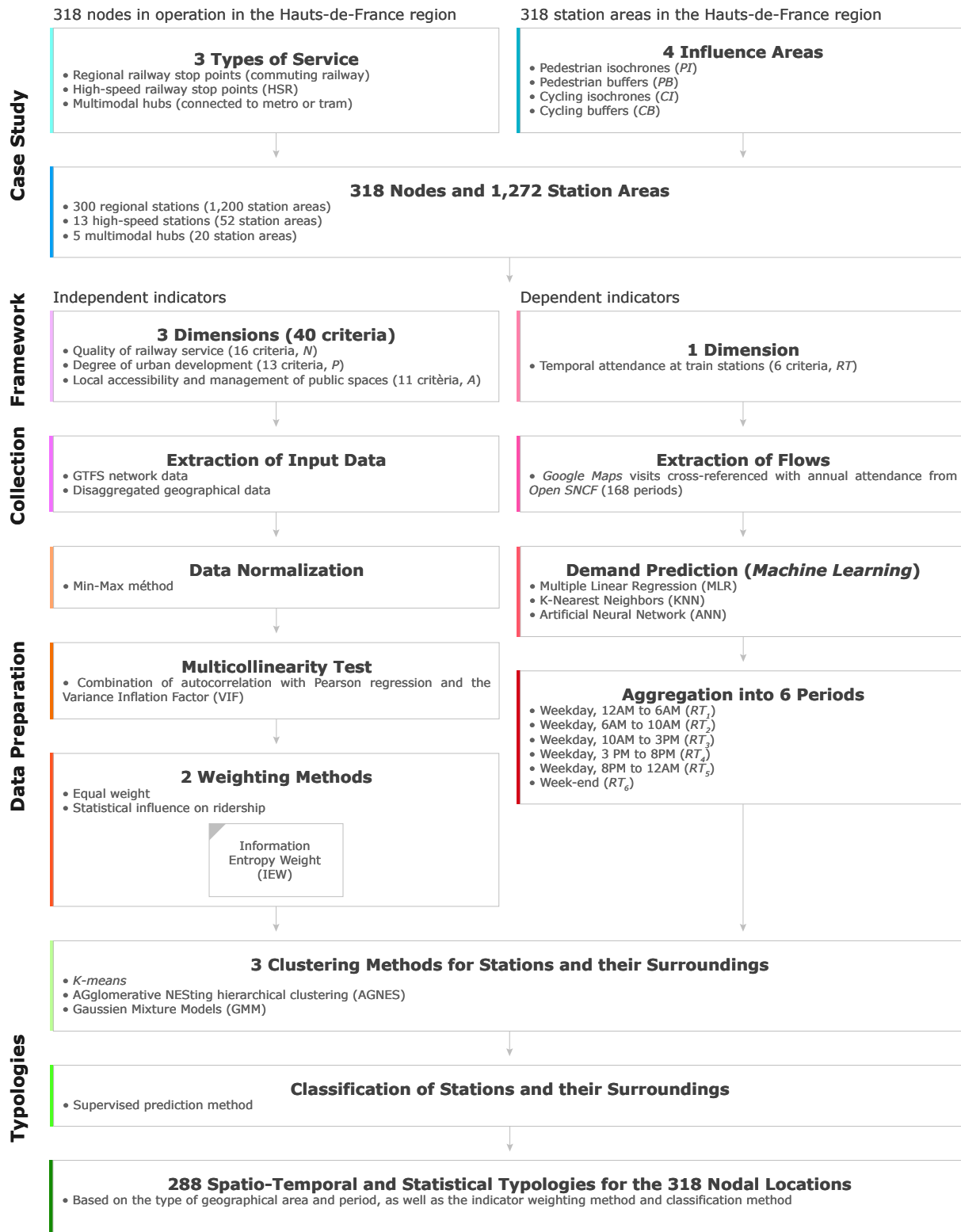


Fig. 9. Flow Diagram Representing the Main Methodological Steps of the Spatial Model.

Authors: Moïnse, L'Hostis, Amini Pishro, Cissé, Lehmann, Zhang, Theureau, Adjeroud, Yuetong, and Xiao (2025)

modeling is to check for multicollinearity. The presence of multicollinearity can compromise the interpretation of the model's results and hinder its accuracy, particularly in analyses based on relationships between variables. Therefore, before moving to the actual modeling phase, a multicollinearity analysis is essential to validate the consistency of the data and ensure their relative independence.

We assessed multicollinearity between the independent variables using two statistical approaches: the simple correlation coefficient, employing Pearson's correlation coefficient R^2 , and the variance inflation factor (*VIF*). By combining these two methods, we can identify and remove independent variables exhibiting very high collinearity issues. Appendices (p. 40 and 41) illustrate the interrelationships between the explanatory criteria.

As a general rule, we consider an independent variable to pose a significant collinearity issue when R^2 reaches 0.90 or when *VIF* exceeds 100.00. In consequence, the variables we may consider excluding are high-speed rail frequency (N_2), betweenness centrality (N_{10}), the "proximity" POIs (P_7), and the car ownership rate of households (A_{11}) for all station area configurations (*PB*, *PI*, *CB*, and *CI*). The method used to adjust this model is Ordinary Least Squares (OLS) regression. This technique aims to determine the optimal regression line by minimizing the sum of squared differences between the observed and predicted values. Mean Squared Error (MSE), is used to assess the accuracy of the model's predictions and, thus, measure its overall performance.

After eliminating the indicators N_2 , N_{10} , P_7 , and A_{11} for each geographic and temporal perimeter, the parameters of the different regression models showed that the adjustment performance barely changed. As a result, we decided to retain all of the initially defined indicators since, from a geographic perspective, they more accurately reflect the complexity of urban reality. In this regard, we draw on the conclusions of Cao et al. (2020, p. 16), who demonstrate that the NPM model, which eliminates variables with too high a *VIF*, ultimately proves less accurate than the complete model that retains all indicators.

After performing the analysis of multicollinearity among the variables, it is now possible to proceed with clustering and then classifying the stations. Proper management of multicollinearity is a key prerequisite to ensure a reliable and interpretable typology, resulting in homogeneous and representative groups.

18.1375 Double Exploratory and Predictive Approach by 18.1376 Partitioning and Classification

Classification, as an analytical framework, aims to group stations into different homogeneous sets based on similar characteristics, to better guide urban planning decisions (Cao et al., 2020, p. 2). The main objective of this approach is to organize a set of data into clusters²⁹, in order to facilitate understanding and concisely summarize the similarities and differences present in the data. The value of classification often lies in its practical utility rather than its absolute truth (Everitt et al., 2011, p. 4). According to Gordon (1999, p. 5), such an approach helps synthesize complex datasets and aids

in detecting structures and interactions within this information. If distinct classes of objects are identified, they can then be named, and their properties defined, thus facilitating the assignment of new objects. In this sense, the notion of "similarity" linked to classification techniques is both central and subjective, as the definition of clustering algorithms and the interpretation of results depend on the modelers' judgment.

To determine the optimal number of clusters k , we chose to use the methods of the silhouette coefficient (*SC*) and the Calinski-Harabasz index, also called the variance criterion (*CH*). These two measures are commonly used to evaluate the quality of data groupings in the three considered unsupervised algorithms (k-means, AGNES, and GMM). The silhouette coefficient quantifies the similarity of objects within the same cluster while evaluating their distinction from objects in other clusters. It allows for an analysis of the internal cohesion and separation of clusters, providing a fine evaluation at the level of each data point, with values ranging from -1 to 1. As for the variance criterion, it measures the ratio between inter-cluster variance and intra-cluster variance, with unbounded values. This measure is particularly useful for comparing different numbers of clusters and various clustering models, relying on the global dispersion of points. For all these indices, a higher value indicates better performance.

The goal of these indicators is to identify the point at which adding new clusters no longer significantly improves their values (Jahaniana et al., 2022, p. 23). This point indicates that the clustering model is balanced and that the number of clusters is reasonably chosen. By identifying the optimal k threshold, it is possible to avoid an excess of clusters while ensuring a coherent segmentation of stations and their surroundings. According to our measurements, the optimal number of k is set to three for the three clustering methods. As an illustration, when $k = 3$ and the parameters are defined at RT_2 , it appears that the k-means algorithm presents the best scores in terms of cluster separation, both for *PI* and *CI*.

Subsequently, the classification of stations, following a clustering step, involves assigning new observations to pre-existing clusters. This phase relies on the use of a supervised prediction method, where the objective is to predict the membership of each new station to one of the clusters defined during the initial clustering phase (James et al., 2013, pp. 134–135). This approach also allows for the continuous integration of new data, keeping the classification updated without the need to restart the entire modeling process. It thus aims to automate the categorization of stations, based on the clusters identified during the exploratory analysis.

To achieve this, we used neural networks. The training of the neural networks was based on consistently labeled data points. As the previous results show, different clustering methods produce varied results. However, we consider that the points consistently labeled by the three algorithms legitimately belong to these clusters. On the other hand, for points labeled inconsistently, it is not possible to directly and explicitly classify them into these clusters. Therefore, we decided to perform a second clustering on these inconsistent data. To do this, we used the consistently labeled data to train the neural network, hoping that it would have a better ability to classify the unclassified points. We allocated 80% of this data to train the model, and the remaining 20% was used as a validation set to test the model's performance. Once the predictions were made by the neural network, each station was assigned to a cluster. This cluster is considered to stem from the combination of the results of the three clustering algorithms, with the model having been trained on

²⁹A cluster is defined as a group of stations sharing common attributes, identified by clustering algorithms based on a measure of distance or similarity in a multidimensional space (Everitt et al., 2011, p. 7). According to Cormack (1971, p. 321) and Gordon (1999, p. 15), a cluster is characterized by its internal cohesion, expressed in terms of *homogeneity*, and its external isolation, defined by the *separation* between groups. Indeed, a classification algorithm will theoretically aim to ensure minimal intra-class variability, meaning minimized distance between individuals within the same group, and high inter-class variability, i.e., maximizing the distance between individuals of different groups.

data labeled with relatively high accuracy. We therefore consider this classification result sufficiently precise to be compared to the results of the clustering algorithms, thus allowing us to reassess their effectiveness.

To validate the clustering and classification processes, we employed the Adjusted Rand Index (*ARI*) and the Jaccard Coefficient (*JC*). These two measures are used to evaluate the similarity between two partitions in order to assess the quality of clustering in relation to a reference classification. The performance evaluation of the Machine Learning model is commonly referred to as *ground truth*. *ARI* is an adjusted version of the Rand Index that measures the similarity between two partitions by considering the pairs of elements correctly grouped together or separated in both partitions. The *ARI* adjusts this measure to account for random matches. It ranges from -1 to 1 and provides a more reliable measure than the base Rand Index, as it incorporates random matches. *JC*, on the other hand, is a similarity measure between two sets. When applied to clustering, it compares two clusters by measuring the percentage of common elements relative to the total size of the sets. It is particularly relevant when clusters are of different sizes. This indicator, which ranges from 0 to 1, focuses solely on the intersection and union of clusters, without adjustment for randomness. As an example, when $k = 3$ and the parameters are set to RT_2 , it appears that both the k-means and AGNES algorithms perform best overall for both *PI* and *CI*. AGNES produces, at this stage, the clusters most similar to the *ground truth*.

After extracting data related to mobility and urban systems and ensuring their reliability, we applied clustering and classification techniques. These methods allowed us to segment the data into groups and develop predictive models. However, the analysis would not be complete without considering the relative importance of each variable used. By assigning specific weights to the defined indicators, we can adjust their influence on the final results, which improves the accuracy of predictions and better reflects the reality of the phenomena being studied. In the next section, we will discuss the strategy for adjusting the weights of our data, alongside the equal-weight approach.

Weighting Indicators

Aware of the common practice of assigning equal weight to indicators in the NPM model across various urban contexts, the research conducted by Liao and Scheuer (2022, p. 9) proposes a revision of this approach by considering the relative weight of each indicator. Monajem and Ekram Nosratian (2015, p. 15) observe that the relative importance of the variables integrated into the model has often been overlooked in previous studies, whereas some criteria exert a more pronounced influence than others. This factor plays a decisive role in the calculation of the NPM, as it significantly impacts the classification of stations (Lukman and Singh, 2014, p. 10).

When discussing the relative weight of indicators from a statistical perspective, it is important to refer to the specific effects of each criterion on station attendance. Indeed, attracting individuals to public transport systems is one of the key goals of TOD, justifying the extension of the NPM to analyze the impacts of the various factors considered. In this context, Cummings and Mahmassani (2022, p. 2) applied multivariate regression to identify the factors influencing the attendance of the *Amtrak* railway network in the United States. Similarly, L. Yang and Song (2021, p. 248) used multi-criteria decision analysis (MCDA) to assign weights to the variables studied on metro station usage in Ningbo,

China. Amini Pishro, L'Hostis, et al. (2023, p. 4) optimized the use of Information Entropy Weighting (IEW) by measuring the relative importance of attributes (Shannon, 1948, p. 4), not only in predicting attendance but also in the final process of node classification.

Driven by the intersection of geography, statistics, and data science, we chose to integrate this recent advancement by adopting the IEW technique in our modeling. This approach aims not only to identify the criteria influencing station attendance but also to more realistically classify the stations within the studied network. In this perspective, within this research, we present the relative weights of each indicator on passenger flows at each station, based on the three independent dimensions: node (*N*), place (*P*), and accessibility (*A*). These results will allow us, in a subsequent phase, to propose a classification of the stations and their surrounding environments, taking into account these various influences, in relation to pedestrian and cycling station areas.

In the context of our multi-criteria model, where the values of each variable have been normalized, the first step consisted in constructing a decision matrix, within which we calculated the entropy for each indicator in each dimension. The entropy calculation formula relies on the weighted sum of the logarithms of the normalized values (Formula 1, p. 19). Ultimately, the detailed calculation of entropy for each criterion allows us to measure the amount of information an indicator contributes to the model. In other words, the weighting of the independent variables depends on their ability to discriminate the rated alternatives i , leading to the analysis of their influence on station attendance.

$$S_j = -k \sum_{i=1}^n p_{ij} \ln(p_{ij}). \quad (1)$$

where :

S_j is the entropy of criterion j ;

n represents the total number of stations ;

p_{ij} is the normalized value of criterion j for station i ;

$k = \frac{1}{\ln(n)}$ is a normalization factor.

The next step consisted in calculating the degree of dispersion, referred to as the degree of diversification, for each criterion. A high variability, denoted as d_j , indicates that the criterion provides a more significant amount of information for the model (Formula 2, p. 19). Indicators with greater dispersion are identified as having a stronger influence on the dependent variable, namely the passenger flows.

$$d_j = 1 - S_j. \quad (2)$$

where :

j represents an independent indicator ;

d_j reflects the variability of criterion j ;

S_j is the entropy of criterion j .

The final step consisted in determining the relative weight of the indicators, denoted as w_j , ensuring that the sum of all weights is limited to 1 for each independent dimension (Formula 3, p. 19).

$$w_j = \frac{d_j}{\sum_{j=1}^n d_j}. \quad (3)$$

where :

w_j is the normalized weight of criterion j .

—4 Results and Discussion

Once the model’s calibration parameters have been established and the methodological protocol outlined, we present the statistical results derived from its application. First, we seek to identify the most influential factors driving the increase in rail traffic, a critical goal of *Transit-Oriented Development*. Based on this analysis, we highlight the key components on which public policies should focus to achieve a *Micromobility-friendly Transit-Oriented Development* (see the subsection on [the effects of examined factors](#), page 20). Next, we assess each station and its urban environment by positioning them within the model’s diagram to determine imbalances or mismatches (see the section on [the evaluation of the rail network](#), page 21). Finally, this analysis is complemented by a classification process that identifies strategic areas with development potential (see the section on [the regional classification](#), page 23).

—4 .1 Influence of Parameters Defining a Micromobility-friendly Transit-Oriented Development

Analyzing the indicators influencing station patronage provides a key lever for understanding the mechanisms underlying their attractiveness and, by extension, their ability to drive positive dynamics in mobility and urban systems. By cross-referencing statistical results with stakeholders’ representations, the objective is to identify points of convergence and divergence, thereby providing a fact-based vision of the priorities to be adopted in planning strategies (see Appendix, p. 38).

Impacts of Node Factors

From the perspective of network structure and station service levels, passenger traffic is primarily determined by the frequency of the high-speed rail network, both on weekdays (N_1) and weekends (N_2), according to the entropy-based weighting method (see Fig. 10, p. 20). Factors related to rail service frequency (from N_1 to N_4) also play a predominant role among the criteria evaluated by urban planners. Moreover, transit network connectivity—measured through closeness centrality (N_{11}) and degree centrality (N_9)—positively influences ridership. Conversely, service schedule temporal coverage (N_5 and N_6), accessibility to urban centralities (from N_{13} to N_{16}), and betweenness centrality (N_{10}) exert a lesser influence.

In light of previous NPMs, these statistical outcomes appear consistent with the conclusions highlighted in the literature. Regarding the dimension *node*, Cummings and Mahmassani (2022, p. 8) established that the number of weekly *Amtrak* services in the United States is the most influential variable in

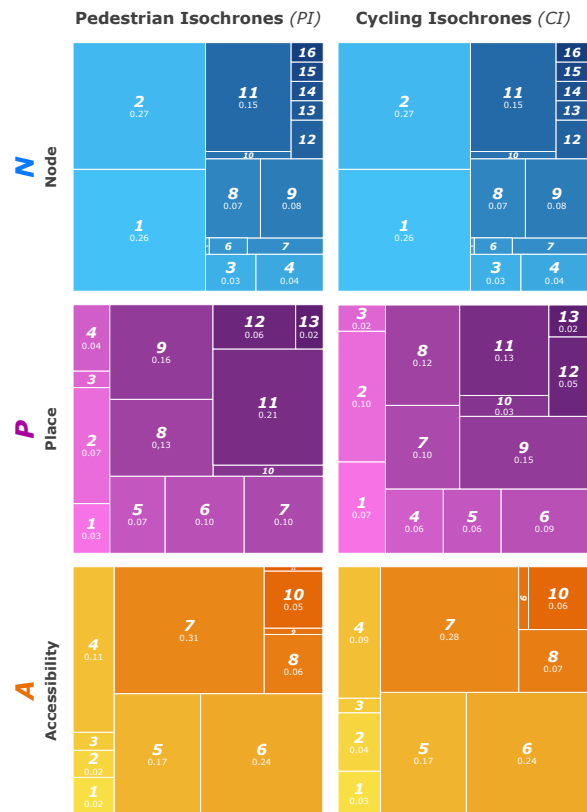


Fig. 10. Statistical Influence of Criteria on Walking and Cycling Scales on Station Ridership.

Authors: Moïnse, L’Hostis, Amini Pishro, Cissé, Lehmann, Zhang, Theureau, Adjero, Yuetong, and Xiao (2025)

various scenarios analyzed. Similar to Caset, Blainey, et al. (2020, p. 14), our study combined service frequency and destination centrality based on GTFS data for regional trains (TER and TERGV) and high-speed trains (TGV). Therefore, Caset, Blainey, et al. (2020, p. 14) observed that an increase in 1% the frequency of regional trains in Flanders, Belgium, translates into a 0.6% increase in the patronage of the railway network. They also determined that degree centrality is an even more decisive indicator: a 1% increase in its value tends to increase station patronage by 2%. In this regard, Amini Pishro, Q. Yang, et al. (2022, p. 11) identified this metric as one of the seven most influential indicators for boosting passenger volumes in Chengdu. Likewise, Cao et al. (2020, p. 9) emphasized degree centrality and the number of *express* lines as the two most critical variables, in Tokyo.

The fundamental role of rail service frequency illustrates how this indicator can significantly enhance station attractiveness. Simultaneously, the strategic positioning of a node within networks underscores the importance of network connectivity. Closeness centrality corresponds to a classical rail network accessibility indicator, thereby facilitating intermodal transfers, while degree centrality confirms the station’s role as a crucial node within the transport network. This suggests that *Transit-Oriented Development* should not be narrowly confined to the immediate surroundings of each station—its local urban environment—as some reductive analyses might imply (Cerema, 2015, p. 10). Instead, a multi-scalar approach is necessary, simultaneously

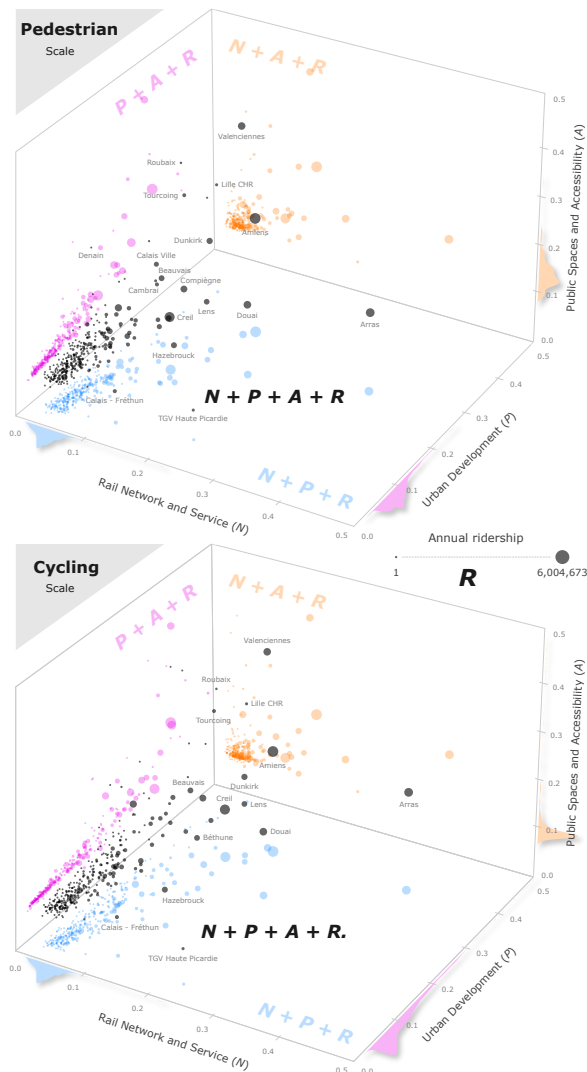


Fig. 11. Multidimensional Diagrams Positioning the Examined Stations (Excluding *Euraflandres* Station), based on Pedestrian and Cycling Isochrone Scales.

