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# From nodes to hubs: A scalable methodology for identifying and classifying multimodal mobility hubs in the Milan metropolitan area

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A B S T R A C T

Multimodal Mobility Hubs have gained increasing attention as a sustainable approach to promoting environmentally friendly transportation in cities. By co-locating multiple transport services, mobility hubs offer efficient multimodal transfers and address issues such as car dependency, congestion, and unequal access to mobility. Building upon these advantages, this paper introduces a reproducible classification method that evaluates both the transport supply (Node) and the physical and functional characteristics of the surrounding context (Place).

The methodology readapts the ABC location policy and the Node–Place classification model to systematically identify existing nodes that can serve as multimodal mobility hubs, combining them with comprehensive indicators derived from the mobility hubs literature. Through this approach, the paper illustrates how open and standardized datasets are used to (i) cluster and score transport nodes based on their multimodal offerings, (ii) analyze land use and urban services in their catchment areas, and (iii) compare current conditions with planned transport and land-use transformations.

Additionally, this paper introduces a cross-scale approach to support the localization of potential multimodal mobility hubs, their classification, and insights into their future performance. The proposed framework is tested in Milan's metropolitan area, where it highlights opportunities to enhance multimodality and, alternatively, provides deeper insights from applying transformations in land use and transport supply. Findings show that this approach is scalable and replicable across diverse urban contexts. Ultimately, the paper contributes to evidence-based policy by offering a tool to guide urban and transport planners in locating, selecting, and upgrading mobility hubs, facilitating more sustainable and inclusive mobility networks.

## 1. Introduction

The escalating awareness of the profound environmental and social consequences of high car dependency has brought several critical issues to the forefront. These issues encompass everything from irreversible emissions (Banister, 2011) to congestion, noise, and road safety (Becker & Gerlach, 2012; Saeidizand et al., 2021), as well as the unfair allocation of public space (Creutzig et al., 2020) and the inequitable distribution of the costs and benefits related to this car-dependent mobility (Baum, 2009; Raphael & Rice, 2002). Multimodal Mobility Hubs (MMHs) have emerged as pivotal elements in promoting sustainable urban mobility. By consolidating and integrating various modes of transportation at key urban sites with intelligent technologies and data-driven solutions, MMHs allow users to switch between different mobility options seamlessly (Graf et al., 2022). This integration enhances accessibility and encourages a shift towards a more inclusive and sustainable urban transportation paradigm (Banister, 2008).

The concept of MMHs and their different typologies has recently gained prominence in the urban mobility agendas and the research domain Weustenenk and Mingardo (2023). In the urban agendas, by indicating the progress and tools for creating, improving (Bezirk Hamburg-Nord, 2023; Minneapolis Metropolitan Council, 2021) and typifying hubs (Aquilué Junyent et al., 2024; Portland Bureau of Transportation, 2020). In the research domain, updating a reflection on the spatial role of transport nodes started in the 1990s (Bertolini, 1999; Joseph, 1995; Kokoreff, 2002). From this perspective, the paper aims to investigate and operationalize their potential roles as an interface between the transport networks and the spatial structure of an area, including various components related to transport and the urban realm (CoMoUK, 2019).

Despite the growing interest in multimodality, the scientific literature lacks a consistent definition. Terms such as mobility hub,

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multimodal mobility hub, shared, and smart hub are used interchangeably. Most definitions are anchored in the presence of several mobility options in physical proximity to one another. However, the focus on MMHs has recently shifted toward defining them as essential components of the transport network and, simultaneously, as parts of a spatial setting (Huang et al., 2018), representing the place where the accessibility offered by the transport supply may support the individuals' opportunities to perform activities, reach valued destinations, and participate in social life (van Wee et al., 2011).

This paper uses the term MMH, as it encompasses a cluster of transport modes integrated with the surrounding urban environment. By examining the locations of potential hubs (Blad et al., 2022; Xanthopoulos et al., 2024) and the profiles of the users and their needs (Bell, 2019; Bösehans et al., 2023; Tran & Draeger, 2021), as well as shared mobility options (Liao et al., 2024), the paper provides a methodology for locating and classifying MMHs. This approach is based on analyzing their spatial distribution, transport performance, and potential for improvement through customized mobility services and pedestrian accessibility infrastructure for different city user profiles, including commuters and residents. The main goal is to generate positive environmental and social impacts by reducing car dependency and enhancing the quality of intermodality, thereby advancing a sustainable and fair urban mobility transition.

We build on the ABC location policy to identify potential MMHs and the Node-Place model (Bertolini, 1999) as the conceptual basis for evaluating them in terms of transport function (node) and surrounding spatial characteristics (place). Using an adapted version of Bertolini's model, we develop a scalable approach to identify, classify, and prioritize existing transport nodes that can be transformed into or strengthened in their role as MMHs. We tested the framework in Milan and its first belt, iterating the approach to measure MMH status and guide future transformations to improve performance. Finally, we compared the current situation with forecasted land-use and transport data to identify which MMHs could be improved to better serve as interfaces between transport systems and their surroundings. The proposed framework aims to support planners and policy makers with evidence-based references for decision-making. It can help identify relevant clusters and interventions that would preserve or improve the status of MMHs, encouraging more sustainable mobility.

## 2. Literature review

### 2.1. Definitions of MMHs

The definition of MMHs continues to evolve within the current literature and remains highly dependent on the scope and objective of each study. For instance, the eHubs project, which focuses on e-shared mobility hubs, defines an MMH as "a one-stop location providing a wide range of mobility modes, typically including multiple shared mobility services and public transport" (Fanchao & Gonçalo, 2020, p. 31). In contrast, the SmartHubs project, which concentrates on shared mobility, describes a hub as "a physical location offering different shared transport options at permanent, dedicated, and obvious sites, with public or collective transport available within walking distance" (Graf et al., 2022, p. 10). Despite these variations, most definitions converge on a common understanding of MMHs as physical spaces that integrate multiple mobility options, fostering seamless connectivity across modes. The SmartHubs project (SmartHubs, 