Authors: Moïnse, L’Hostis, Amini Pishro, Cissé, Lehmann, Zhang, Theureau, Adjeroud, Yuetong, and Xiao (2025)

Euraflandres, Lens, Lille CHR, Pont de Bois, Roubaix, Tourcoing, and Valenciennes (see Fig. 11, p. 22). As can be observed, the stations deemed “accessible” at the pedestrian scale are either located in Lille Metropolis or in the urban cores of certain sub-prefectures within the region.

It is therefore noteworthy that by expanding station areas, the number of “accessible” connection points in the region doubles. The 11 stations that join this category as a result of the cycling catchment areas are as follows: Beauvais, Béthune, Boulogne-sur-Mer, Boulogne – Tintelleries, Calais Ville, Creil, Croix – Wasquehal, La Madeleine, Lille Porte de Douai, Saint-Quentin, and Saint-Roch (see Fig. 11, p. 22). In this respect, the stations that become “accessible” following the isochrone extension are either located in other sub-prefectures of the region or in close proximity to the central stations of major urban areas.

The identification of a substantial majority of stations classified in the “dependence” category is hardly surprising at the regional scale, given the diversity of the territories covered and the variety of rail services within the studied system. In Brussels, Caset (2019, p. 46) highlights a predominance of “imbalanced” stations to the detriment of design. The observation of a larger share of stops exhibiting an imbalance at the expense of the place component is further supported by Kutty (2018, p. 190) and Monajem and Ekram Nosrati (2015, p. 19), who report this profile for 20% of metro stations in Tehran. Regarding BRT networks in Wates and Tehran, Alfyan and Widyastuti (2022, p. 15) and Pezeshknejad et al. (2020, p. 13) also identify a majority of stops in asymmetric situations, with poor assessment of urban development and walkability. We also observed that the number of stations characterized by strong coordination among the three analyzed dimensions doubles when the spatial extent of station areas is expanded, thereby validating the hypothesis formulated by Caset, Vale, et al. (2018, p. 518), which posits a marked contrast between rail service areas evaluated at 800 or 1,200 meters and those measured at 3,000 meters. This result suggests that increasing the spatial scale allows for a better capture of the local and regional dynamics that influence the “equilibrium” between transit network, territorial, and connectivity functions.

Profiles of “Accessible” and “Dependent” Stations based on Descriptive Indicators

On average, the weighted indicator values (IEW) for stations classified as “accessible” (A_{cs}) and “dependent” (D_{pt}) are as follows:

- For the node dimension (N), the weighted average value reaches 0.01 for N_{Acs} and 0.00 for N_{Dpt} across both pedestrian and cycling scales. The gap in favor of the former category is thus 5.05 times greater at the pedestrian scale (PI), while it narrows to 3.65 at the cycling scale (CI);
- Regarding the place dimension (P), the weighted average is 0.02 for P_{Acs} compared to 0.00 for P_{Dpt} at the pedestrian scale. This advantage in favor of accessible stations corresponds to a factor of 4.40 for PI and 3.64 for CI ;
- For the accessibility dimension (A), the weighted average reaches 0.03 for A_{Acs} and 0.01 for A_{Dpt} at the pedestrian scale. The difference is thus 3.52 for PI , and it decreases to 2.34 for CI ;
- Concerning ridership (RT), the normalized average value is 0.15 for RT_{Acs} and 0.01 for RT_{Dpt} . The resulting gap is 23.53 for PI and 18.35 for CI .

Stations classified as “accessible” exhibit significantly higher relative values in terms of high-speed rail frequency, regardless of the day of the week (N_1 and N_2). Moreover, for pedestrian station areas, they benefit from better urban rail transit service coverage (A_7), while for cycling station areas, they show stronger connections to bike-sharing services (A_6). Conversely, nodes classified as “dependent” are characterized by higher median household incomes (P_{13}), lower availability of car parking in public spaces (A_{10}), and greater residential specialization (P_3), regardless of the spatial scale considered. More broadly, the average indicator gap amounts to 12.10 at the pedestrian scale (PI) and 8.54 at the cycling scale (CI), suggesting that the cycling catchment area tends to somewhat mitigate disparities between “accessible” and “dependent” stations.

22.1841 **Strength and Direction of Relationships among the** 22.1842 **Model's Constitutive Dimensions**

23.1843 From the perspective of the four dimensions structuring the
23.1844 NPART framework, it appears that some of them are closely
23.1845 interconnected. By computing Pearson correlation matrices
23.1846 for each pair of dimensions, we first highlighted a particularly
23.1847 significant positive association between the dimension related
23.1848 to rail network quality (N) and that related to mobility
23.1849 demand for each station (RT). Across the entire initial
23.1850 dataset, the coefficient of determination R^2 reaches 0.93
23.1851 between the rail node and station ridership dimensions,
23.1852 regardless of the geographic perimeters considered (PI and
23.1853 CI). The associated t -test, with a high value of 43.60,
23.1854 demonstrates that this correlation is statistically highly
23.1855 significant. However, this strong linear relationship between
23.1856 the *Transit* and *Ridership per Time* components is only
23.1857 verified for the subgroup of stations classified as "accessible,"
23.1858 with a correlation coefficient of 0.96. Conversely, this
23.1859 coefficient drops to a moderate value of 0.53 when the
23.1860 analysis is limited to stations classified as "dependent." This
23.1861 observation results from a segmentation effect, indicating
23.1862 that the relationship between N and RT depends on the
23.1863 intensity and degree of articulation of values specific to each
23.1864 dimension, characterizing certain stations as so-called
23.1865 "accessible" nodes. Within this perspective, we also explored
23.1866 the existing relationships between the other dimensions.

23.1867 A second significant positive relationship is established
23.1868 between the node dimension (N) and design, embodied by
23.1869 public space development and local connectivity (A). The
23.1870 Pearson correlation coefficient R^2 reaches 0.75 for the
23.1871 pedestrian station area (PI) and 0.64 for the cycling station
23.1872 area (CI). Even more markedly than in the first examined
23.1873 relationship, a considerable gap is observed between stations
23.1874 classified as "accessible" and those deemed "dependent." The
23.1875 former exhibit high coefficients of determination (R^2 of 0.77
23.1876 for PI and 0.71 for CI), whereas for the latter, the correlation
23.1877 is almost non-existent (R^2 of 0.21 for PI and 0.02 for CI).

23.1878 A final significant positive linear relationship is observed
23.1879 between the dimensions related to place (P) and design (A).
23.1880 This can be seen on the left-hand side of the cube diagrams
23.1881 (see Fig. 11, p. 22). This association remains significant at
23.1882 both pedestrian and cycling scales, with coefficients of
23.1883 determination of 0.80 (with a t -test value of 23.36) and 0.77
23.1884 (with a t -test value of 21.47), respectively. These results
23.1885 suggest that the intensification of human activities within a
23.1886 given territory either drives or results from strong
23.1887 interdependencies with the quality of public spaces. While
23.1888 consistently distinguishing stations classified as "accessible"
23.1889 from those classified as "dependent," and unlike the two
23.1890 previously analyzed relationships, we observe minor
23.1891 variations concerning the pedestrian catchment areas, with
23.1892 correlation coefficients R^2 of 0.77 for the former and 0.72 for
23.1893 the latter. However, the gap is slightly more pronounced in
23.1894 cycling station areas, where "accessible" stations exhibit a
23.1895 coefficient of 0.80, compared to 0.65 for "dependent" ones.

23.1896 Statistical regression analysis applied to the various studied
23.1897 dimensions reveals interesting interdependencies,
23.1898 particularly within the subsample of stations classified as
23.1899 "accessible." These quantitative measures echo the work on
23.1900 the extended NPM developed by Vale et al. (2018, p. 289),
23.1901 which, similarly to our study, highlight a significant positive
23.1902 correlation between the dimensions associated with place and
23.1903 design. Likewise, Yuerong Zhang et al. (2019, p. 10) have
23.1904 demonstrated the same important link, with an R^2 of 0.81, as
23.1905 well as a relevant relationship between node and place (R^2 of
23.1906 0.70), thereby confirming the observation by Vale et al.
23.1907 (2018, p. 289) of a moderate correlation between node and
23.1908 design (R^2 of 0.60). However, this latter point differs from

our empirical observations, corroborated in literature (Papa
and Bertolini, 2015, p. 79), which seem to indicate a strong
correlation between N and A , particularly at the pedestrian
scale. Finally, the major positive relationship between N and
 RT , notably during peak hours, constitutes a novel
contribution to the NPM literature. This does not imply,
however, that a simple improvement of railway infrastructure
and service would suffice to increase demand. The bilateral
nature of the relationship similarly suggests that demand
induces infrastructure improvements, which evolve to meet
this growing demand.

By adopting an initial approach based on zones of
"accessibility" and "dependency," we were able to classify
and assign specific values to each studied station. It thus
emerges that stations classified as "accessible" benefit from
feedback effects among these four dimensions, as expressed
earlier in the current section. Nevertheless, as emphasized by
M. Zhang and J. B. Lee (2023, p. 4), "the original node-place
model's five types of categories do not encompass all
possible typologies of station areas and TODs." Beyond the
normative approach of the initial NPM model, in a *data
science* approach, the purpose of this modeling is to propose
a classification of stations and their catchment areas
according to their respective performances. It aims to move
beyond a binary categorization ("accessible" or "dependent")
to develop a more nuanced typology of nodal points and their
surrounding territories, taking into account their capacity to
comply with the principles of M-TOD. The ambition is not
limited to statistical classification; it also seeks, within a
framework converging data science and geography, to
contextualize and give meaning to these categories.

—4 .3 A Regional Classification to Guide Policy-making

The application of the employed method revealed three
classes of stations (see Fig. 12, p. 25). In the context of our
case study, the classification of the 318 stations and their
surrounding areas, both at the pedestrian scale (PI) and the
cycling scale (CI), led to the identification of a first class ($C1$)
grouping the most attractive stations, whose urban
environment is well-developed and well-planned; a second
class ($C2$), comprising stations with developed infrastructure
located in dynamic territories, but with a weak orientation
towards the mobility hub; and a final class ($C3$), made up of
stations with poorer service and located in territories where
the automobile predominates.

Classification of the Regional Railway Network and their Surroundings

Nearly all of stations classified as "dependent" in the region
fall into the last two classes. For PI , only 5.7% of stations are
assigned to class $C1$ (18 stations), while 47.5% are in $C2$ (151
stations) and 46.9% in $C3$ (149 stations). However, for CI , the
number of stations in $C1$ doubles (10.7%, 34 stations), mainly
at the expense of $C2$ (41.8%, 133 stations), while $C3$ retains a
similar share (47.5%, or 151 stations). Thus, extending station
areas using cycling modes allows various stops to progress
from class $C2$ to $C1$. It is interesting to note that while the
expansion of station areas doubles the number of stations in
 $C1$, among the 16 new stations integrated into this category, 7
of them remain classified as "dependent" (see Fig. 11, p. 22).

This observation suggests that the typology based on the
original NPM model is not only less precise but also deviates
from the statistical classification carried out. This finding

24.1971 24.1972 24.1973 24.1974 24.1975 24.1976 24.1977 24.1978	aligns with contemporary critiques in the scientific literature, which advocate moving away from a simplistic interpretation based solely on a normative and strictly diagrammatic view. Thus, the classification approach allows us to deepen the characterization of stations and their surroundings, going beyond the simple dichotomy between “accessible” and “non-accessible” stations, particularly through the distinction that emerges between classes C2 and C3.	24.2026
24.1979	Towards a Temporal Classification	24.2027
24.1980 24.1981 24.1982 24.1983 24.1984 24.1985 24.1986 24.1987 24.1988 24.1989 24.1990 24.1991	Through a more dynamic analysis based on the temporality of flows, we observe a slight evolution in the classification. We examined the distribution of stations within the classes defined according to the RT_2 reference. It is interesting to note that, while the proportion of C1 remains relatively stable around 6% for the pedestrian scale (PI), it fluctuates between 6% and 13% at the cycling scale (CI). However, the class showing the greatest variation is undoubtedly C2, particularly during RT_2 and RT_4 periods, corresponding to morning peak hours. Indeed, the share of C2 is higher during peak periods and for CI , indicating increased attractiveness of stations in these spatio-temporal contexts.	24.2028 24.2029 24.2030 24.2031 24.2032 24.2033 24.2034 24.2035
24.1992 24.1993 24.1994 24.1995 24.1996 24.1997 24.1998 24.1999 24.2000 24.2001	In an effort to gain a more systemic view of the changes in station class affiliation, we adopted the approach developed by Caset, Vale, et al. (2018, p. 518), which they called the “DNA sequence.” This approach allows the representation of a station’s affiliation to its clusters based on the variation in the size of its surrounding area. The “DNA sequence,” denoted DNA , consists in an ordered succession of classes to which each station is associated, depending on the considered temporal scales (RT_1 to RT_6) and geographical scales (PI and CI) (see equation 4, page 24).	24.2036 24.2037 24.2038 24.2039 24.2040 24.2041 24.2042 24.2043 24.2044 24.2045 24.2046 24.2047 24.2048 24.2049 24.2050 24.2051 24.2052 24.2053 24.2054 24.2055
24.2002	$DNA_k = \sum_{k=1}^6 (C_{PI}^{RT_k} + C_{CI}^{RT_k}). \quad (4)$ <p>where: DNA_k is the DNA sequence of station k.</p>	24.2056 24.2057 24.2058 24.2059 24.2060 24.2061 24.2062 24.2063 24.2064 24.2065 24.2066 24.2067 24.2068 24.2069
24.2003 24.2004 24.2005 24.2006 24.2007	Finally, nearly as many combinations as stations are observed, with no less than 263 unique sequences across the railway network for the 12 components analyzed. This result shows that only 1.89% of stations consistently retain the same class affiliation. However, several recurrent chains can be cited:	24.2070 24.2071 24.2072 24.2073 24.2074 24.2075 24.2076 24.2077 24.2078 24.2079 24.2080 24.2081 24.2082 24.2083 24.2084
24.2008 24.2009 24.2010 24.2011 24.2012 24.2013 24.2014 24.2015	<ul style="list-style-type: none"> • “C2C2C2C2C2C2 – C2C2C2C2C2C2”, representing stations entirely within C2; • “C2C2C2C2C2C2 – C1C1C1C1C1C1”, corresponding to stations that transition from C2 in the PI context to C1 for CI across all periods; • “C3C3C3C3C3C3 – C2C2C2C2C2C3”, denoting stations that move from C3 to C2 across all time intervals except weekends. 	24.2085 24.2086 24.2087 24.2088 24.2089 24.2090 24.2091 24.2092
24.2016 24.2017 24.2018 24.2019 24.2020 24.2021 24.2022 24.2023 24.2024 24.2025	Continuing the exploration of the typology thus obtained, and after clarifying the distribution of stations within each category, we now undertake a detailed analysis of these classes. The following section provides a definition of the identified categories from an urban planning perspective, supported by a statistical analysis of the determining factors. This interpretative framework not only helps to grasp the specificities of each class but also offers a conceptual reading of the observed distinctions, shedding light on the spatial and functional logics underlying this regional classification.	24.2093 24.2094 24.2095 24.2096 24.2097 24.2098 24.2099 24.2100 24.2101 24.2102
	From Definition to Interpretation of the Categories	24.2103
	In order to define the categories as faithfully as possible to the statistical data, while offering a simplified framework for operationalization and communication, we chose to draw inspiration from the “butterfly model” as the visual framework for analysis. This conceptual representation was adopted by Caset (2019, p. 52), who applied it to the Belgian stations of Waterloo, Watermael, and Buggenhout, relying on the initial models developed by the Hollande-Septentrionale and Association Deltametropolis (2024).	24.2104 24.2105 24.2106 24.2107 24.2108 24.2109 24.2110 24.2111 24.2112 24.2113 24.2114 24.2115 24.2116 24.2117 24.2118 24.2119 24.2120 24.2121 24.2122 24.2123 24.2124 24.2125
	Based on Fig. 13, (p. 26), divided into four axes constituting the NPART model, we have the opportunity to compare not only the normalized and weighted values of each dimension and variable but also the two types of station areas. It appears that the dimensions related to station ridership during morning peak hours (RT_2) and the concentration and diversification of urban functions (P) generally present the lowest values. This statistical observation suggests that some stations compensate for low urban intensity with higher accessibility. In this specific case, the contribution of urban intensity to ridership is low in many cases, indicating potential for development through urban intensification. However, the weakest indicators are almost all found in the dimension related to local connectivity (A), particularly regarding metro and tram service coverage (A_7), bike-sharing systems (A_6), bicycle parking availability (A_5), and the length of the cycling network (A_4), for both pedestrian (PI) and cycling (CI) catchment areas. This suggests that bike-friendly connections remain largely marginalized.	24.2126 24.2127 24.2128 24.2129 24.2130 24.2131 24.2132 24.2133 24.2134 24.2135 24.2136 24.2137 24.2138 24.2139 24.2140 24.2141 24.2142 24.2143 24.2144 24.2145 24.2146 24.2147 24.2148 24.2149 24.2150 24.2151 24.2152 24.2153 24.2154 24.2155
	In light of these data, we are able to give a more precise meaning to this classification within the regional context of our empirical study. At this stage, it is important to consider that class C1 encompasses stations and their surrounding urban areas, accessible by foot or by bike, that adhere to or approach the principles of TOD and M-TOD planning. The first class, C1, displays remarkably high scores across the four dimensions that constitute the NPART, positioning these stations as the closest candidates to the TOD model and its variant, compared to what is present in the studied network. This class is primarily distinguished by better cycling connections within public spaces, a strategic position within the technical network, and strong industrial and commercial attractiveness.	24.2156 24.2157 24.2158 24.2159 24.2160 24.2161 24.2162 24.2163 24.2164 24.2165 24.2166 24.2167 24.2168 24.2169
	Class C2, on the other hand, holds TOD development potential, under certain conditions that we will elaborate on. If C1 displays weighted average values significantly higher than those of C2, with differences of 103% for P (PI) and 92% (CI), 103% for A (PI) and 50% (CI), and 815% for RT_2 (PI) and 343% (CI), the gap narrows for N , reaching only 36% (PI) and 16% (CI). These disparities thus raise a relevant question about the identity of C2. The main differences are observed in the treatment of public spaces. This allows us to infer that C2 encompasses stations with potential for rail-oriented urban development, as the infrastructure and rail service are of good quality, although there are gaps in terms of human activity concentration and territorial hospitality. Furthermore, these are TOD station areas with a residential dominance.	24.2170 24.2171 24.2172 24.2173 24.2174 24.2175 24.2176 24.2177 24.2178 24.2179 24.2180 24.2181 24.2182 24.2183 24.2184
	Finally, class C3 records very low scores across all the NPART indicators. The quality of rail service (N) is generally not ensured, with low frequency of trains, reduced commercial speed, and a poor strategic position within the network, offering few directional choices and limited access to other stations within a given distance-time. The surrounding areas are weakly developed or poorly designed (P), with very low employment density, relatively few green spaces, a very	24.2185 24.2186 24.2187 24.2188 24.2189 24.2190 24.2191 24.2192

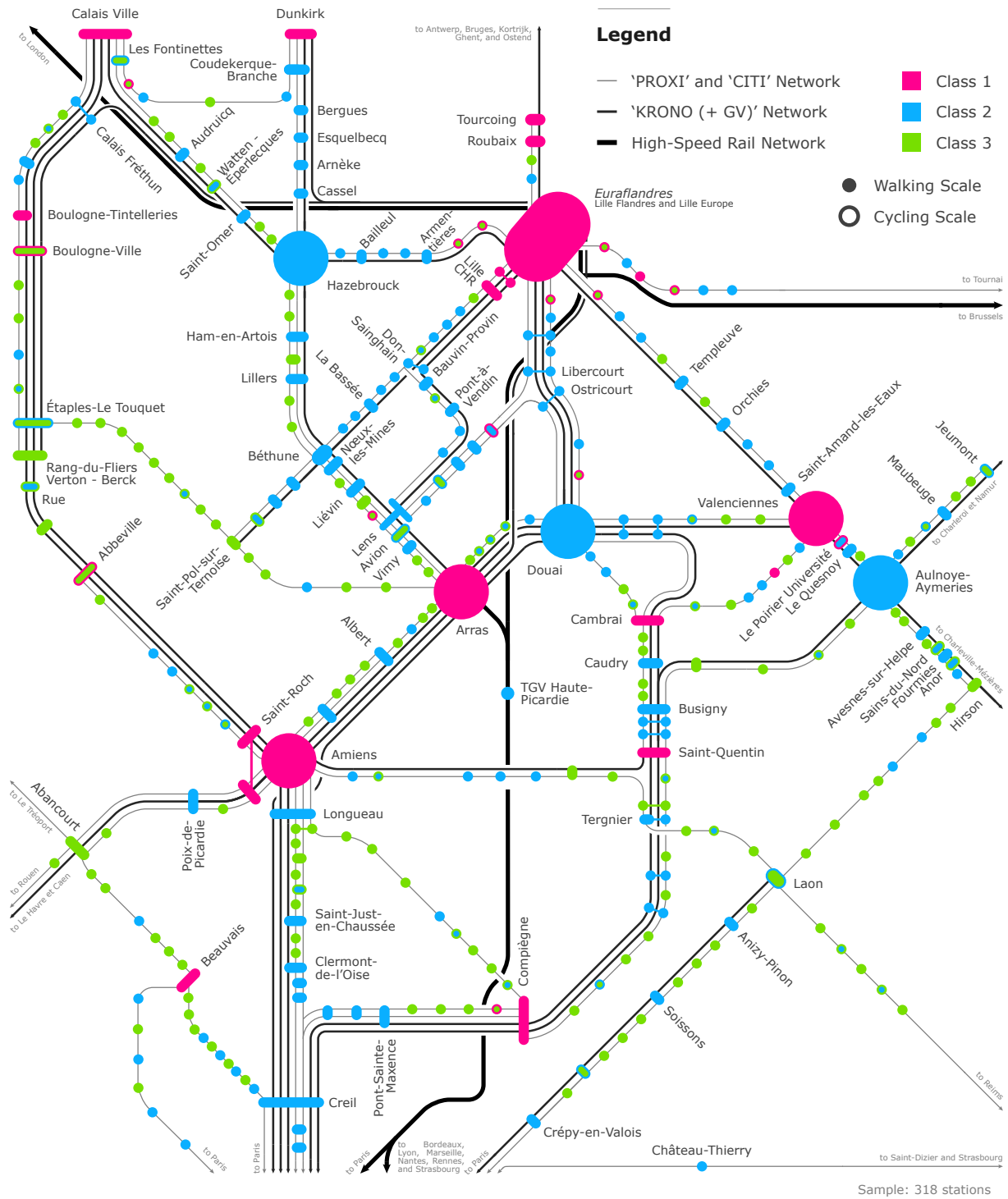


Fig. 12. Regional Classification of Station Areas Accessible by Walking and Cycling, Based on Three Classes.

Authors: Moïnse, L'Hostis, Amini Pishro, Cissé, Lehmann, Zhang, Theureaux, Adjeroud, Yuetong, and Xiao (2025)

25.2093
25.2094
25.2095

limited number of POIs, and low land attractiveness for industrial and commercial sectors. These areas also tend to host more affluent populations. In addition to the need for

urban intensification, these station areas do little to promote the use of the walking, cycling, and public transport triptych (A). Cycling infrastructure is virtually non-existent for both

25.2096
25.2097
25.2098

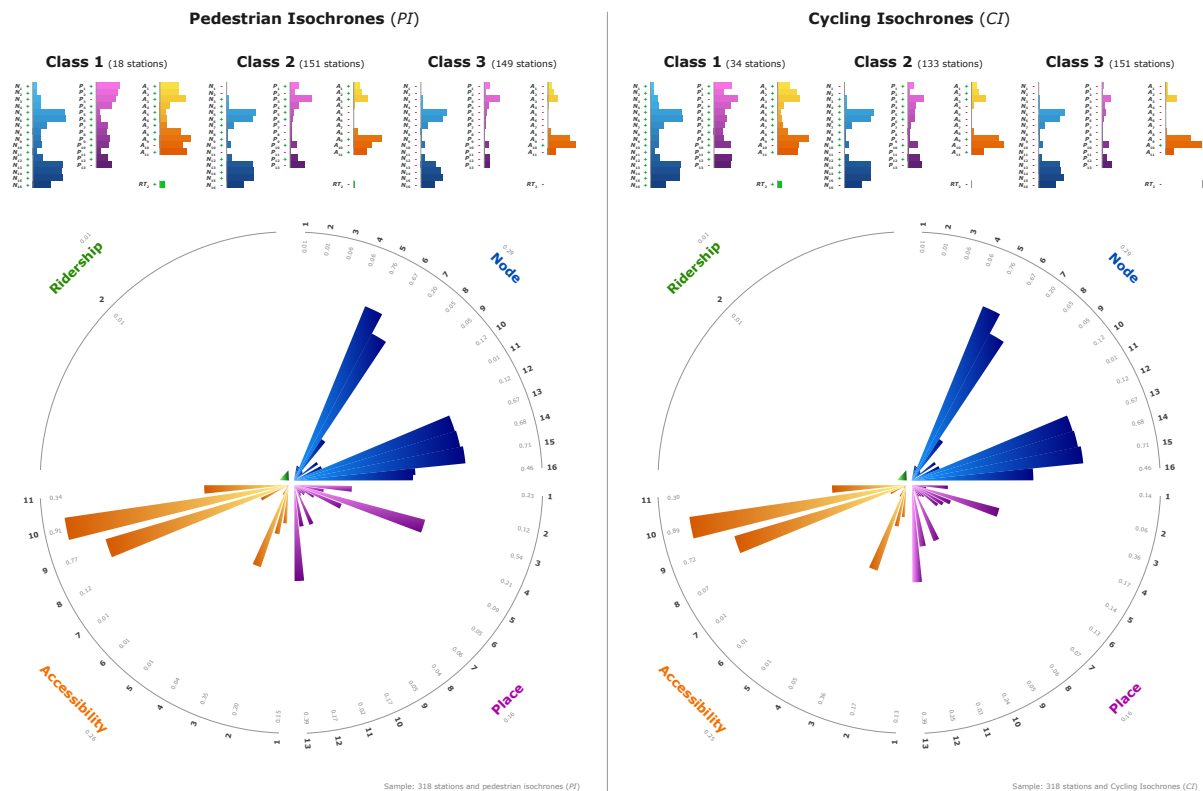


Fig. 13. Radar Chart of the NPART Model Indicators by Station Area Class.

Authors: Moïnse, L’Hostis, Amini Pishro, Cissé, Lehmann, Zhang, Theureaux, Adjeroud, Yuetong, and Xiao (2025)

26.2099 *PI* and *CI*, and bus service remains very limited. Moreover, 26.2100 the space allocated to cars is generous, with moderate 26.2101 restrictions on motorized traffic and a high rate of car 26.2102 ownership among residents. Finally, this lack of accessibility 26.2103 and development is reflected in very low ridership at the 26.2104 stations (RT_2). In a way, class C3 does not designate 26.2105 “stations to close,” but rather stations with potential, where it 26.2106 would be appropriate to explore development avenues 26.2107 combining *N*, *P*, and *A* in relevant and realistic combinations, 26.2108 in order to increase ridership and trigger the TOD virtuous 26.2109 circle (Jamme et al., 2019, p. 416). This leads us to remind 26.2110 that the concept of urban planning is primarily a metropolitan 26.2111 and regional “pearl necklace,” and that each element of the 26.2112 system, from the largest to the smallest, has a role to play. 26.2113 Thus, the smallest stations should not be overlooked.

26.2114 The detailed analysis of each station leads us to summarize 26.2115 them concisely, in line with the requirements of the 26.2116 classification, as follows: C1 includes nodes and areas truly 26.2117 oriented towards rail or those that tend towards this urban 26.2118 planning model, C2 pertains to nodes and areas with TOD 26.2119 potential—some of which could also fall under 26.2120 Transit-Adjacent Development (Renne, 2009, p. 3)—and C3 26.2121 corresponds to car-centric nodes and areas, which tend to 26.2122 turn their backs on railway transport infrastructure. This 26.2123 distinction between TOD, TAD, and car-dominated systems 26.2124 follows the clustering produced within the NPM framework by 26.2125 Z. Li et al. (2019, p. 271). Specifically questioning the actual 26.2126 presence of TAD within these groupings, it became clear that 26.2127 it was necessary to go beyond the simple typology opposing 26.2128 TOD, TAD, and non-TOD. Based on a commonly accepted

26.2129 definition of TAD, characterized by a high level of public 26.2130 transport service, a high population density, and, conversely, 26.2131 relatively low ridership and density of pedestrian and cycling 26.2132 areas, we identified 86 pedestrian station areas (*PI*) and 33 26.2133 cycling station areas (*CI*), distributed across the entire set of 26.2134 classes. Among the *PI* perimeters, 63% belong to class C3 26.2135 (54 stations), while 34% are in C2 (29 stations). For the *CI* 26.2136 perimeters, the distribution is more balanced, with 21% in C3 26.2137 and 55% in C2. The results suggest that the concept of TAD 26.2138 transcends the established typological classes, calling for a 26.2139 reconsideration of their meaning. To this end, we drew 26.2140 inspiration from the four clusters identified by L. Yang and 26.2141 Song (2021, p. 249), who distinguish between “already 26.2142 TODs” (*ATOD*); “potential TODs” (*PTOD*); “improvable 26.2143 TODs” (*ITOD*); and “no TODs” (*NTOD*). By transposing this 26.2144 analytical framework to our own results, we propose a 26.2145 reading grid to requalify our three classes. Class C1 could be 26.2146 assimilated to an *ATOD*, that is, a fully structured area 26.2147 according to the principles of TOD and M-TOD. Class C2 26.2148 would correspond to a *PTOD*, i.e., an area that meets the 26.2149 fundamental conditions to evolve into a mature TOD and 26.2150 M-TOD model. Finally, class C3 would resemble more of an 26.2151 *ITOD*, marked by an incomplete spatial organization and 26.2152 requiring adjustments to maximize its rail-oriented urban 26.2153 development potential.

26.2154 The proposed classification of station areas was validated 26.2155 using a triangulation approach that combined quantitative 26.2156 analysis, planning references, and expert input. First, the 26.2157 results were benchmarked against regional planning 26.2158 documents and technical reports, which confirmed the

relevance of our regional typology. The proposed station area classification is fully aligned with the objectives set out in national and regional planning documents. It operationalizes several ambitions defined in the SRADDET³¹, including the increase the modal share of public transport between 10% and 12% (Région Hauts-de-France, 2024b, p. 169). Furthermore, our approach complements the bike-and-ride priorities to increase the modal share of cycling from 3% to 12%, expressed in the *planification régionale de l'intermodalité* (PRI), *planification régionale des infrastructures de transports* (PRIT), and *schéma régional des véloroutes et voies vertes* (SR3V) by offering a spatialized tool to identify and prioritize stations where walking and cycling can serve as viable feeder modes to regional rail (Région Hauts-de-France, 2024a, p. 46). Moreover, the segmentation provided by the national *Document de Référence des Gares* (DRG) (SNCF Gares & Connexions, 2024), as well as the earlier classification developed for the former Picardie region prior to its integration into Hauts-de-France (CETE Nord Picardie and DREAL Picardie, 2011), served as external validation references. These classifications distinguish stations based on annual ridership and territorial significance. While most of the stations in our study align with these existing classifications, our approach incorporates a broader set of indicators, enabling a more dynamic and fine-grained typology. In particular, it highlights stations with untapped development potential at walking and cycling scales, which are not always captured by conventional segmentation methods. Lastly, we recently had the opportunity to present the results of our NPART model to urban and transport planning practitioners involved in our case study area, during a dedicated workshop organized with planners working in the *Région Hauts-de-France*, the *Métropole Européenne de Lille* (MEL), and the *Agence de développement et d'urbanisme de Lille Métropole* (ADULM). The discussions confirmed the strategic relevance of the proposed classification, which was recognized as a useful framework for supporting integrated planning approaches and identifying priority areas for intervention. The shared and spatialized nature of the typology was particularly appreciated for its potential to foster dialogue between institutions and to inform operational decision-making.

—5 Conclusion

Developing station neighborhoods often requires prioritizing one aspect or criterion over others, thereby raising international debates around TOD regarding the feasibility of simultaneously optimizing a large number of parameters (Veloso e Zarate and Triggianese, 2024, p. 181). In this perspective, it is essential to identify the levers of action and their effects in order to promote TODs supported by active mobility, especially in a context where specialized forms of TOD are emerging (Cervero et al., 2017, p. 111). Within this framework, we developed the NPART model, designed to identify and better understand the mechanisms supporting an *Micromobility-friendly TOD* (Moïnse, 2025b, p. 621).

The classification of stations and their surroundings revealed three distinct classes, thereby refining the overall picture of

³¹ The *schéma régional d'aménagement, de développement durable et d'égalité des territoires* (SRADDET) of the Hauts-de-France region, adopted in 2020 and revised in 2024, is the strategic instrument that sets the objectives and general rules applicable to intercommunal urban planning documents. Regarding mobility, this plan precisely defines the region's medium- and long-term ambitions in terms of intermodality, development of passenger transport, logistics, planning of regional infrastructure and routes of regional interest, as well as its airport strategy for certain airfields (Cerema, 2024, p. 1). This strategic document is structured around three major ambitions for 2050: (i) a connected region, (ii) enhanced multipolarity for balanced development, and (iii) a rethought daily life, focused on new proximities and improved quality of life (Région Hauts-de-France, 2024b, p. 7).

the rail network, which is predominantly composed of so-called "dependent" stations—both at the pedestrian and cycling scales. Only 6% of stations fall within the class corresponding to the TOD model, while nearly half of the network belongs to the category of stations with TOD potential. Notably, the share of stations in the first class—considered to reflect the highest level of urban development—doubles when the boundaries of station neighborhoods are expanded. This finding highlights the importance of promoting solutions adapted to the first and last mile issue, such as bike-and-ride. Furthermore, improvements in design—significantly supported by cycling infrastructure—are positively correlated with other dimensions of the model. These interdependencies underscore the strategic role of the connection between rail service quality and urban development intensity, thus confirming the value of an integrated approach to enhance both the attractiveness and functionality of the areas served.

Through this modelling process, we were able to better define and situate the impact of the main criteria contributing to the definition of an M-TOD approach. On the side of infrastructure and public transport service—both at the pedestrian and cycling scales—factors such as rail service frequency, betweenness centrality, centrality degree, number of directions served, and the number of stations accessible within one hour prove to be decisive for increasing station usage. Regarding activity intensity, key components include the land value of industrial, commercial, and office functions, the presence of "superior" and "intermediate" POIs, as well as the availability of green spaces. However, at the cycling scale, job density emerges as an even more decisive factor, ranking highest among all key indicators. Finally, in terms of local connectivity, metro and tram service, along with elements fostering a comprehensive territorial hospitality toward cycling—such as the presence of bikeshare systems, bicycle parking, and dedicated cycling infrastructure—are the most influential factors at both spatial scales.

By structuring these contributions around a reflection on infrastructures, mobility services, and the territorial configurations of station areas, an *Micromobility-friendly TOD* (M-TOD) formalized by Moïnse (2025b, p. 621) helps renew our interpretation of rail-based urbanism and the planning strategies for territories served by rail. This study thus represents the translation of theoretical and empirical findings into a structured and operational proposal for intermodal rail-oriented urbanism. By fully integrating cycling into the design of station areas and intermodal hubs, the M-TOD opens up a new perspective on urban mobility planning. It transcends a segmented view of transport modes to promote a high-performing intermodal system articulated with the urban fabric. These reflections provide concrete tools for urban stakeholders seeking to integrate cycling into their land use policies and public transport strategies.

For the purpose of showcasing the model as a practical and interactive visual tool, we developed a prototype dynamic map using the *Python* programming language. This map could later be enhanced through the integration of *JavaScript* for increased interactivity. Concretely, this mapping interface allows users to navigate among the various stations in the region and to explore the different criteria of the model, both through numerical data and radar charts for *PI*, *PB*, *CI*, and *CB* (see Fig. 14, p. 28). The associated radar chart puts this information into perspective relative to other stations, enhancing the readability of results and facilitating their interpretation in a decision-making or operational context (see *Data Availability* section, p. 30).

While the dissemination of our model represents a key step in ensuring a robust scientific outcome, we remain aware of

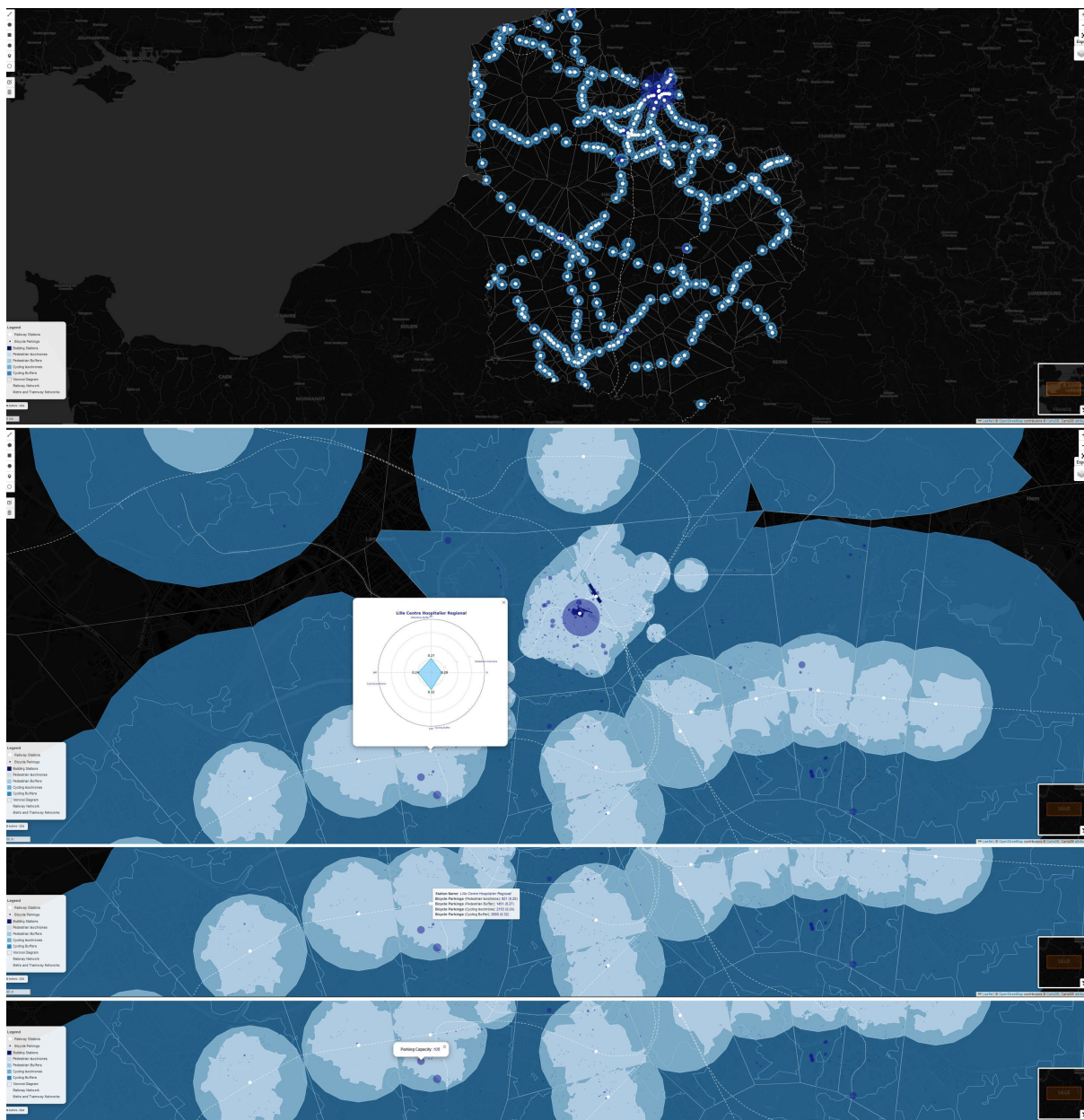


Fig. 14. Visual Examples from the Interactive Map Showing Bicycle Parking Locations.

Authors: Moine, L'Hostis, Amini Pishro, Cissé, Lehmann, Zhang, Theureau, Adjeroud, Yuetong, and Xiao (2025)

28.2284 certain limitations. By focusing on the direct applications of
28.2285 these recommendations, the relevance of an M-TOD strategy
28.2286 could be further consolidated through an in-depth study
28.2287 regarding shared mobility, more specifically about dockless
28.2288 services, which has been only marginally addressed in this
28.2289 work due to its limited deployment in the studied area.
28.2290 Likewise, the analysis should be extended to other transport
28.2291 networks, particularly bus systems, while data collection
28.2292 should be enhanced by novel techniques like street view data
28.2293 (J. Liu et al., 2025, p. 7). A complementary reflection also
28.2294 raises questions about the economic and financial models
28.2295 needed to support the development of an M-TOD. Finally,

28.2296 although NPMs are grounded in empirical observations that
28.2297 reflect local transport and land-use dynamics, this very
28.2298 specificity raises a potential paradox regarding their
28.2299 transferability. This underscores the importance of their
28.2300 structured analytical framework and adaptable set of
28.2301 indicators, which together enable the model to be
28.2302 recalibrated for diverse geographical contexts. Such a
28.2303 balance makes NPMs both robust and sensitive to local
28.2304 planning conditions.

28.2305 Broadening these perspectives, a study on the
28.2306 implementation conditions of an M-TOD through the lens of

29.2307 governance and stakeholder dynamics also appears essential.
29.2308 An evaluation of institutional levers and regulatory
29.2309 mechanisms could provide concrete tools for action in
29.2310 support of this renewed urban planning model. Finally, a
29.2311 relevant extension of this research would be to compare
29.2312 several geographical contexts to assess the transferability of
29.2313 the conclusions to diverse territories. The study of M-TOD
29.2314 would thus benefit from being applied to areas with varied
29.2315 urban configurations and transport systems, as well as being
29.2316 updated in our case study with the upcoming joint
29.2317 implementation of a rail project—the *Services express*
29.2318 *régionaux métropolitains* (SERM)—and a cycling infrastructure
29.2319 project—the *Vélo Plus* network—around the Lille metropolitan
29.2320 area.

CRedit Author Statement

30.2321

Dylan Moïnse: Conceptualization; Methodology; Software; Investigation; Writing - Original Draft; Visualization. **Alain L'Hostis:** Conceptualization; Methodology; Validation; Writing - Review & Editing; Supervision; Project administration; Funding acquisition. **Ahad Amini Pishro:** Conceptualization; Methodology; Software; Validation; Investigation; Writing - Review & Editing; Visualization; Supervision. **Ndèye Aïta Cissé:** Conceptualization; Methodology; Validation; Investigation; Writing - Review & Editing. **Xavier Lehmann:** Conceptualization; Methodology; Validation; Investigation; Writing - Review & Editing. **Shiquan Zhang:** Conceptualization; Methodology; Validation; Supervision; Writing - Review & Editing. **Olivier Theureau:** Software; Validation; Writing - Review & Editing. **Heythem Adjeroud:** Validation; Writing - Review & Editing. **Yuetong Liu:** Formal analysis. **Qixiao Hu:** Formal analysis.

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Data Availability

30.2364

The authors have made this model both reproducible and adaptable by sharing the programming code developed for extracting and processing spatial databases and station areas (Moïnse, L'Hostis, et al., 2025). The code is publicly accessible for review and reuse in the following GitHub repository: <https://github.com/dylan-moine/Node-Place-Accessibility-Ridership-Time-Model>.

References

30.2372

- 6t-Bureau de recherche** (2019). *Livre blanc de la mobilité en free-floating : Pour une régulation efficace et pertinente des services*, p. 144. URL: <https://www.ademe.fr/livre-blanc-mobilite-free-floating-regulation-efficace-pertinente-services> (visited on 08/13/2020) (cited on page 1). 30.2373
- ADULM** (2017). *Rapport de présentation du SCOT de Lille Métropole - Livre I*. Agence de développement et d'urbanisme de Lille Métropole, p. 288. URL: <https://www.scot-lille-metropole.org/cartes-et-ressources/documents-de-reference/rapport-de-presentationscot-de-lille-metropole-livre-i/> (visited on 01/29/2023) (cited on page 9). 30.2378
- ADULM** and **Cattan**, Nadine (2016). *Métropolisation & systèmes territoriaux au sein de la région Hauts-de-France. Premières réflexions pour une approche renouvelée des relations entre les territoires de la nouvelle région*. Rapport d'étude. Agence de développement et d'urbanisme de Lille Métropole, p. 88. URL: <https://www.adu-lille-metropole.org/wp-content/uploads/2021/05/MetroSysTerr.pdf> (visited on 12/02/2024) (cited on page 7). 30.2385
- Albertelli**, Marion (2024). "Les variations de l'insertion urbaine des gares françaises : des infrastructures métropolitaines à trois visages : technique, monumental et serviciel". PhD thesis. Université Panthéon-Sorbonne - Paris I. URL: <https://theses.hal.science/tel-04788958> (visited on 11/22/2024) (cited on page 1). 30.2386
- Alfyan**, Muhammad Yusuf and **Widyastuti**, Dyah Titisari (2022). "Node-Place Model Analysis on Attached Transit Oriented Development (TOD) Areas : The Case of Wates Train and Bus Station Area". In: *Built Environment Studies* 3.1. Number: 1 Publisher: Department of Architecture and Planning, Faculty of Engineering, Universitas Gadjah Mada, pp. 8-16. ISSN: 2746-9069. DOI: 10/gtg7ff (cited on page 2). 30.2387
- Amar**, Georges (2016). *Homo mobilis : Une civilisation du mouvement*. 2e édition. Limoges: FYP EDITIONS. 224 pp. ISBN: 978-2-36405-133-1. (Visited on 05/15/2021) (cited on page 1). 30.2388
- Amini Pishro**, Ahad, **L'Hostis**, Alain, **Chen**, Dong, **Chen**, Mojdeh, **Amini Pishro**, Mojdeh, **Zhang**, Zhengrui, **Li**, Jun, **Zhao**, Yuandi, and **Zhang**, Lili (2023). "The Integrated ANN-NPRT-HUB Algorithm for Rail-Transit Networks of Smart Cities: A TOD Case Study in Chengdu". In: *Structure* 13, p. 24. DOI: 10/gsmfkk (cited on page 19). 30.2389
- Amini Pishro**, Ahad, **Yang**, Qihong, **Zhang**, Shiquan, **Amini Pishro**, Mojdeh, **Zhang**, Zhengrui, **Zhao**, Yana, **Postel**, Victor, **Huang**, Dengshi, and **Li**, WeiYu (2022). "Node, Place, Ridership, and Time Model for Rail-Transit Stations: a Case Study". In: *Scientific Reports* 12.1. Number: 1 Publisher: Nature Publishing Group, p. 16120. ISSN: 2045-2322. DOI: 10/gtg7fd (cited on pages 2, 5, 20, 21). 30.2390
- Arliani**, Vani, **Sjafuruddin**, Ade, **Santoso**, Idwan, and **Winarso**, Haryo (2023). "Measuring TOD Index in Jakarta with Accessibility and Land Use Function - Case Study on Three Transit Nodes". In: Proceedings of the International Conference on Sustainable Engineering, Infrastructure and Development, ICO-SEID 2022, 23-24 November 2022, Jakarta, Indonesia. ISBN: 978-1-63190-437-0. URL: <https://eudl.eu/doi/10.4108/eai.23-11-2022.2341568> (visited on 02/12/2024) (cited on page 14). 30.2400
- Banister**, David (2008). "The Sustainable Mobility Paradigm". In: *Transport Policy*. New Developments in Urban Transportation Planning 15.2. Number: 2, pp. 73-80. ISSN: 0967-070X. DOI: 10/csnq4v (cited on page 2). 30.2401
- Barone**, Sylvain and **Thébert**, Mariane (2020). "Transports". In: *Dictionnaire des politiques territoriales*. Vol. 2. Presses 30.2402

- 30.2442 de Sciences Po, pp. 543–548. ISBN: 978-2-7246-2600-1.
31.2443 DOI: 10.3917/scpo.pasqu.2020.01.0543 (cited on page 7).
- 31.2444 **Bavoux**, Jean-Jacques (2005). "La nodalité : un concept
31.2445 fondamental de l'organisation de l'espace. Introduction au
31.2446 dossier". In: *Les Cahiers Scientifiques du Transport -*
31.2447 *Scientific Papers in Transportation* 48 | 2005. Publisher:
31.2448 Episciences.org. ISSN: 2804-2107, 1150-8809. DOI:
31.2449 10/gt2v9p (cited on page 21).
- 31.2450 **Bentayou**, Gilles (2015). "Le Transit-Oriented Development
31.2451 nord-américain : principes et vue d'ensemble. Articuler
31.2452 urbanisme et transport. Les contrats d'axes français à la
31.2453 lumière du Transit-Oriented Development (TOD)". In:
31.2454 pp. 56–90 (cited on page 1).
- 31.2455 **Bentayou**, Gilles, **Perrin**, Emmanuel, and **Richer**, Cyprien
31.2456 (2015). "Contrat d'axe et Transit-Oriented Development :
31.2457 quel renouvellement de l'action publique en matière de
31.2458 mobilité et d'aménagement ? (Point de vue d'acteurs)".
31.2459 In: *Flux* 101-102.3. Number: 3-4 Place: Marne-la-Vallée
31.2460 Publisher: Université Gustave Eiffel, pp. 111–123. ISSN:
31.2461 1154-2721. DOI: 10/grgv78 (cited on page 7).
- 31.2462 **Bergès**, Sébastien (2023). "Plus de 3 millions de locations :
31.2463 des chiffres 2022 « historiques » pour le V'lille". In: *La*
31.2464 *Voix du Nord*. Section: Se déplacer. URL:
31.2465 [https://www.lavoixdunord.fr/1397853/article/2023-11-](https://www.lavoixdunord.fr/1397853/article/2023-11-17/plus-de-3-millions-de-locations-des-chiffres-2022-historiques-pour-le-v-lille)
31.2466 [17/plus-de-3-millions-de-locations-des-chiffres-2022-](https://www.lavoixdunord.fr/1397853/article/2023-11-17/plus-de-3-millions-de-locations-des-chiffres-2022-historiques-pour-le-v-lille)
31.2467 [historiques-pour-le-v-lille](https://www.lavoixdunord.fr/1397853/article/2023-11-17/plus-de-3-millions-de-locations-des-chiffres-2022-historiques-pour-le-v-lille) (visited on 11/24/2023)
31.2468 (cited on page 8).
- 31.2469 **Bernier**, Xavier (2023). *Atlas des mobilités et des transports*
31.2470 *- Pratiques, flux et échanges: Pratiques, flux et échanges.*
31.2471 Illustrated édition. Paris: AUTREMENT. 96 pp. ISBN: 978-
31.2472 2-08-029625-2 (cited on page 1).
- 31.2473 **Bertolini**, Luca (1996). "Nodes and Places: Complexities of
31.2474 Railway Station Redevelopment". In: *European Planning*
31.2475 *Studies* 4.3. Number: 3, pp. 331–345. ISSN: 0965-4313.
31.2476 DOI: 10/fr4z3r (cited on pages 2, 9).
- 31.2477 — (1999). "Spatial Development Patterns and Public
31.2478 Transport: The Application of an Analytical Model in the
31.2479 Netherlands". In: *Planning Practice and Research*.
31.2480 Publisher: Taylor & Francis Group. DOI: 10/fckj75 (cited
31.2481 on pages 1, 2, 5, 21).
- 31.2482 — (2017). *Planning the Mobile Metropolis: Transport for*
31.2483 *People, Places and the Planet*. 1st ed. 2017 édition.
31.2484 London: Red Globe Press. 253 pp. ISBN:
31.2485 978-0-230-30877-0 (cited on page 1).
- 31.2486 **Boeing**, Geoff (2017). "OSMnx: New Methods for Acquiring,
31.2487 Constructing, Analyzing, and Visualizing Complex Street
31.2488 Networks". In: *Computers, Environment and Urban*
31.2489 *Systems* 65, pp. 126–139. ISSN: 0198-9715. DOI:
31.2490 10/gbvjxq (cited on pages 10, 11).
- 31.2491 **Bonin**, Olivier, **Bonneau**, Patricia, **Clerc**, Milan,
31.2492 **Cousin**, Julie, **Frankhauser**, Pierre,
31.2493 **Gouvello**, Bernard de, **Haffner**, Maud, **Lehmann**, Xavier,
31.2494 **Pioli**, Rémi, **Poirel**, Maylis, **Stransky**, Vaclav, and
31.2495 **Thébert**, Mariane (2020). *Projet SOFT*. Rapport de
31.2496 recherche. ThéMA, Institut pour la Transition Énergétique,
31.2497 Efficacy, LVMT, p. 214. URL:
31.2498 <https://hal.science/hal-03111221> (visited on 06/02/2024)
31.2499 (cited on page 12).
- 31.2500 **Bortoli**, Anne de and **Christoforou**, Zoi (2020).
31.2501 "Consequential LCA for Territorial and Multimodal
31.2502 Transportation Policies: Method and Application to the
31.2503 Free-Floating E-Scooter Disruption in Paris". In: *Journal of*
31.2504 *Cleaner Production* 273, p. 122898. ISSN: 0959-6526.
31.2505 DOI: 10/gg5qjn (cited on page 1).
- 31.2506 **Burlando**, Claudia and **Guihéry**, Laurent (2004). "La
31.2507 régionalisation du transport ferroviaire régional de
31.2508 voyageurs : expériences françaises et italiennes". In: *Les*
31.2509 *Cahiers Scientifiques du Transport / Scientific Papers in*
31.2510 *Transportation* 45 | 2004, p. 125. DOI: 10/g8tnrb (cited on
31.2511 page 7).
- 31.2512 **Butts**, Kuan (2017). *Better Rendering of Isochrones from*
31.2513 *Network Graphs*. kuan butts. URL:
<http://kuanbutts.com/2017/12/16/osm-nx-isochrones/>
(visited on 11/29/2022) (cited on page 10).
- 31.2514 **Calthorpe**, Peter (1993). *The Next American Metropolis:*
31.2515 *Ecology, Community, and the American Dream*. 3e édition.
31.2516 New York: Princeton Architectural Press. 175 pp. ISBN:
31.2517 1-878271-68-7. (Visited on 05/22/2020) (cited on
31.2518 page 1).
31.2519
31.2520
- 31.2521 **Cao**, Zhejing, **Asakura**, Yasuo, and **Tan**, Zongbo (2020).
31.2522 "Coordination between Node, Place, and Ridership:
31.2523 Comparing Three Transit Operators in Tokyo". In:
31.2524 *Transportation Research Part D: Transport and*
31.2525 *Environment* 87, p. 102518. ISSN: 13619209. DOI:
31.2526 10/gjt53r (cited on pages 3, 5, 13, 18, 20).
- 31.2527 **Caset**, Freke (2019). "Planning for Nodes, Places, and People
31.2528 : a Strategic Railway Station Development Tool for
31.2529 Flanders". PhD thesis. Ghent University. URL:
31.2530 <http://hdl.handle.net/1854/LU-8637955> (visited on
31.2531 02/12/2024) (cited on pages 13, 22, 24).
- 31.2532 **Caset**, Freke, **Blainey**, Simon, **Derudder**, Ben, **Boussauw**,
31.2533 Kobe, and **Witlox**, Frank (2020). "Integrating Node-Place
31.2534 and Trip End Models to Explore Drivers of Rail Ridership
31.2535 in Flanders, Belgium". In: *Journal of Transport Geography*
31.2536 87, p. 102796. ISSN: 0966-6923. DOI: 10/gmf83x (cited on
31.2537 pages 3, 20).
- 31.2538 **Caset**, Freke, **Vale**, David S., and **Viana**, Cláudia M. (2018).
31.2539 "Measuring the Accessibility of Railway Stations in the
31.2540 Brussels Regional Express Network: a Node-Place
31.2541 Modeling Approach". In: *Networks and Spatial Economics*
31.2542 18.3. Number: 3, pp. 495–530. ISSN: 1572-9427. DOI:
31.2543 10/gjt5w3 (cited on pages 2, 21, 22, 24).
- 31.2544 **Cerema** (2015). *Articuler urbanisme et transport. Les*
31.2545 *contrats d'axe français à la lumière du Transit-Oriented*
31.2546 *Development (TOD)*. SKU1837104219. Issue:
31.2547 SKU1837104219, p. 152. URL:
31.2548 [https://www.cerema.fr/fr/centre-](https://www.cerema.fr/fr/centre-ressources/boutique/articuler-urbanisme-transport-tod)
31.2549 [ressources/boutique/articuler-urbanisme-transport-tod](https://www.cerema.fr/fr/centre-ressources/boutique/articuler-urbanisme-transport-tod)
31.2550 (visited on 02/26/2023) (cited on page 20).
- 31.2551 — (2017). *La mobilité en 2017, quelle organisation*
31.2552 *institutionnelle ?* URL: [https://www.cerema.fr/fr/centre-](https://www.cerema.fr/fr/centre-ressources/newsletters/flash-mobilites-ex-transflash/transflash-ndeg-411-mai-juillet-2017/mobilite-2017-quelle-organisation-institutionnelle)
31.2553 [ressources/newsletters/flash-mobilites-ex-](https://www.cerema.fr/fr/centre-ressources/newsletters/flash-mobilites-ex-transflash/transflash-ndeg-411-mai-juillet-2017/mobilite-2017-quelle-organisation-institutionnelle)
31.2554 [transflash/transflash-ndeg-411-mai-juillet-](https://www.cerema.fr/fr/centre-ressources/newsletters/flash-mobilites-ex-transflash/transflash-ndeg-411-mai-juillet-2017/mobilite-2017-quelle-organisation-institutionnelle)
31.2555 [2017/mobilite-2017-quelle-organisation-institutionnelle](https://www.cerema.fr/fr/centre-ressources/newsletters/flash-mobilites-ex-transflash/transflash-ndeg-411-mai-juillet-2017/mobilite-2017-quelle-organisation-institutionnelle)
31.2556 (visited on 12/03/2024) (cited on page 7).
- 31.2557 — (2024). *SRADDET et mobilités*. Cerema, p. 7. URL:
31.2558 [https://outil2amenagement.cerema.fr/ressources/guides-](https://outil2amenagement.cerema.fr/ressources/guides-fiches/sraddet-et-mobilites)
31.2559 [fiches/sraddet-et-mobilites](https://outil2amenagement.cerema.fr/ressources/guides-fiches/sraddet-et-mobilites) (visited on 02/24/2024)
31.2560 (cited on page 27).
- 31.2561 **Cervero**, Robert (1998). *The Transit Metropolis: A Global*
31.2562 *Inquiry*. 4th ed. édition. Washington, D.C: Island Press.
31.2563 480 pp. ISBN: 978-1-55963-591-2 (cited on page 21).
- 31.2564 — (2020). "The Transit Metropolis: A 21st Century
31.2565 Perspective". In: *Transportation, Land Use, and*
31.2566 *Environmental Planning*. Elsevier, pp. 131–149. ISBN:
31.2567 978-0-12-815167-9. DOI:
31.2568 10.1016/B978-0-12-815167-9.00007-4 (cited on page 1).
- 31.2569 **Cervero**, Robert, **Guerra**, Erick, and **Al**, Stefan (2017).
31.2570 "Transit-Oriented Development". In: *Beyond Mobility:*
31.2571 *Planning Cities for People and Places*. Washington, DC:
31.2572 Island Press/Center for Resource Economics, pp. 109–142.
31.2573 ISBN: 978-1-61091-835-0. DOI:
31.2574 10.5822/978-1-61091-835-0_7 (cited on page 27).
- 31.2575 **CESER Hauts-de-France** (2021). *La mobilité en*
31.2576 *Hauts-de-France, voir loin, agir maintenant. Rapport-avis.*
31.2577 Conseil Économique, Social et Environnement Régional,
31.2578 p. 114. URL: [https://ceser.hautsdefrance.fr/rapports/article/la-mobilite-](https://ceser.hautsdefrance.fr/rapports/article/la-mobilite-en-hauts-de-france-voir-loin-agir-maintenant-810)
31.2579 [en-hauts-de-france-voir-loin-agir-maintenant-810](https://ceser.hautsdefrance.fr/rapports/article/la-mobilite-en-hauts-de-france-voir-loin-agir-maintenant-810) (visited
31.2580 on 05/29/2022) (cited on pages 7, 8).
31.2581
- 31.2582 **CETE Nord Picardie** and **DREAL Picardie** (2011). *Les profils*
31.2583 *des gares de Picardie*. 72. Issue: 72, p. 6. URL: [https://](https://www.hauts-de-france.developpement-durable.gouv.fr/?no-)
31.2584 www.hauts-de-france.developpement-durable.gouv.fr/?no-

- 31.2585 72-Dec-2011-Les-profils-des-gares-de-Picardie (visited on
32.2586 01/11/2022) (cited on page 27).
- 32.2587 **Chauvineau, Jacques** (2001). *La régionalisation ferroviaire*.
32.2588 Rapport public. Conseil économique et social, p. 173. URL:
32.2589 [https://www.vie-publique.fr/rapport/28096-la-](https://www.vie-publique.fr/rapport/28096-la-regionalisation-ferroviaire)
32.2590 [regionalisation-ferroviaire](https://www.vie-publique.fr/rapport/28096-la-regionalisation-ferroviaire) (visited on 04/13/2022)
32.2591 (cited on page 7).
- 32.2592 **Chen, Xueming and Lin, Lin** (2015). "The Node-Place
32.2593 Analysis on the "Hubtropolis" Urban Form: The Case of
32.2594 Shanghai Hongqiao Air-Rail Hub". In: *Habitat International*
32.2595 49, pp. 445–453. ISSN: 0197-3975. DOI: 10/ghk3bx (cited
32.2596 on page 4).
- 32.2597 **Chorus, Paul and Bertolini, Luca** (2011). "An Application of
32.2598 the Node Place Model to Explore the Spatial Development
32.2599 Dynamics of Station Areas in Tokyo". In: *Journal of*
32.2600 *Transport and Land Use* 4.1. Number: 1 Publisher: Journal
32.2601 of Transport and Land Use, pp. 45–58. ISSN: 1938-7849.
32.2602 URL: <https://www.jstor.org/stable/26201661> (visited on
32.2603 02/04/2024) (cited on pages 1, 2, 5).
- 32.2604 **Commission nationale du débat public** (2024).
32.2605 *Chronologie : le transport ferroviaire, compétence*
32.2606 *régionale*. [debatpublic.fr](https://cpdp.debatpublic.fr/). URL:
32.2607 [https://cpdp.debatpublic.fr/cdpd-regl/chronologie-](https://cpdp.debatpublic.fr/cdpd-regl/chronologie-transport-ferroviaire-competence-regionale.html)
32.2608 [transport-ferroviaire-competence-regionale.html](https://cpdp.debatpublic.fr/cdpd-regl/chronologie-transport-ferroviaire-competence-regionale.html) (visited
32.2609 on 12/03/2024) (cited on page 7).
- 32.2610 **Cormack, R. M.** (1971). "A Review of Classification". In:
32.2611 *Journal of the Royal Statistical Society. Series A (General)*
32.2612 134.3. Number: 3 Publisher: [Royal Statistical Society,
32.2613 Wiley], pp. 321–367. ISSN: 0035-9238. DOI: 10/fv3scd
32.2614 (cited on page 18).
- 32.2615 **Cummings, Christopher and Mahmassani, Hani** (2022).
32.2616 "Does Intercity Rail Station Placement Matter? Expansion
32.2617 of the Node-Place Model to Identify Station Location
32.2618 Impacts on Amtrak Ridership". In: *Journal of Transport*
32.2619 *Geography* 99, p. 103278. ISSN: 0966-6923. DOI:
32.2620 10/gtg7fs (cited on pages 14, 19–21).
- 32.2621 **Dalvi, M. Q. and Martin, K. M.** (1976). "The Measurement of
32.2622 Accessibility: Some Preliminary Results". In: *Transportation*
32.2623 5.1. Number: 1, pp. 17–42. ISSN: 1572-9435. DOI: 10/
32.2624 bh3cr7 (cited on page 2).
- 32.2625 **Debrezion, Ghebreegziabih, Pels, Eric, and Rietveld, Piet**
32.2626 (2009). "Modelling the Joint Access Mode and Railway
32.2627 Station Choice". In: *Transportation Research Part E:*
32.2628 *Logistics and Transportation Review* 45.1. Number: 1,
32.2629 pp. 270–283. DOI: 10/fqbnp7 (cited on page 13).
- 32.2630 **Deimon, Tristan Buteau** (2024). "Les projets de Services
32.2631 express métropolitains au défi des chemins de
32.2632 dépendances techniques et institutionnels : le cas des
32.2633 métropoles de l'ex-région Rhône-Alpes". In: *Flux* 137.3.
32.2634 Number: 3 Publisher: Université Gustave Eiffel, pp. 23–38.
32.2635 ISSN: 1154-2721. DOI: 10/g8tnrc (cited on page 7).
- 32.2636 **Dou, Mingxuan, Wang, Yandong, and Dong, Shihai** (2021).
32.2637 "Integrating Network Centrality and Node-Place Model to
32.2638 Evaluate and Classify Station Areas in Shanghai". In:
32.2639 *ISPRS International Journal of Geo-Information* 10.6.
32.2640 Number: 6 Publisher: Multidisciplinary Digital Publishing
32.2641 Institute, p. 414. ISSN: 2220-9964. DOI: 10/gqjj52 (cited
32.2642 on page 13).
- 32.2643 **Ducharme, Olivier** (2021). *Ville contre automobiles :*
32.2644 *Redonner l'espace urbain aux piétons*. Illustrated édition.
32.2645 Editions Ecosociété. 200 pp. ISBN: 978-2-89719-678-3
32.2646 (cited on page 1).
- 32.2647 **Ducruet, César and Beauguitte, Laurent** (2014). "Spatial
32.2648 Science and Network Science: Review and Outcomes of a
32.2649 Complex Relationship". In: *Networks and Spatial*
32.2650 *Economics* 14.3. Number: 3, pp. 297–316. ISSN:
32.2651 1572-9427. DOI: 10/f6rkv4 (cited on page 2).
- 32.2652 **Dupuy, Gabriel** (1991). *L'urbanisme des réseaux, théories et*
32.2653 *méthodes*. Pages: 198. Paris: Armand Colin. ISBN: 978-
32.2654 2-200-31294-7. URL: [https://shs.hal.science/halshs-](https://shs.hal.science/halshs-00438867)
32.2655 [00438867](https://shs.hal.science/halshs-00438867) (visited on 01/06/2022) (cited on page 1).
- Everitt, Brian S., Landau, Sabine, Leese, Morven, and Stahl, Daniel** (2011). *Cluster Analysis*. 5e édition. Chichester: Wiley. 346 pp. ISBN: 978-0-470-74991-3 (cited on page 18).
- Forsch, Axel and Haurert, Jan-Henrik** (2023). "Metrochrones: Schematic Isochrones for Schematic Metro Maps". In: *The Cartographic Journal* 60.4. Number: 4 Publisher: Taylor & Francis, eprint: <https://doi.org/10.1080/00087041.2023.2284436>, pp. 383–401. ISSN: 0008-7041. DOI: 10.1080/00087041.2023.2284436 (cited on page 8).
- Gallez, Caroline** (2018). *La Dépendance automobile. Symptômes, analyses, diagnostic, traitement de Gabriel Dupuy* (1999). Forum Vies Mobiles. URL: [https://forumviesmobiles.org/livres-clefs/12645/la-](https://forumviesmobiles.org/livres-clefs/12645/la-dependance-automobile-symptomes-analyses-diagnostic-traitement-de-gabriel-dupuy-1999)
32.2667 [dependance-automobile-symptomes-analyses-diagnostic-](https://forumviesmobiles.org/livres-clefs/12645/la-dependance-automobile-symptomes-analyses-diagnostic-traitement-de-gabriel-dupuy-1999)
32.2668 [traitement-de-gabriel-dupuy-1999](https://forumviesmobiles.org/livres-clefs/12645/la-dependance-automobile-symptomes-analyses-diagnostic-traitement-de-gabriel-dupuy-1999) (visited on 12/05/2024)
32.2669 (cited on page 7).
- GART** (2024). *Les AOM régionales*. URL: [https://www.gart.org/nos-adherents-autorites-](https://www.gart.org/nos-adherents-autorites-organisatrices-mobilite-regionales/)
32.2674 [organisatrices-mobilite-regionales/](https://www.gart.org/nos-adherents-autorites-organisatrices-mobilite-regionales/) (visited on
32.2675 12/03/2024) (cited on page 7).
- Geovelo** (2024). *Pistes Cyclables en France*. [geovelo.app](https://www.geovelo.app/blog/piste-cyclable/). URL: [https://www.geovelo.app/blog/piste-](https://www.geovelo.app/blog/piste-cyclable/)
32.2678 [cyclable/](https://www.geovelo.app/blog/piste-cyclable/)
32.2679 (visited on 12/08/2024) (cited on page 8).
- Google Maps** (2024). *Google Maps*. Google Maps. URL: [maps.google.fr](https://www.google.fr/maps) (visited on 03/18/2024) (cited on page 15).
- Gordon, A. D.** (1999). *Classification*. Classification, 2nd ed. Pages: x, 256. Boca Raton, FL: Chapman & Hall/CRC. x, 256. ISBN: 978-1-58488-013-4. DOI: 10.1201/9781584888536 (cited on page 18).
- Hasiak, Sophie and Bodard, Géraldine** (2016). "Influence Areas of Railway Stations: How Can We Explain Their Geographic Forms?" In: World Congress on Railway Research. URL: [https://halshs.archives-ouvertes.fr/halshs-](https://halshs.archives-ouvertes.fr/halshs-01715927)
32.2687 [01715927](https://halshs.archives-ouvertes.fr/halshs-01715927)
32.2688 (visited on 02/24/2022) (cited on page 9).
- Heddebaut, Odile and Di Ciommo, Floridae** (2018). "City-Hubs for Smarter Cities. The Case of Lille "EuraFlandres" Interchange". In: *European Transport Research Review* 10.1. Number: 1 Publisher: SpringerOpen, pp. 1–14. ISSN: 1866-8887. DOI: 10/ch2h (cited on page 9).
- Héran, Frédéric** (2001). "Le système vélo". 3e journée d'étude de la FUBicy. 3e journée d'étude de la FUBicy. Pour un usage généralisé du vélo. Lyon. (Visited on 10/01/2023) (cited on page 21).
- (2009). "Des distances à vol d'oiseau aux distances réelles ou de l'origine des détours". In: *Flux* 76-77.2. Number: 2-3 Place: Bû Publisher: Métropolis, pp. 110–121. ISSN: 1154-2721. DOI: 10/ggw6bx (cited on page 9).
- (2015). *Le retour de la bicyclette. Une histoire des déplacements urbains en Europe, de 1817 à 2050*. La Découverte (20 août 2015). Poche / Essais. 256 pp. ISBN: 978-2-7071-8681-2. (Visited on 06/17/2020) (cited on page 21).
- Héran, Frédéric and Pouillaude, Laurence** (2009). "Les zones de desserte à pied autour des stations de transport public urbain". In: Communication au 2e colloque francophone de la Plate-Forme Intégratrice COPIE (Comportement du Piéton dans son Environnement) de l'INRETS : Le Piéton : nouvelles connaissances, nouvelles pratiques et besoins de recherche. Lyon, p. 14. URL: [http://heran.univ-lille1.fr/wp-content/uploads/Zones-](http://heran.univ-lille1.fr/wp-content/uploads/Zones-accessibles-a-%CC%80-pied-2009.pdf)
32.2712 [accessibles-a-%CC%80-pied-2009.pdf](http://heran.univ-lille1.fr/wp-content/uploads/Zones-accessibles-a-%CC%80-pied-2009.pdf) (visited on
32.2713 11/17/2019) (cited on page 10).
- Higgins, Christopher D. and Kanaroglou, Pavlos S.** (2016). "Forty Years of Modelling Rapid Transit's Land Value Uplift in North America: Moving Beyond the Tip of the Iceberg". In: *Transport Reviews* 36.5. Number: 5, pp. 610–634. DOI: 10/ggw575 (cited on page 2).

- 33.2727 **Hollande-Septentrionale** and **Association**
33.2728 **Deltametropolis** (2024). *Maak Plaats! Werken aan*
33.2729 *knooppuntontwikkeling in Noord-Holland*.
33.2730 9789076630168. Issue: 9789076630168 Section:
33.2731 mobiliteit en bereikbaarheid. URL:
33.2732 <https://deltametropool.nl/publicaties/maak-plaats-nieuwe-visie-op-ruimtegebruik-in-noord-holland/> (visited
33.2733 on 02/09/2024) (cited on page 24).
33.2734
- 33.2735 **Hu, Songhua, Chen, Mingyang, Jiang, Yuan, Sun, Wei, and**
33.2736 **Xiong, Chenfeng** (2022). "Examining Factors Associated
33.2737 with Bike-and-Ride (BnR) Activities Around Metro Stations
33.2738 in Large-Scale Dockless Bikesharing Systems". In: *Journal*
33.2739 *of Transport Geography* 98, p. 103271. ISSN: 0966-6923.
33.2740 DOI: 10/gr6nhn (cited on page 9).
- 33.2741 **Huang, Runjie, Grigolon, Anna, Madureira, Ana Mafalda,**
33.2742 **and Brussel, Mark** (2018). "Measuring Transit-Oriented
33.2743 Development (TOD) Network Complementarity based on
33.2744 TOD Node Typology". In: *Journal of Transport and Land*
33.2745 *Use* 11.1. Number: 1. ISSN: 1938-7849. DOI: 10/gdmj5p
33.2746 (cited on page 14).
- 33.2747 **IAU** (2017). *Articulation entre gares et quartiers de gare : la*
33.2748 *méthode Node-Place*. Note rapide 762. Issue: 762. Institut
33.2749 d'Aménagement et d'Urbanisme Île-de-France, p. 6. URL:
33.2750 <https://www.institutparisregion.fr/nos-travaux/publications/articulation-entre-gares-et-quartiers-de-gare-la-methode-node-place/> (visited on
33.2751 02/04/2024) (cited on pages 2, 3).
33.2752
- 33.2753 **Ibrahim, Sara, Ayad, Hany, and Saadallah, Dina** (2022).
33.2754 "Planning Transit-Oriented Development (TOD): A
33.2755 Systematic Literature Review of Measuring the
33.2756 Transit-Oriented Development Levels". In: *International*
33.2757 *Journal of Transport Development and Integration* 6,
33.2758 pp. 378–398. DOI: 10/gr9c72 (cited on pages 3, 5).
33.2759
- 33.2760 **Ibrahim, Sara, Ayad, Hany, Turki, Eslam, and**
33.2761 **Saadallah, Dina** (2023). "Measuring Transit-Oriented
33.2762 Development (TOD) Levels: Prioritize Potential Areas for
33.2763 TOD in Alexandria, Egypt Using GIS-Spatial Multi-Criteria
33.2764 Based Model". In: *AEJ - Alexandria Engineering Journal*
33.2765 67, pp. 241–255. DOI: 10/gstdfj (cited on page 14).
- 33.2766 **Insee** (2021). *Base permanente des équipements*. Insee.fr.
33.2767 URL: <https://www.insee.fr/fr/metadonnees/source/serie/s1161> (visited on 05/20/2024) (cited on page 14).
33.2768
- 33.2769 — (2023). *Documentation fichier détail : Mobilités*
33.2770 *professionnelles*. Insee.fr. URL:
33.2771 <https://www.insee.fr/fr/information/2383243> (visited on
33.2772 10/02/2023) (cited on page 8).
- 33.2773 **Ivan, Igor, Boruta, Tomáš, and Horak, Jiri** (2012).
33.2774 "Evaluation of Railway Surrounding Areas: The Case of
33.2775 Ostrava City". In: *Urban Transport XVIII*. International
33.2776 Conference on Urban Transport and the Environment.
33.2777 Vol. 128. Journal Abbreviation: WIT Transactions on the
33.2778 Built Environment Pages: 152 Publication Title: WIT
33.2779 Transactions on the Built Environment. Valence: WIT
33.2780 Transactions on The Built Environment, pp. 141–152.
33.2781 ISBN: 978-1-84564-580-9. DOI: 10.2495/UT120131 (cited
33.2782 on page 13).
- 33.2783 **Izembard, Arnaud** (2020). "Loi d'orientation des mobilités :
33.2784 du transport à la mobilité". In: *Droit et Ville* 89.1. Number: 1
33.2785 Publisher: Institut des Études Juridiques de l'Urbanisme, de
33.2786 la Construction et de l'Environnement, pp. 281–292. ISSN:
33.2787 0396-4841. DOI: 10/g8tnq9 (cited on page 7).
- 33.2788 **Jahaniana, Mojtaba, Karimi, Abbas, and**
33.2789 **Zarafshan, Faraneh** (2022). "Selecting Optimal k in the
33.2790 k-Means Clustering Algorithm". In: *Journal of Computer &*
33.2791 *Robotics Summer and Autumn*.21. Number: 21–27, p. 7
33.2792 (cited on page 18).
- 33.2793 **James, Gareth, Witten, Daniela, Hastie, Trevor, and**
33.2794 **Tibshirani, Robert** (2013). *An Introduction to Statistical*
33.2795 *Learning: with Applications in R*. 1st ed. 2013, Corr. 7th
33.2796 printing 2017 edition. New York: Springer. 440 pp. ISBN:
33.2797 978-1-4614-7137-0 (cited on page 18).
- Jamme, Huê-Tâm, Rodriguez, Janet, Bahl, Deepak, and**
33.2798 **Banerjee, Tridib** (2019). "A Twenty-Five-Year Biography
33.2799 of the TOD Concept: From Design to Policy, Planning, and
33.2800 Implementation". In: *Journal of Planning Education and*
33.2801 *Research* 39.4. Publisher: SAGE Publications Inc,
33.2802 pp. 409–428. ISSN: 0739-456X. DOI:
33.2803 10.1177/0739456X19882073 (cited on page 26).
33.2804
- Jang, Seongman and An, Youngsoo** (2022). "Influence of
33.2805 Centrality Indices of Urban Railway Stations: Social
33.2806 Network Analysis of Transit Ridership and Travel
33.2807 Distance". In: *Journal of Regional and City Planning* 33.3.
33.2808 Number: 3, pp. 323–344. ISSN: 2502-6429. DOI:
33.2809 10/gt27qs (cited on page 13).
33.2810
- Kamruzzaman, Md., Baker, Douglas, Washington, Simon,**
33.2811 **and Turrell, Gavin** (2014). "Advance Transit Oriented
33.2812 Development Typology: Case Study in Brisbane,
33.2813 Australia". In: *Journal of Transport Geography* 34,
33.2814 pp. 54–70. ISSN: 0966-6923. DOI: 10/gddwk3 (cited on
33.2815 pages 2, 3).
33.2816
- Kang, Wei** (2020). "University Students' Adoption and
33.2817 Post-Adoption Behaviors of New Mobility Services in China
33.2818 : Three Empirical Essays". PhD thesis. Université Paris-Est.
33.2819 URL: <https://theses.hal.science/tel-03331932> (visited on
33.2820 12/30/2024) (cited on page 1).
33.2821
- Kashfi, Syeed Anta, Bunker, Jonathan M., and**
33.2822 **Yigitcanlar, Tan** (2015). "Effects of Transit Quality of
33.2823 Service Characteristics on Daily Bus Ridership". In:
33.2824 *Transportation Research Record* 2535.1. Number: 1
33.2825 Publisher: SAGE Publications Inc, pp. 55–64. ISSN:
33.2826 0361-1981. DOI: 10/gt27nm (cited on page 13).
33.2827
- Kim, Hyojin, Sultana, Selima, and Weber, Joe** (2018). "A
33.2828 Geographic Assessment of the Economic Development
33.2829 Impact of Korean High-Speed Rail Stations". In: *Transport*
33.2830 *Policy* 66, pp. 127–137. ISSN: 0967-070X. DOI: 10/gh6cvn
33.2831 (cited on page 14).
33.2832
- Krismer, Nikolaus** (2017). "Enhancing isochrones in
33.2833 multimodal spatial networks". PhD thesis. Faculty of
33.2834 Mathematics, Computer Science and Physics of the
33.2835 University of Innsbruck. 156 pp. URL: <https://ulb-dok.uibk.ac.at/ulbtirolhs/content/titleinfo/2290756>
33.2836 (visited on 11/27/2024) (cited on page 9).
33.2837
- Kuby, Michael, Barranda, Anthony, and**
33.2838 **Upchurch, Christopher** (2004). "Factors Influencing
33.2839 Light-Rail Station Boardings in the United States". In:
33.2840 *Transportation Research Part A: Policy and Practice* 38.3.
33.2841 Number: 3, pp. 223–247. ISSN: 0965-8564. DOI:
33.2842 10/dpqwn (cited on page 13).
33.2843
- Kutty, Najeeba Ali Kunju Abdulla** (2018). "Assessment And
33.2844 Classification Of Transit Stations For Transit Oriented
33.2845 Development (Tod) Potential Using Node-Place Model: The
33.2846 Case Of Doha Gold Metro Line". Accepted:
33.2847 2019-03-11T11:32:31Z. Master Thesis. URL:
33.2848 <http://qspace.qu.edu.qa/handle/10576/11400> (visited on
33.2849 02/04/2024) (cited on page 22).
33.2850
- Le Bot, Nils** (2019). "Quel avenir pour les gares
33.2851 métropolitaines françaises et allemandes ? analyse
33.2852 prospective de la dialectique « système gare » : ville, face
33.2853 au devenir des politiques publiques françaises &
33.2854 allemandes en matière de transport". Thèse de doctorat.
33.2855 Université Toulouse le Mirail - Toulouse II ; Universität
33.2856 Potsdam. URL: <https://theses.hal.science/tel-02417572>
33.2857 (visited on 01/14/2024) (cited on page 9).
33.2858
- Lebedeva, Olga, Kripak, Marina, and Gozbenko, Valeriy**
33.2859 (2018). "Increasing Effectiveness of the Transportation
33.2860 Network by Using the Automation of a Voronoi Diagram".
33.2861 In: *Transportation Research Procedia*. System and digital
33.2862 technologies for ensuring traffic safety 36, pp. 427–433.
33.2863 ISSN: 2352-1465. DOI: 10/gr2dqf (cited on page 10).
33.2864
- Lee, Jaeyeong, Choi, Keechoo, and Leem, Yountaik** (2016).
33.2865 "Bicycle-Based Transit-Oriented Development as an
33.2866 Alternative to Overcome the Criticisms of the Conventional
33.2867 Transit-Oriented Development". In: *International Journal*
33.2868 *of Sustainable Transportation* 10.10. Number: 10
33.2869
33.2870

- 34.2871 Publisher: Taylor & Francis _eprint:
34.2872 <https://doi.org/10.1080/15568318.2014.923547>,
34.2873 pp. 975–984. ISSN: 1556-8318. DOI: 10/gntfvc (cited on
34.2874 pages 1, 9).
- 34.2875 **Lee**, Jinwoo Brian and **Salih**, Samal Hama (2024). "Passive
34.2876 Transit Accessibility: Modelling and Application for Transit
34.2877 Gap Analysis and Station Area Assessment". In: *Journal of*
34.2878 *Transport Geography* 114, p. 103757. ISSN: 0966-6923.
34.2879 DOI: 10/gtg7fh (cited on page 4).
- 34.2880 **Leroux**, Line and **Tieng-Majcherczak**, Sophie (2023). *La*
34.2881 *région Hauts-de-France au 5e rang des régions les plus*
34.2882 *peuplées, dépassée par l'Occitanie*. Insee.fr. URL:
34.2883 <https://www.insee.fr/fr/statistiques/7740221> (visited on
34.2884 12/04/2024) (cited on page 7).
- 34.2885 **Li**, Wei and **Joh**, Kenneth (2017). "Exploring the Synergistic
34.2886 Economic Benefit of Enhancing Neighbourhood Bikeability
34.2887 and Public Transit Accessibility Based on Real Estate Sale
34.2888 Transactions". In: *Urban Studies* 54.15. Number: 15
34.2889 Publisher: SAGE Publications Ltd, pp. 3480–3499. ISSN:
34.2890 0042-0980. DOI: 10/gcjm4 (cited on page 9).
- 34.2891 **Li**, Wenxiang, **Chen**, Shawan, **Dong**, Jieshuang, and
34.2892 **Wu**, Jingxian (2021). "Exploring the Spatial Variations of
34.2893 Transfer Distances Between Dockless Bike-Sharing
34.2894 Systems and Metros". In: *Journal of Transport Geography*
34.2895 92, p. 103032. ISSN: 0966-6923. DOI: 10/gjmdmp (cited on
34.2896 page 9).
- 34.2897 **Li**, Zekun, **Han**, Zixuan, **Xin**, Jing, **Luo**, Xin, **Su**, Shiliang,
34.2898 and **Weng**, Min (2019). "Transit Oriented Development
34.2899 among Metro Station Areas in Shanghai, China: Variations,
34.2900 Typology, Optimization and Implications for Land Use
34.2901 Planning". In: *Land Use Policy* 82, pp. 269–282. ISSN:
34.2902 0264-8377. DOI: 10/gf8wth (cited on pages 5, 14, 26).
- 34.2903 **Liao**, Cong and **Scheuer**, Bronte (2022). "Evaluating the
34.2904 Performance of Transit-Oriented Development in Beijing
34.2905 Metro Station Areas: Integrating Morphology and Demand
34.2906 into the Node-Place Model". In: *Journal of Transport*
34.2907 *Geography* 100, p. 103333. ISSN: 0966-6923. DOI:
34.2908 10/gtg7fp (cited on pages 5, 19).
- 34.2909 **Liu**, Chao, **Erdogan**, Sevgi, **Ma**, Ting, and
34.2910 **Ducca**, Frederick W. (2016). "How to Increase Rail
34.2911 Ridership in Maryland: Direct Ridership Models for Policy
34.2912 Guidance". In: *Journal of Urban Planning and*
34.2913 *Development* 142.4. Number: 4 Publisher: American
34.2914 Society of Civil Engineers, p. 04016017. ISSN:
34.2915 1943-5444. DOI: 10/ggn379 (cited on page 13).
- 34.2916 **Liu**, Jiayu, **Yang**, Xiping, **Huang**, Xiaoyan, **Li**, Jiyuan,
34.2917 **Li**, Junyi, **Chen**, Hongfei, **An**, Rui, and **Song**, Yongyong
34.2918 (2025). "Introducing Street View into Node-Place Model for
34.2919 Evaluating Transit-Oriented Development". In: *Journal of*
34.2920 *Transport Geography* 128, p. 104334. ISSN: 0966-6923.
34.2921 DOI: 10.1016/j.jtrangeo.2025.104334 (cited on page 28).
- 34.2922 **Liu**, Liu (2016). "Corridors urbains et Transit Oriented
34.2923 Development : Enseignements d'une modélisation intégrée
34.2924 des transports et de l'usage du sol appliquée à la
34.2925 métropole lilloise". Thèse de doctorat. Lille 1. URL:
34.2926 <http://www.theses.fr/2016LIL10117> (visited on
34.2927 06/15/2022) (cited on page 5).
- 34.2928 **Lo Feudo**, Fausto (2014). "Un scénario pour la région
34.2929 Nord-Pas-de-Calais. Enseignements d'une modélisation
34.2930 intégrée Transport-Usage du sol". Thèse de doctorat.
34.2931 LVMT (IFSTTAR), TVES, Università della Calabria:
34.2932 Université de Lille 1 Sciences et Technologies. 326 pp.
34.2933 (Visited on 06/16/2020) (cited on page 7).
- 34.2934 **Lukman**, Azhari and **Singh**, Yamini Jain (2014).
34.2935 "Development and Implementation of a Transit Oriented
34.2936 Development (TOD) Index around the Current Transit
34.2937 Nodes". Master Thesis. University of Twente. 63 pp. URL:
34.2938 [https://www.semanticscholar.org/paper/DEVELOPMENT-AND-IMPLEMENTATION-OF-A-TRANSIT-\(TOD\)-Lukman-Singh/3e58dcb7ebdfe705be96ec71464e6c78b683e001](https://www.semanticscholar.org/paper/DEVELOPMENT-AND-IMPLEMENTATION-OF-A-TRANSIT-(TOD)-Lukman-Singh/3e58dcb7ebdfe705be96ec71464e6c78b683e001) (visited
34.2939 on 02/12/2024) (cited on pages 4, 14, 19).
- 34.2942 **Lyu**, Guowei, **Bertolini**, Luca, and **Pfeffer**, Karin (2016).
34.2943 "Developing a TOD Typology for Beijing Metro Station
34.2944 Areas". In: *Journal of Transport Geography* 55, pp. 40–50.
34.2945 ISSN: 0966-6923. DOI: 10/gjqkcd (cited on page 5).
- 34.2946 **Ma**, Xinwei, **Ji**, Yanjie, **Yang**, Mingyuan, **Jin**, Yuchuan, and
34.2947 **Tan**, Xu (2018). "Understanding Bikeshare Mode as a
34.2948 Feeder to Metro by Isolating Metro-Bikeshare Transfers
34.2949 from Smart Card Data". In: *Transport Policy* 71,
34.2950 pp. 57–69. ISSN: 0967-070X. DOI: 10/gfjk6h (cited on
34.2951 page 9).
- 34.2952 **Maheshwari**, Richa, **Grigolon**, Anna, and **Brussel**, Mark
34.2953 (2022). "Evaluating TOD in the Context of Local Area
34.2954 Planning Using Mixed-Methods". In: *Case Studies on*
34.2955 *Transport Policy*. ISSN: 2213-624X. DOI: 10/gprznr (cited
34.2956 on page 14).
- 34.2957 **Malekzadeh**, Ali and **Chung**, Edward (2020). "A Review of
34.2958 Transit Accessibility Models: Challenges in Developing
34.2959 Transit Accessibility Models". In: *International Journal of*
34.2960 *Sustainable Transportation* 14.10. Number: 10 Publisher:
34.2961 Taylor & Francis _eprint:
34.2962 <https://doi.org/10.1080/15568318.2019.1625087>,
34.2963 pp. 733–748. ISSN: 1556-8318. DOI: 10/gjtwxh (cited on
34.2964 page 13).
- 34.2965 **Menerault**, Philippe and **Barré**, Alain (2001). *Gares et*
34.2966 *quartiers de gares : signes et marges. Lille, Rennes et*
34.2967 *expériences internationales (Italie, Japon, Pays-Bas)*.
34.2968 IFSTTAR/INRETS. Actes 9782857825494. 216 pp. ISBN:
34.2969 2-85782-549-8. URL:
34.2970 <https://www.decitre.fr/livres/gares-et-quartiers-de-gares-signes-et-marges-9782857825494.html> (visited on
34.2971 11/28/2022) (cited on page 8).
- 34.2972 **Métropole Européenne de Lille** (2021). *Ville : déjà 10 ans*
34.2973 *et toujours en croissance ! Métropole Européenne de Lille,*
34.2974 *p. 2. URL: <https://www.lillemetropole.fr/communiquede-presse/ville-deja-10-ans-et-toujours-en-croissance#:~:text=Le%20V%20de%202011%20C3%A0%202021&text=Avec%20pr%20C3%A8s%20de%2020%25%20d%2024h%20ou%207%20jours>* (visited on 05/23/2023) (cited on page 8).
- 34.2975 **Michel**, Marylise and **Werquin**, Benoît (2016). *La voiture, un*
34.2976 *mode de transport privilégié pour les travailleurs du bassin*
34.2977 *minier*. Insee.fr. URL:
34.2978 <https://www.insee.fr/fr/statistiques/2019616> (visited on
34.2979 12/05/2024) (cited on page 7).
- 34.2980 **Mignot**, Dominique, **Aguiléra**, Anne, **Bloy**, Danièle, **Caubel**,
34.2981 David, **Madre**, Jean-Loup, **Proulhac**, Laurent, and **Vanco**,
34.2982 Florian (2007). *Formes urbaines, mobilités et ségrégation*
34.2983 *: une comparaison Lille - Lyon - Marseille. Rapport final*.
34.2984 URL: <https://shs.hal.science/halshs-00203462> (visited on
34.2985 12/30/2024) (cited on page 7).
- 34.2986 **Mission Bassin Minier Nord-Pas-de-Calais** (2024).
34.2987 *Portrait du Bassin minier du Nord et du Pas-de-Calais*.
34.2988 URL: <https://bassinminier-patrimoine mondial.org/>
34.2989 (visited on 12/17/2024) (cited on page 7).
- 34.2990 **Moïnse**, Dylan (2023). "A Systematic Literature Review on
34.2991 Station Area Integrating Micromobility in Europe: A 21st
34.2992 Century Transit-Oriented Development". In: *Smart Cities*.
34.2993 *Social and Environmental Challenges and Opportunities for*
34.2994 *Local Authorities*. 1st ed. Springer Cham, pp. 171–204.
34.2995 ISBN: 978-3-031-35663-6. URL: <https://link.springer.com/book/10.1007/978-3-031-35664-3#toc>
34.2996 (visited on 09/30/2023) (cited on page 3).
- 34.3000 – (2025a). "Exploring the Relationship between Perceived
34.3001 Bikeability and Gender-inclusive Micromobility Usage: A
34.3002 Study across 53 French Cities". In: *Transportation*
34.3003 *Research Part A: Policy and Practice* 193, p. 24. ISSN:
34.3004 0965-8564. DOI: 10/g83329 (cited on page 15).
- 34.3005 – (2025b). "Le modèle urbain du Transit-Oriented
34.3006 Development revisité par la mobilité individuelle légère
34.3007 émergente. Une investigation dans la région
34.3008 Hauts-de-France". Thèse de doctorat. Université Gustave
34.3009 Eiffel. 750 pp. URL: <https://hal.science/tel-05160113>
34.3010 (visited on 07/27/2025) (cited on pages 1, 27).

- 35.3014 **Moïnse**, Dylan and **L'Hostis**, Alain (2024). "Optimizing
35.3015 Intermodal Commuting by way of Detours and Breaks:
35.3016 Evidence of Micromobility Users in France". In: *Journal of*
35.3017 *Transport Geography* 116.103821. Number: 103821,
35.3018 pp. 1–16. ISSN: 0966-6923. DOI: 10 / gtkvs9 (cited on
35.3019 page 9).
- 35.3020 **Moïnse**, Dylan, **L'Hostis**, Alain, **Amini Pishro**, Ahad,
35.3021 **Cissé**, Ndèye Aïta, **Lehmann**, Xavier, **Zhang**, Shiquan,
35.3022 **Theureau**, Olivier, **Adjeroud**, Heythem, **Yuetong**, Liu,
35.3023 and **Xiao**, Huqi (2025). *GitHub Repository:*
35.3024 *Node-Place-Accessibility-Ridership-Time-Model*.
35.3025 Programmers: _:n14898. URL: [https://github.com/dylan-](https://github.com/dylan-moinse/Node-Place-Accessibility-Ridership-Time-Model)
35.3026 [moinse/Node-Place-Accessibility-Ridership-Time-Model](https://github.com/dylan-moinse/Node-Place-Accessibility-Ridership-Time-Model)
35.3027 (visited on 02/17/2025) (cited on page 30).
- 35.3028 **Molino**, Marie, **Rampon**, Anne-Sophie, and **Cipolla**, Romain
35.3029 (2015). *Les pratiques d'intermodalité vélo-transport*
35.3030 *collectifs*. GART, p. 91. URL:
35.3031 [https://www.gart.org/publication/pratiques-](https://www.gart.org/publication/pratiques-dintermodalite-velo-transport-collectifs/)
35.3032 [dintermodalite-velo-transport-collectifs/](https://www.gart.org/publication/pratiques-dintermodalite-velo-transport-collectifs/) (visited on
35.3033 04/22/2021) (cited on page 1).
- 35.3034 **Monajem**, Saeed and **Ekram Nosratian**, Farzan (2015). "The
35.3035 Evaluation of the Spatial Integration of Station Areas via the
35.3036 Node Place Model; an Application to Subway Station Areas
35.3037 in Tehran". In: *Transportation Research Part D: Transport*
35.3038 *and Environment* 40, pp. 14–27. ISSN: 1361-9209. DOI:
35.3039 10/f7z96s (cited on pages 19, 22).
- 35.3040 **Moretti**, Anna and **Vacheret**, Guy (1999). "L'interconnexion
35.3041 : regards et politiques entre lignes, territoires et acteurs".
35.3042 In: Publisher: Persée - Portail des revues scientifiques en
35.3043 SHS. DOI: 10/czh5vm (cited on page 11).
- 35.3044 **Mota**, Diego Rosa, **Takano**, Marise, and
35.3045 **Taco**, Pastor Willy Gonzales (2014). "A Method Using GIS
35.3046 Integrated Voronoi Diagrams for Commuter Rail Station
35.3047 Identification: A Case Study from Brasilia (Brazil)". In:
35.3048 *Procedia - Social and Behavioral Sciences*. XVIII Congreso
35.3049 Panamericano de Ingeniería de Tránsito, Transporte y
35.3050 Logística (PANAM 2014) 162, pp. 477–486. ISSN:
35.3051 1877-0428. DOI: 10/gr2dqg (cited on page 9).
- 35.3052 **Motieyan**, Hamid and **Mesgari**, Mohammad Saadi (2018).
35.3053 "Development of a TOD Index through Spatial Analyses
35.3054 and HFIS in Tehran, Iran". In: *Journal of Urban Planning*
35.3055 *and Development* 144.4. Number: 4 Publisher: American
35.3056 Society of Civil Engineers, p. 04018038. ISSN:
35.3057 1943-5444. DOI: 10/gjt5z6 (cited on page 5).
- 35.3058 **Motte-Baumvol**, Benjamin, **Belton-Chevallier**, Leslie, and
35.3059 **Morel-Brochet**, Annabelle (2014). "Les territoires
35.3060 périurbains entre dépendance automobile et ségrégation
35.3061 socio-spatiale : les ménages modestes fragilisés par les
35.3062 coûts de la mobilité". In: Les éditions Recherche du PUCA,
35.3063 p. 63. URL: [https://shs.hal.science/halshs-](https://shs.hal.science/halshs-00983498)
35.3064 [00983498](https://shs.hal.science/halshs-00983498)
(visited on 12/05/2024) (cited on page 7).
- 35.3065 **Munch**, Emmanuel (2017). "Les périodes de fréquentation
35.3066 des transports collectifs urbains. Quels enjeux pour la
35.3067 planification ?" In: *Concevoir une offre de transport public*.
35.3068 Territorial Editions. Dossiers d'experts 813, pp. 63–70.
35.3069 URL: [https://hal.science/hal-](https://hal.science/hal-01435363)
35.3070 [01435363](https://hal.science/hal-01435363) (visited on
04/11/2024) (cited on page 15).
- 35.3071 **Nigro**, Antonio, **Bertolini**, Luca, and
35.3072 **Moccia**, Francesco Domenico (2019). "Land Use and
35.3073 Public Transport Integration in Small Cities and Towns:
35.3074 Assessment Methodology and Application". In: *Journal of*
35.3075 *Transport Geography* 74, pp. 110–124. ISSN: 0966-6923.
35.3076 DOI: 10/gf8zgr (cited on pages 3, 5, 13).
- 35.3077 **O'Sullivan**, Sean and **Morrall**, John (1996). "Walking
35.3078 Distances to and from Light-Rail Transit Stations". In:
35.3079 *Transportation Research Record: Journal of the*
35.3080 *Transportation Research Board* 1538.1. Number: 1,
35.3081 pp. 19–26. ISSN: 0361-1981, 2169-4052. DOI: 10/gjvh2m
35.3082 (cited on page 9).
- 35.3083 **Observatoire des territoires** (2019). *Se déplacer au*
35.3084 *quotidien : enjeux spatiaux, enjeux sociaux*. Agence
35.3085 nationale de la cohésion des territoires, p. 40. (Visited on
35.3086 01/19/2023) (cited on page 8).
- Olaru**, Doina, **Moncrieff**, Simon, **McCarney**, Gary,
35.3087 **Sun**, Yuchao, **Reed**, Tristan, **Pattison**, Cate,
35.3088 **Smith**, Brett, and **Biermann**, Sharon (2019). "Place vs.
35.3089 Node Transit: Planning Policies Revisited". In:
35.3090 *Sustainability* 11.2. Number: 2 Publisher: Multidisciplinary
35.3091 Digital Publishing Institute, p. 477. ISSN: 2071-1050.
35.3092 DOI: 10/gtg7fk (cited on page 5). 35.3093
- Papa**, Enrica and **Bertolini**, Luca (2015). "Accessibility and
35.3094 Transit-Oriented Development in European Metropolitan
35.3095 Areas". In: *Journal of Transport Geography* 47, pp. 70–83.
35.3096 ISSN: 0966-6923. DOI: 10/f7t3jj (cited on pages 13, 23). 35.3097
- Passavant-Guion**, Lisa (2016). "Financer les politiques
35.3098 régionales : De l'autonomie à la contrainte budgétaire : Le
35.3099 cas des Régions Alsace, Limousin et Nord-Pas-de-Calais".
35.3100 PhD thesis. Université Montpellier. URL:
35.3101 [https://theses.hal.science/tel-](https://theses.hal.science/tel-01544586)
35.3102 [01544586](https://theses.hal.science/tel-01544586) (visited on
12/02/2024) (cited on page 7). 35.3103
- Peek**, Gert-Joost, **Bertolini**, Luca, and **Jonge**, Hans de
35.3104 (2006). "Gaining Insight in the Development Potential of
35.3105 Station Areas: A Decade of Node-Place Modelling in The
35.3106 Netherlands". In: *Planning Practice & Research* 21.4.
35.3107 Number: 4 Publisher: Routledge _eprint:
35.3108 [https://doi.org/10.1080/02697450701296247,](https://doi.org/10.1080/02697450701296247)
35.3109 pp. 443–462. ISSN: 0269-7459. DOI: 10/ddm9zx (cited on
35.3110 page 14). 35.3111
- Pezeshknejad**, Parsa, **Monajem**, Saeed, and
35.3112 **Mozafari**, Hamid (2020). "Evaluating Sustainability and
35.3113 Land Use Integration of BRT Stations via Extended Node
35.3114 Place Model, an Application on BRT Stations of Tehran".
35.3115 In: *Journal of Transport Geography* 82, p. 102626. ISSN:
35.3116 0966-6923. DOI: 10/ghtvmj (cited on pages 21, 22). 35.3117
- Rabaud**, Mathieu and **Richer**, Cyprien (2022). "Quand les
35.3118 engins de déplacement personnel transforment la mobilité
35.3119 urbaine". In: *Les mobilités décarbonnées : un défi global*.
35.3120 Cerema. Les Dossiers. CEREMA, pp. 59–62. ISBN:
35.3121 978-2-37180-542-2. URL:
35.3122 <https://hal.science/hal-03666504> (visited on 04/18/2023)
35.3123 (cited on page 9). 35.3124
- Randell**, Richard (2020). "No Paradigm to Mobilize: The New
35.3125 Mobilities Paradigm Is Not a Paradigm". In: *Applied*
35.3126 *Mobilities* 5.2. Number: 2, pp. 206–223. ISSN:
35.3127 2380-0127, 2380-0135. DOI: 10/gqtjnj (cited on page 1). 35.3128
- Région Hauts-de-France** (2023). *Plan vélo 2024-2028*.
35.3129 rev3. (Visited on 01/22/2024) (cited on page 8). 35.3130
- (2024a). *Planification Régionale de l'Intermodalité et*
35.3131 *Planification Régionale des Infrastructures de Transport*,
35.3132 p. 327. URL: [https://www.hautsdefrance.fr/la-region-](https://www.hautsdefrance.fr/la-region-adopte-son-sraddet-modifie/)
35.3133 [adopte-son-sraddet-modifie/](https://www.hautsdefrance.fr/la-region-adopte-son-sraddet-modifie/) (visited on 12/06/2024)
35.3134 (cited on pages 7, 27). 35.3135
- (2024b). *SRADDET. Le rapport. Une région attractive, des*
35.3136 *territoires moteurs, un développement équilibré. Adopté en*
35.3137 *juin 2020, approuvé en août 2020, modification apportée*
35.3138 *par le Conseil régional le 21 novembre 2024*, p. 327. URL:
35.3139 [https://www.hautsdefrance.fr/la-region-adopte-son-](https://www.hautsdefrance.fr/la-region-adopte-son-sraddet-modifie/)
35.3140 [sraddet-modifie/](https://www.hautsdefrance.fr/la-region-adopte-son-sraddet-modifie/) (visited on 12/06/2024) (cited on
35.3141 pages 8, 27). 35.3142
- Renne**, John Luciano (2009). "From Transit-Adjacent to
35.3143 Transit-Oriented Development". In: *Local Environment*
35.3144 14.1. Number: 1 Publisher: Routledge _eprint:
35.3145 [https://doi.org/10.1080/13549830802522376,](https://doi.org/10.1080/13549830802522376) pp. 1–15.
35.3146 ISSN: 1354-9839. DOI: 10/b2cr6s (cited on pages 5, 26). 35.3147
- Reusser**, Dominik E., **Loukopoulos**, Peter,
35.3148 **Stauffacher**, Michael, and **Scholz**, Roland W. (2008).
35.3149 "Classifying Railway Stations for Sustainable Transitions –
35.3150 Balancing Node and Place Functions". In: *Journal of*
35.3151 *Transport Geography* 16.3. Number: 3, pp. 191–202.
35.3152 ISSN: 0966-6923. DOI: 10/brd7z9 (cited on pages 2–4,
35.3153 14). 35.3154
- Revelli**, Bruno (2019). "Des transports pour faire région ? :
35.3155 les transports comme élément de légitimation de la fusion
35.3156 régionale en Occitanie". Thèse de doctorat en Géographie.
35.3157 Université Toulouse le Mirail - Toulouse II Jean Jaurès. URL:
35.3158

- 36.3159 <https://theses.fr/2019T0U20090> (visited on 12/02/2024)
36.3160 (cited on page 7).
- 36.3161 **Richer**, Cyprien (2021). *[Dossier Mobilités] #11 -*
36.3162 *Micromobilités et intermodalités : l'enjeu des engins de*
36.3163 *déplacement personnels*. construction21.org. URL: [https://www.construction21.org/france/articles/h/dossier-](https://www.construction21.org/france/articles/h/dossier-mobilites-9-micromobilites-et-intermodalites-1-enjeu-des-engins-de-deplacement-personnels.html)
36.3164 [mobilites-9-micromobilites-et-intermodalites-1-enjeu-](https://www.construction21.org/france/articles/h/dossier-mobilites-9-micromobilites-et-intermodalites-1-enjeu-des-engins-de-deplacement-personnels.html)
36.3165 [des-engins-de-deplacement-personnels.html](https://www.construction21.org/france/articles/h/dossier-mobilites-9-micromobilites-et-intermodalites-1-enjeu-des-engins-de-deplacement-personnels.html) (visited on
36.3166 03/25/2021) (cited on page 1).
36.3167
- 36.3168 **Richer**, Cyprien, **Meissonnier**, Joël, and **Rabaud**, Mathieu
36.3169 (2016). "Quelle(s) intermodalité(s) dans les mobilités
36.3170 quotidiennes ?" In: *ISTE Editions. Sciences, société et*
36.3171 *nouvelles technologies Transports et intermodalité*.
36.3172 Publisher: ISTE Editions, pp. 261–288. DOI:
36.3173 halshs-01386621 (cited on page 1).
- 36.3174 **Richer**, Cyprien, **Pitout**, Nicolas, and **Fabry**, Alexandre
36.3175 (2024). "Quoi de neuf dans le millefeuille ? L'organisation
36.3176 des transports en France depuis la loi d'orientation des
36.3177 mobilités (2019)". In: *Transports, Infrastructures &*
36.3178 *Mobilité MARS & AVRIL 2024.544*. Number: 544 Publisher:
36.3179 EMH éditions, pp. 29–35. URL:
36.3180 <https://hal.science/hal-04649623> (visited on 12/03/2024)
36.3181 (cited on page 7).
- 36.3182 **Robillard**, Arianne, **Boisjoly**, Geneviève, and
36.3183 **Lierop**, Dea van (2024). "Transit-Oriented Development
36.3184 and Bikeability: Classifying Public Transport Station Areas
36.3185 in Montreal, Canada". In: *Transport Policy* 148, pp. 79–91.
36.3186 ISSN: 0967-070X. DOI: 10/gtg7fj (cited on pages 5, 14).
- 36.3187 **Sajous**, Patricia, **Salze**, Paul, and **Bailly-Hascoët**, Valérie
36.3188 (2020). "Système automobile et modèles de transports :
36.3189 quelles évolutions pour planifier la mobilité de demain ?"
36.3190 In: *Flux* 119120.1. Number: 1 Publisher: Université
36.3191 Gustave Eiffel Section: Economie, pp. 173–184. ISSN:
36.3192 1154-2721. DOI: 10/gghn47 (cited on page 7).
- 36.3193 **Schultz**, Stéphane and **Grisot**, Sylvain (2019). *Micromobility*
36.3194 *Explorer - How to Make it Sustainable*. Automotive.
36.3195 15marches et dixit.net. URL:
36.3196 [https://www.slideshare.net/15marches/micromobility-](https://www.slideshare.net/15marches/micromobility-explorer-how-to-make-it-sustainable)
36.3197 [explorer - how - to - make - it - sustainable](https://www.slideshare.net/15marches/micromobility-explorer-how-to-make-it-sustainable) (visited on
36.3198 09/21/2020) (cited on page 1).
- 36.3199 **Sebban**, Annie-Claude (2003). "La complémentarité entre
36.3200 vélo et transport public". Thèse de doctorat. Aix-Marseille
36.3201 3. URL: <http://www.theses.fr/2003AIX32060> (visited on
36.3202 07/27/2021) (cited on page 1).
- 36.3203 **Serviant**, Océane (2015). "La gare et la ville: articulation
36.3204 des dynamiques urbaines". Master Sciences du Territoire -
36.3205 Urbanisme et Projet Urbain. Grenoble: Université Pierre
36.3206 Mendès France. 122 pp. URL:
36.3207 <https://dumas.ccsd.cnrs.fr/dumas-01266843v1> (visited on
36.3208 12/01/2024) (cited on page 8).
- 36.3209 **Shannon**, Claude Elwood (1948). "A Mathematical Theory of
36.3210 Communication". In: *Bell System Technical Journal* 27.3.
36.3211 Number: 3 [_eprint:](https://onlinelibrary.wiley.com/doi/pdf/10.1002/j.1538-7305.1948.tb01338.x)
36.3212 [https://onlinelibrary.wiley.com/doi/pdf/10.1002/j.1538-](https://onlinelibrary.wiley.com/doi/pdf/10.1002/j.1538-7305.1948.tb01338.x)
36.3213 [7305.1948.tb01338.x](https://onlinelibrary.wiley.com/doi/pdf/10.1002/j.1538-7305.1948.tb01338.x), pp. 379–423. ISSN: 1538-7305.
36.3214 DOI: 10/b39t (cited on page 19).
- 36.3215 **Sheller**, Mimi and **Urry**, John (2006). "The New Mobilities
36.3216 Paradigm". In: *Environment and Planning A: Economy and*
36.3217 *Space* 38.2. Number: 2 Publisher: SAGE Publications Ltd,
36.3218 pp. 207–226. ISSN: 0308-518X. DOI: 10/brd7rf (cited on
36.3219 page 1).
- 36.3220 — (2016). "Mobilizing the New Mobilities Paradigm". In:
36.3221 *Applied Mobilities* 1.1. Number: 1 Publisher: Routledge
36.3222 [_eprint:](https://doi.org/10.1080/23800127.2016.1151216)
36.3223 <https://doi.org/10.1080/23800127.2016.1151216>,
36.3224 pp. 10–25. ISSN: 2380-0127. DOI: 10/ggskp7 (cited on
36.3225 page 1).
- 36.3226 **Shi**, Zhuangbin, **Zhang**, Ning, **Liu**, Yang, and **Xu**, Wei
36.3227 (2018). "Exploring Spatiotemporal Variation in Hourly
36.3228 Metro Ridership at Station Level: The Influence of Built
36.3229 Environment and Topological Structure". In: *Sustainability*
36.3230 10.12. Number: 12 Publisher: Multidisciplinary Digital
Publishing Institute, p. 4564. ISSN: 2071-1050. DOI: 10/gt27qn (cited on page 13).
- 36.3231 **Singh**, Yamini Jain (2015). "Measuring Transit-Oriented
36.3232 Development (TOD) at Regional and Local Scales: A
36.3233 Planning Support Tool". Thèse de doctorat. Enschede:
36.3234 University of Twente, Department of Urban et al. URL:
36.3235 [https://research.utwente.nl/en/publications/measuring-](https://research.utwente.nl/en/publications/measuring-transit-oriented-development-tod-at-regional-and-local-)
36.3236 [transit-oriented-development-tod-at-regional-and-local-](https://research.utwente.nl/en/publications/measuring-transit-oriented-development-tod-at-regional-and-local-)
36.3237 [visited on 07/05/2024](https://research.utwente.nl/en/publications/measuring-transit-oriented-development-tod-at-regional-and-local-) (cited on page 14).
36.3238
36.3239
- 36.3240 **Singh**, Yamini Jain, **Fard**, Pedram, **Zuidgeest**, Mark,
36.3241 **Brussel**, Mark, and **Maarseveen**, Martin van (2014).
36.3242 "Measuring Transit Oriented Development: A Spatial Multi
36.3243 Criteria Assessment Approach for the City Region Arnhem
36.3244 and Nijmegen". In: *Journal of Transport Geography* 35,
36.3245 pp. 130–143. ISSN: 0966-6923. DOI: 10/f6t7fj (cited on
36.3246 page 14).
- 36.3247 **SNCF** (2024). *Fréquentation en gares*. Ressources data
36.3248 SNCF. URL: [https://ressources.data.sncf.com/explore/](https://ressources.data.sncf.com/explore/dataset/frequeantation-gares/table/?disjunctive.nom_gare&disjunctive.code_postal)
36.3249 [dataset/frequeantation-gares/table/?disjunctive.nom_](https://ressources.data.sncf.com/explore/dataset/frequeantation-gares/table/?disjunctive.nom_gare&disjunctive.code_postal)
36.3250 [gare&disjunctive.code_postal](https://ressources.data.sncf.com/explore/dataset/frequeantation-gares/table/?disjunctive.nom_gare&disjunctive.code_postal) (visited on 10/25/2021)
36.3251 (cited on page 14).
- 36.3252 **SNCF Gares & Connexions** (2024). *Gares de voyageurs*
36.3253 *(jeu de données déprécié)*. ressources.data.sncf.com.
36.3254 URL: [https://ressources.data.sncf.com/explore/](https://ressources.data.sncf.com/explore/dataset/referentiel-gares-voyageurs/)
36.3255 [dataset/referentiel-](https://ressources.data.sncf.com/explore/dataset/referentiel-gares-voyageurs/)
36.3256 [gares - voyageurs/](https://ressources.data.sncf.com/explore/dataset/referentiel-gares-voyageurs/) (visited on 07/10/2024) (cited on
36.3257 page 27).
- 36.3258 **SNCF Réseau** (2024). *Hauts-de-France*. sncf-reseau.com.
36.3259 URL: [https://www.sncf-reseau.com/fr/hauts-de-](https://www.sncf-reseau.com/fr/hauts-de-france?utm_source=chatgpt.com)
36.3260 [france?utm_source=chatgpt.com](https://www.sncf-reseau.com/fr/hauts-de-france?utm_source=chatgpt.com) (visited on 12/06/2024)
36.3261 (cited on page 8).
- 36.3262 **Sung**, Hyungun and **Oh**, Ju-Taek (2011). "Transit-Oriented
36.3263 Development in a High-Density City: Identifying its
36.3264 Association with Transit Ridership in Seoul, Korea". In:
36.3265 *Cities* 28.1. Number: 1, pp. 70–82. ISSN: 0264-2751.
36.3266 DOI: 10/ct2dn3 (cited on page 13).
- 36.3267 **Talandier**, Magali (2023). "L'hospitalité, ou penser
36.3268 l'attractivité autrement". In: *Habiter en toute hospitalité*.
36.3269 CFDU (Conseil Français des Urbanistes), p. 9. ISBN:
36.3270 978-2-9559669-6-9 (cited on page 1).
- 36.3271 **Transportation Research Board of the National**
36.3272 **Academies** (2007). *Transit Oriented Development:*
36.3273 *Traveler Response to Transportation System Changes*. 95.
36.3274 Issue: 95. Washington, D.C., p. 135. URL: [https://nap.nationalacademies.org/catalog/14077/traveler-](https://nap.nationalacademies.org/catalog/14077/traveler-response-to-transportation-system-changes-handbook-third-edition-chapter-17-transit-oriented-development)
36.3275 [response-to-transportation-system-changes-handbook-](https://nap.nationalacademies.org/catalog/14077/traveler-response-to-transportation-system-changes-handbook-third-edition-chapter-17-transit-oriented-development)
36.3276 [third-edition-chapter-17-transit-oriented-development](https://nap.nationalacademies.org/catalog/14077/traveler-response-to-transportation-system-changes-handbook-third-edition-chapter-17-transit-oriented-development)
36.3277 [visited on 06/12/2024](https://nap.nationalacademies.org/catalog/14077/traveler-response-to-transportation-system-changes-handbook-third-edition-chapter-17-transit-oriented-development) (cited on pages 5, 14).
36.3278
- 36.3279 **Vale**, David S., **Viana**, Cláudia M., and **Pereira**, Mauro
36.3280 (2018). "The Extended Node-Place Model at the Local
36.3281 Scale: Evaluating the Integration of Land Use and
36.3282 Transport for Lisbon's Subway Network". In: *Journal of*
36.3283 *Transport Geography* 69, pp. 282–293. ISSN: 0966-6923.
36.3284 DOI: 10/gdh9cw (cited on page 23).
- 36.3285 **Vélo & Territoires** (2023). *Atlas régional des*
36.3286 *Hauts-de-France. Vélo & Territoires*. URL:
36.3287 [https://www.velo-territoires.org/schemas-](https://www.velo-territoires.org/schemas-itineraires/schemas-regionaux/hauts-de-france/)
36.3288 [itineraires/schemas-regionaux/hauts-de-france/](https://www.velo-territoires.org/schemas-itineraires/schemas-regionaux/hauts-de-france/) (visited
36.3289 on 12/08/2024) (cited on page 8).
- 36.3290 **Veloso e Zarate**, Halina and **Triggianese**, Manuela (2024).
36.3291 "Des quartiers de gare plus verts, plus denses ?
36.3292 Geo-design et Green Transit-Oriented Development à Los
36.3293 Angeles". In: *La nouvelle nature des gares*. 1er édition.
36.3294 Saint-Denis Cedex: PU Vincennes, pp. 179–191. ISBN:
36.3295 978-2-37924-458-2 (cited on page 27).
- 36.3296 **Vincent-Geslin**, Stéphanie (2012). "Les « altermobilités »
36.3297 contre la voiture, tout contre". In: Publisher: Persée -
36.3298 Portail des revues scientifiques en SHS, pp. 84–93. DOI:
36.3299 10/g84qpn (cited on page 1).
- 36.3300 **Vongvanich**, Teethat, **Sun**, Wenzhe, and
36.3301 **Schmöcker**, Jan-Dirk (2023). "Explaining and Predicting
36.3302 Station Demand Patterns Using Google Popular Times

- 37.3303 Data". In: *Data Science for Transportation* 5.2. Number:
37.3304 2, p. 10. ISSN: 2948-1368. DOI: 10 / gt2t2s (cited on
37.3305 page 15).
- 37.3306 **Vuchic**, Vukan R. (2007). *Urban Transit Systems And*
37.3307 *Technology*. Hoboken, N.J: John Wiley & Sons Inc. 624 pp.
37.3308 ISBN: 978-0-471-75823-5 (cited on page 13).
- 37.3309 **Wang**, Rui and **Liu**, Chen (2013). "Bicycle-Transit
37.3310 Integration in the United States, 2001–2009". In: *Journal*
37.3311 *of Public Transportation* 16.3. Number: 3, pp. 95–119.
37.3312 ISSN: 1077-291X. DOI: 10/f5frrb (cited on page 1).
- 37.3313 **Wei**, Sheng and **Wang**, Lei (2023). "Classifying High-Speed
37.3314 Rail Stations in the Yangtze River Delta, China: The Node-
37.3315 Place Modelling Approach". In: *Applied Spatial Analysis and*
37.3316 *Policy* 16.2. Number: 2, pp. 625–646. ISSN: 1874-4621.
37.3317 DOI: 10/gtg7fg (cited on page 5).
- 37.3318 **Yang**, Liu and **Song**, Xiaoyu (2021). "TOD Typology Based on
37.3319 Urban Renewal: A Classification of Metro Stations for Ningbo
37.3320 City". In: *Urban Rail Transit* 7.3. Number: 3, pp. 240–255.
37.3321 ISSN: 2199-6679. DOI: 10 / gnz42p (cited on pages 2, 19,
37.3322 26).
- 37.3323 **Zemp**, Stefan, **Stauffacher**, Michael, **Lang**, Daniel J., and
37.3324 **Scholz**, Roland W. (2011). "Classifying Railway Stations
37.3325 for Strategic Transport and Land Use Planning: Context
37.3326 Matters!" In: *Journal of Transport Geography* 19.4.
37.3327 Number: 4, pp. 670–679. ISSN: 0966-6923. DOI:
37.3328 10/dn83cj (cited on page 3).
- 37.3329 **Zhang**, Mengyuan and **Lee**, Jinwoo Brian (2023). "Make TOD
37.3330 More Bicycling-Friendly: An Extended Node-Place Model
37.3331 Incorporating a Cycling Accessibility Index". In: *Buildings*
37.3332 13.5. Number: 5 Publisher: Multidisciplinary Digital
37.3333 Publishing Institute, p. 1240. ISSN: 2075-5309. DOI:
37.3334 10/gscbrd (cited on pages 5, 14, 23).
- 37.3335 **Zhang**, Yuerong, **Marshall**, Stephen, and **Manley**, Ed
37.3336 (2019). "Network Criticality and the Node-Place-Design
37.3337 Model: Classifying Metro Station Areas in Greater London".
37.3338 In: *Journal of Transport Geography* 79, p. 102485. ISSN:
37.3339 0966-6923. DOI: 10/gkgbpg (cited on page 23).
- 37.3340 **Zhang**, Yushan, **Kasraian**, Dena, and **Wesemael**, Pieter van
37.3341 (2023). "Built Environment and Micro-mobility: A
37.3342 Systematic Review of International Literature". In: *Journal*
37.3343 *of Transport and Land Use* 16.1. Number: 1. ISSN:
37.3344 1938-7849. DOI: 10/gspff2 (cited on page 14).
- 37.3345 **Zheng**, Lingwei and **Austwick**, Martin Zaltz (2023).
37.3346 "Classifying Station Areas in Greater Manchester Using the
37.3347 Node-Place-Design Model: A Comparative Analysis with
37.3348 System Centrality and Green Space Coverage". In: *Journal*
37.3349 *of Transport Geography* 112, p. 103713. ISSN:
37.3350 0966-6923. DOI: 10/gs34mn (cited on page 13).
- 37.3351 **Zhou**, Mingzhi, **Zhou**, Jiali, **Zhou**, Jiangping, **Lei**, Shuyu, and
37.3352 **Zhao**, Zhan (2023). "Introducing Social Contacts into the
37.3353 Node-Place Model: A Case Study of Hong Kong". In: *Journal*
37.3354 *of Transport Geography* 107, p. 103532. ISSN: 0966-6923.
37.3355 DOI: 10/grqk25 (cited on page 14).
- 37.3356 **Zuo**, Ting, **Wei**, Heng, and **Rohne**, Andrew (2018).
37.3357 "Determining Transit Service Coverage by Non-Motorized
37.3358 Accessibility to Transit: Case Study of Applying GPS Data
37.3359 in Cincinnati Metropolitan Area". In: *Journal of Transport*
37.3360 *Geography* 67, pp. 1–11. ISSN: 0966-6923. DOI:
37.3361 10/gctn8c (cited on page 9).

Appendices

38.3362

Relative influence, by entropy (IEW), of independent indicators related to the four dimensions of the NPART model on station ridership

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ID	Indicator	Pedestrian Isochrones	Cycling Isochrones
Node Dimension (Transit)			
N ₁	Frequency (Weekdays, High-speed Rail)	0.264 (2 nd)	0.264 (2 nd)
N ₂	Frequency (Weekends, High-speed Rail)	0.266 (1 st)	0.266 (1 st)
N ₃	Frequency (Weekdays, Regional Rail)	0.034 (7 th)	0.034 (7 th)
N ₄	Frequency (Weekends, Regional Rail)	0.039 (6 th)	0.039 (6 th)
N ₅	Service Span (Weekdays)	0.001 (16 th)	0.001 (16 th)
N ₆	Service Span (Weekends)	0.009 (14 th)	0.009 (14 th)
N ₇	Commercial Rail Speed	0.015 (9 th)	0.015 (9 th)
N ₈	Number of Directions	0.068 (5 th)	0.068 (5 th)
N ₉	Degree Centrality	0.077 (4 th)	0.077 (4 th)
N ₁₀	Closeness Centrality	0.011 (12 nd)	0.011 (12 nd)
N ₁₁	Betweenness Centrality	0.152 (3 rd)	0.152 (3 rd)
N ₁₂	Reachable Stations (One Hour)	0.019 (8 th)	0.019 (8 th)
N ₁₃	Stations to Lille	0.010 (13 rd)	0.010 (13 rd)
N ₁₄	Travel Time to Lille	0.014 (10 th)	0.014 (10 th)
N ₁₅	Stations to Paris	0.014 (11 th)	0.014 (11 th)
N ₁₆	Travel Time to Paris	0.007 (15 th)	0.007 (15 th)
Place Dimension (Development)			
P ₁	Population Density	0.035 (10 th)	0.072 (7 th)
P ₂	Employment Density	0.068 (7 th)	0.104 (4 th)
P ₃	Residential Land Use	0.007 (13 rd)	0.023 (12 nd)
P ₄	Commercial and Public Service Land Use	0.039 (9 th)	0.062 (9 th)
P ₅	Office and Industry Land Use	0.070 (6 th)	0.062 (8 th)
P ₆	Green Space Land Use	0.096 (4 th)	0.094 (6 th)
P ₇	Proximity Points of Interest	0.096 (5 th)	0.096 (5 th)
P ₈	Intermediate Points of Interest	0.131 (3 rd)	0.118 (3 rd)
P ₉	Superior Points of Interest	0.160 (2 nd)	0.153 (1 st)
P ₁₀	Residential Real Estate	0.018 (11 th)	0.026 (11 th)
P ₁₁	Industrial, Commercial and Office Real Estate	0.206 (1 st)	0.130 (2 nd)
P ₁₂	Share of affordable housing	0.055 (8 th)	0.046 (10 th)
P ₁₃	Income per Household	0.018 (12 nd)	0.016 (13 rd)
Accessibility Dimension (Oriented)			
A ₁	Length of Walking Paths	0.025 (7 th)	0.027 (8 th)
A ₂	Intersection Density	0.018 (8 th)	0.037 (7 th)
A ₃	Pedshed and Bikeshed Ratios	0.012 (9 th)	0.009 (10 th)
A ₄	Length of Cycling Paths	0.110 (4 th)	0.085 (4 th)
A ₅	Cycling Parking Capacity	0.169 (3 rd)	0.171 (3 rd)
A ₆	Public Sharing Bicycles	0.239 (2 nd)	0.244 (2 nd)
A ₇	Metro and Tramway Stops	0.307 (1 st)	0.284 (1 st)
A ₈	BRT and Bus Stops	0.056 (5 th)	0.068 (5 th)
A ₉	Motorized Speed Limit	0.006 (10 th)	0.009 (9 th)
A ₁₀	Car Parking Area	0.054 (6 th)	0.064 (6 th)
A ₁₁	Household Motorization	0.004 (11 th)	0.003 (11 th)

Authors: Moïnse, L'Hostis, Amini Pishro, Cissé, Lehmann, Zhang, Theureaux, Adjeroud, Yuetong, and Xiao (2025)

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Composition of the Three Station Classes based on the Temporal Period and Station Area Size.

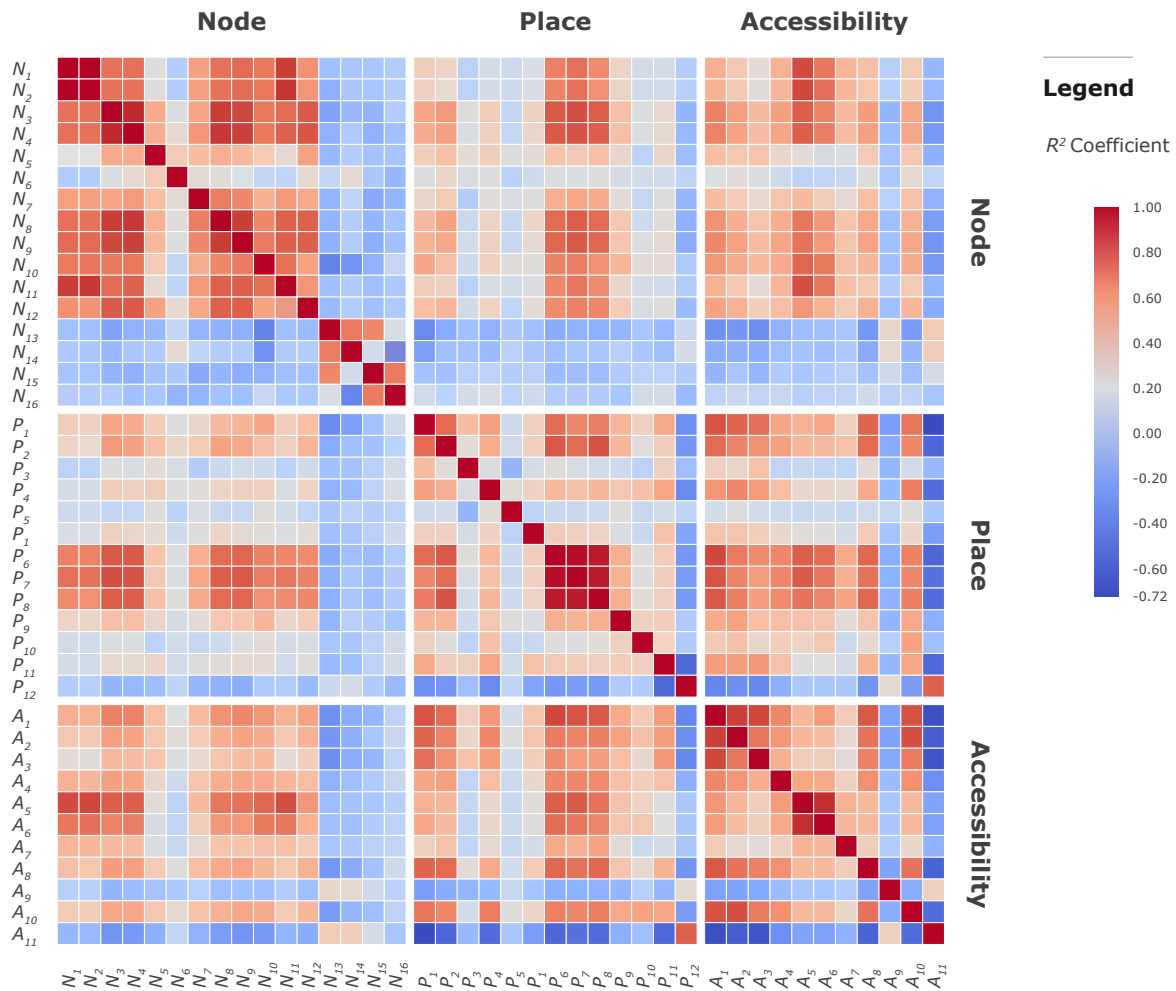
Classes	RT_1	RT_2	RT_3	RT_4	RT_5	RT_6
Pedestrian isochrones (PI)						
Class 1 (C1)	6.92%	5.66%	5.97%	5.97%	6.29%	5.97%
	22	18	19	19	20	19
Class 2 (C2)	30.19%	46.86%	45.91%	42.14%	37.11%	33.65%
	96	149	146	134	118	107
Class 3 (C3)	62.89%	47.48%	48.11%	51.89%	56.60%	60.38%
	200	151	153	165	180	192
Cycling isochrones (CI)						
Class 1 (C1)	11.32%	10.69%	11.01%	12.89%	5.97%	6.29%
	36	34	35	41	19	20
Class 2 (C2)	26.42%	41.82%	34.91%	36.16%	32.08%	42.14%
	84	133	111	115	102	134
Class 3 (C3)	62.26%	47.48%	54.09%	50.94%	61.95%	51.57%
	198	151	172	162	197	164

Authors: Moïnse, L'Hostis, Amini Pishro, Cissé, Lehmann, Zhang, Theureaux, Adjeroud, Yuetong, and Xiao (2025)

Autocorrelation Matrix of the NPART Model Applied to Pedestrian Isochrones (*PI*).

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40.3369



Reading Guide

Walking Scale

Sample: 318 Pedestrian Isochrones (*PI*)

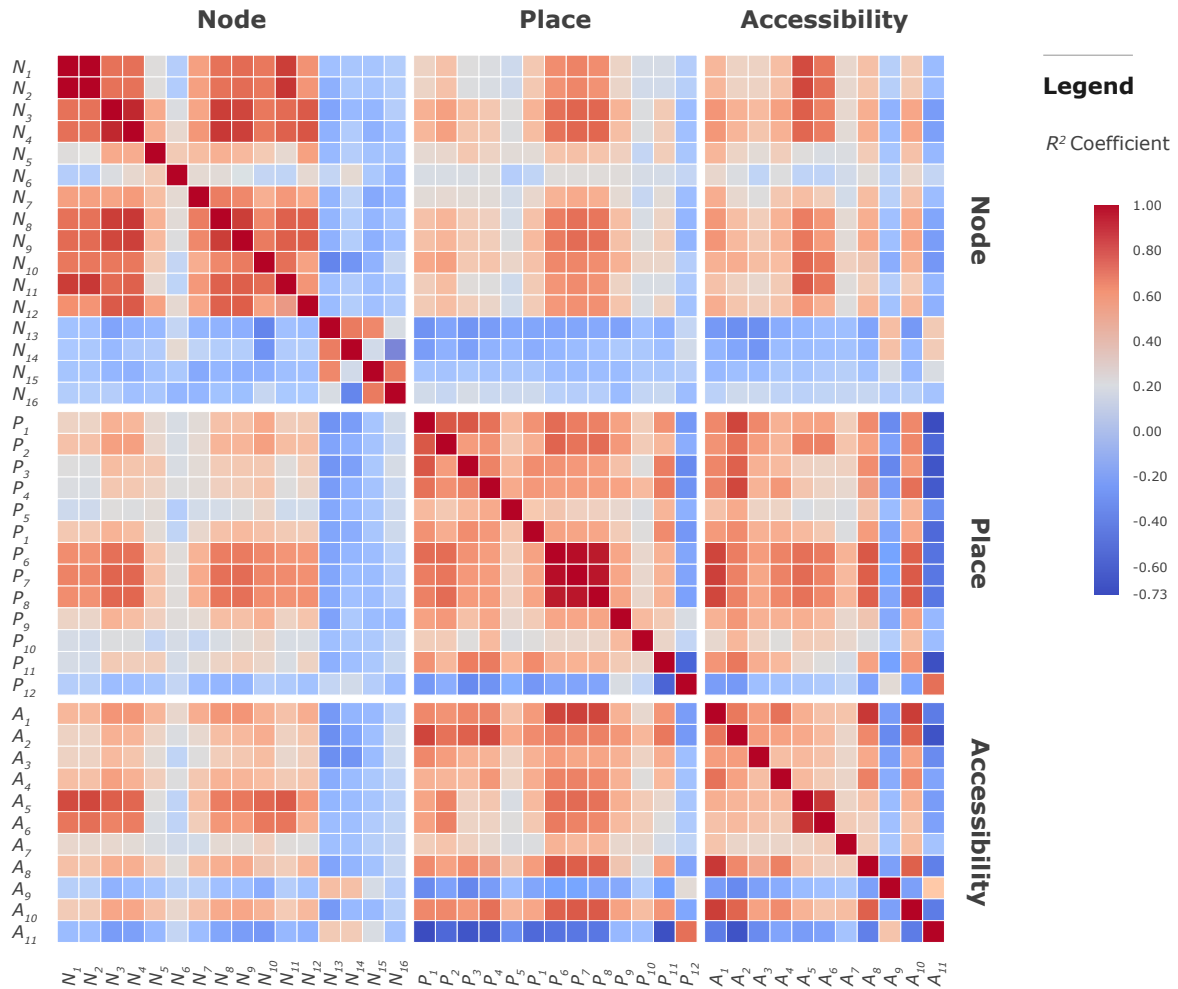
The *Pearson* correlation matrix, relating each of the indicators integrated into the model, represents **their respective influence**, on average, across the 318 isochrones generated at the pedestrian scale (*PI*). On one hand, this graph shows the presence of **29 positive associations**, with a regression coefficient greater than or equal to 0.80. On the other hand, **2 negative associations**, with a regression coefficient less than or equal to 0.70, are observed in this series of statistical regressions.

Authors: Moïnse, L'Hostis, Amini Pishro, Cissé, Lehmann, Zhang, Theureau, Adjeroud, Yuetong, and Xiao (2025)

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Autocorrelation Matrix of the NPART Model Applied to Cycling Isochrones (CI).



Reading Guide

Cycling Scale

Sample: 318 Cycling Isochrones (CI)

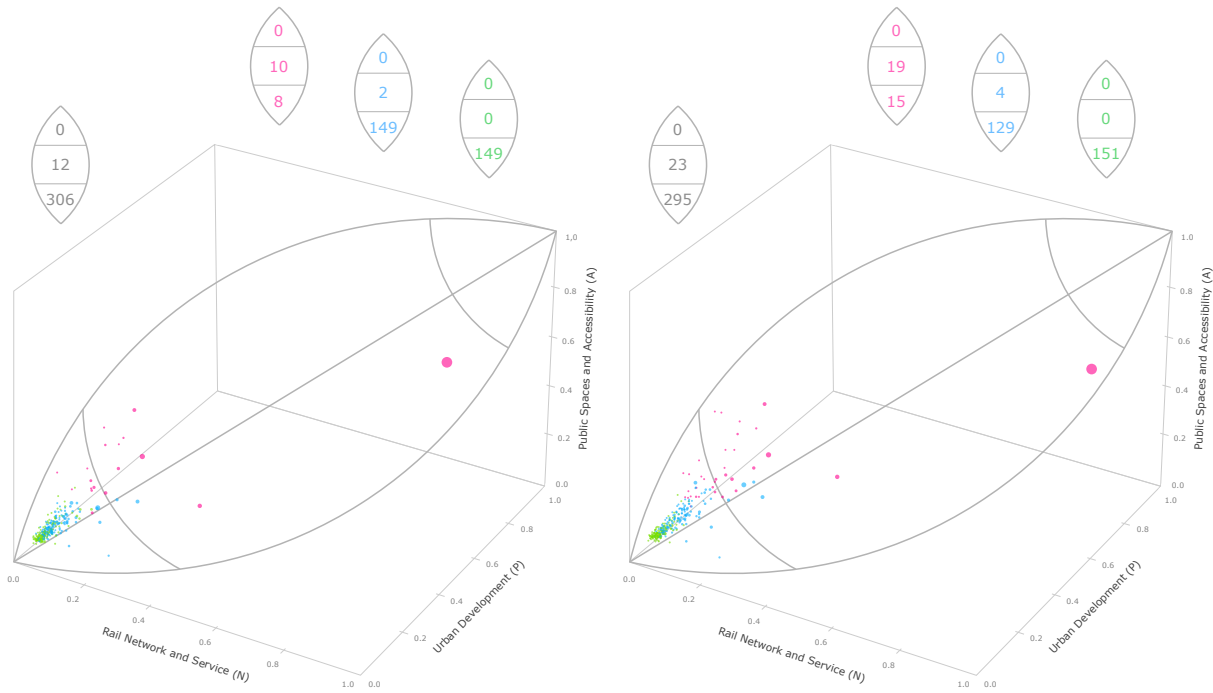
At the cycling scale, the correlation matrix includes only **23 positive associations**, with a regression coefficient greater than 0.80. In contrast, there is **only one negative association identified**, with a value less than 0.70.

Authors: Moïnse, L'Hostis, Amini Pishro, Cissé, Lehmann, Zhang, Theureau, Adjeroud, Yuetong, and Xiao (2025)

Towards a Doubling of the Number of Stations included in the First Class.

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42.3373



Reading Guide

Walking
Scale

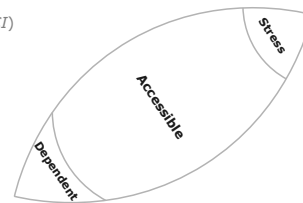
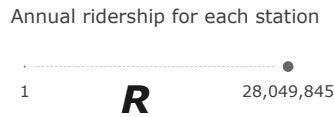
Cycling
Scale

The integration of the classification of nodes and surrounding areas within the cube diagrams highlights a notable difference between pedestrian (*PI*) and cycling (*CI*) isochrones. Expanding station areas to the cycling scale effectively **doubles the number of points in the so-called 'accessible' zone** compared to the pedestrian scale. As a result, the central part of this diagram increases from 12 to 23 points. These are mostly pedestrian isochrones from **the second class** and in a **'dependent'** situation, which, at the scale of cycling influence areas, merge with both **the first class** and **the accessibility zone**.

Legend

- Class 1
- Class 2
- Class 3

Sample: 318 Pedestrian (*PI*) and Cycling Isochrones (*CI*)



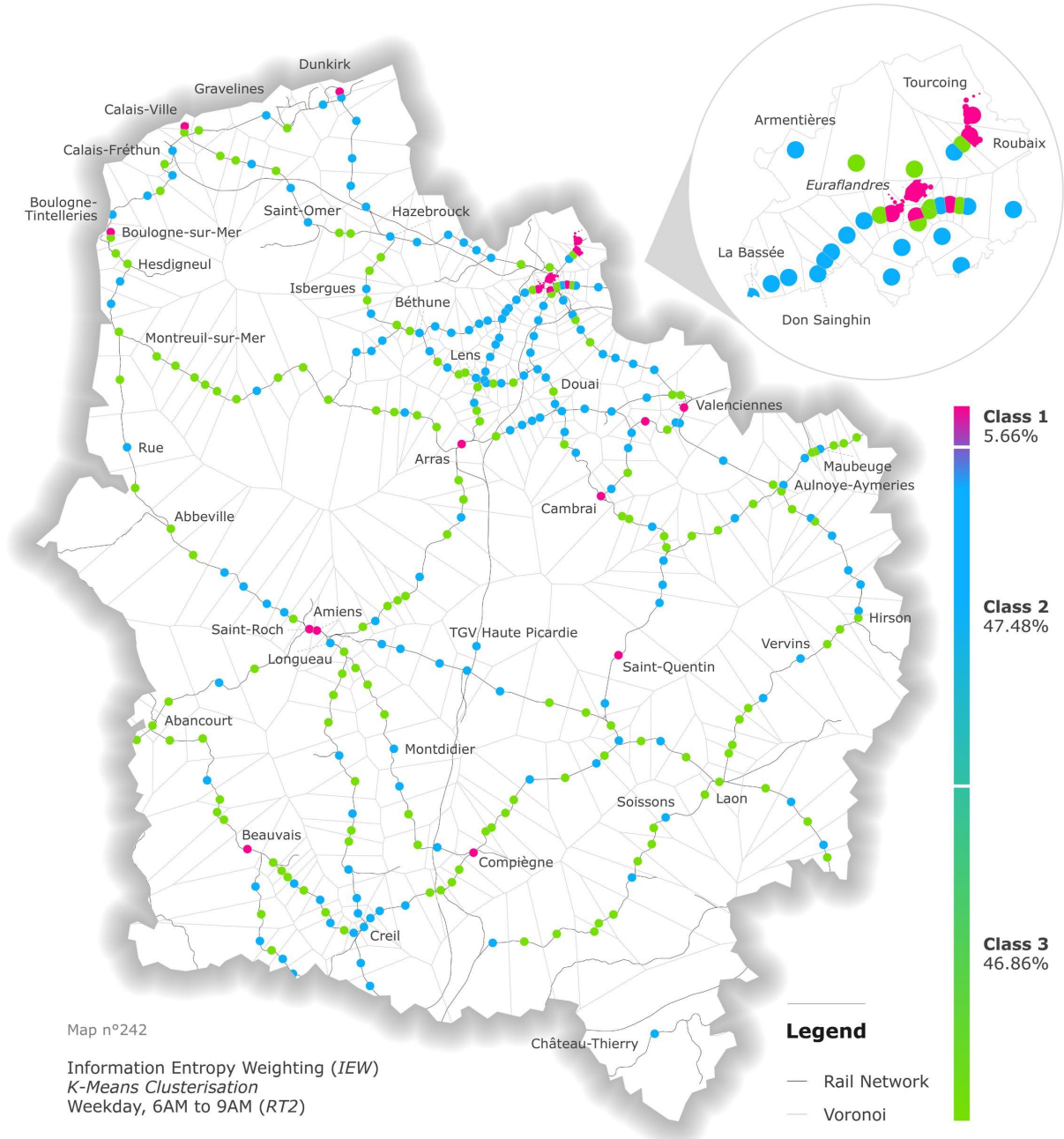
Authors: Moïnse, L'Hostis, Amini Pishro, Cissé, Lehmann, Zhang, Theureau, Adjeroud, Yuetong, and Xiao (2025)

43.3374

Regional Classification of Pedestrian Isochrones (PI).

HAUTS-DE-FRANCE REGION

European Metropolis of Lille



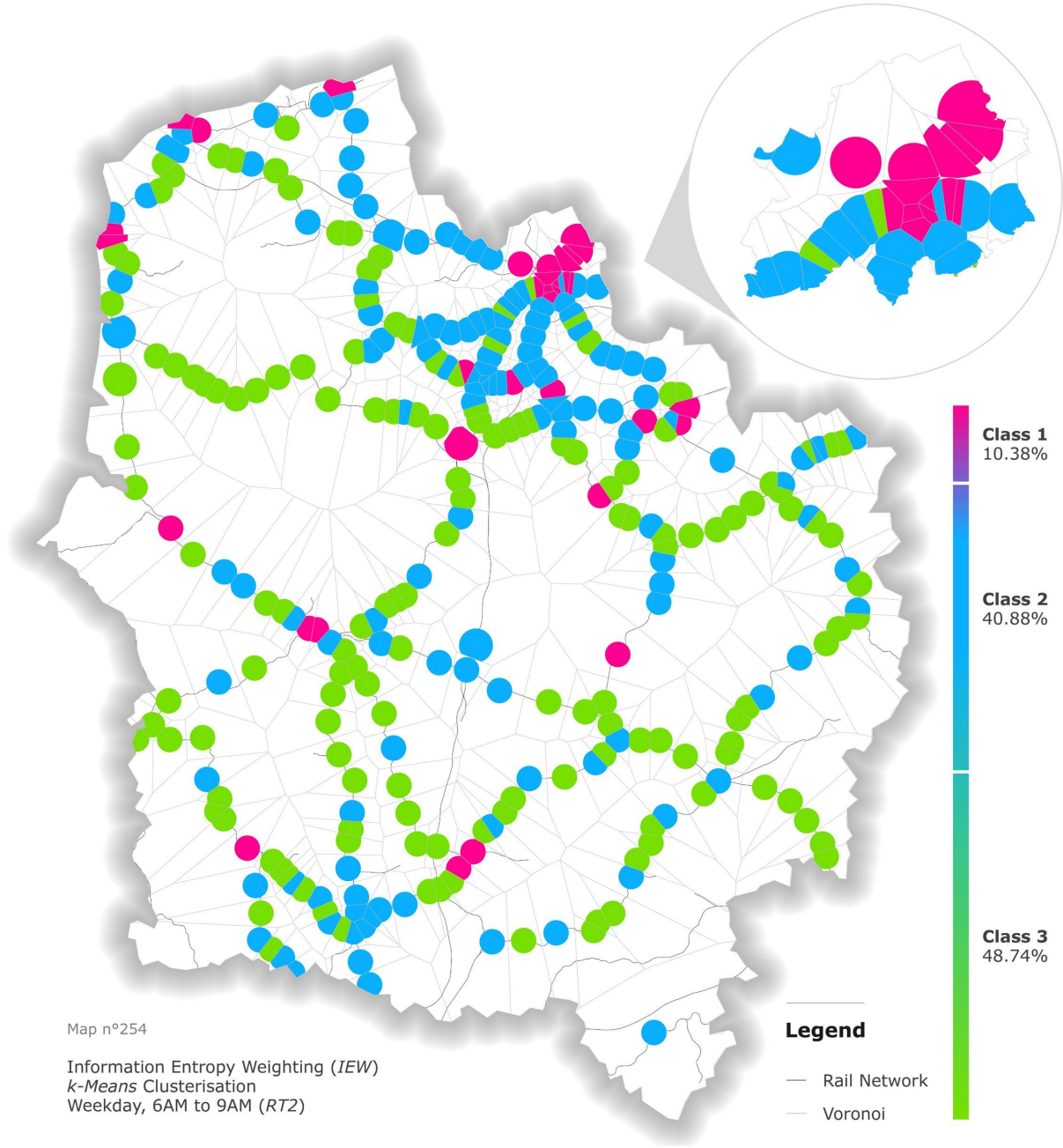
Authors: Moins, L'Hostis, Amini Pishro, Cissé, Lehmann, Zhang, Theureaux, Adjeroud, Yuetong, and Xiao (2025)

Regional Classification of Cycling Isochrones (CI).

44.3375

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European Metropolis of Lille



Authors: Moïnse, L'Hostis, Amini Pishro, Cissé, Lehmann, Zhang, Theureaux, Adjeroud, Yuetong, and Xiao (2025)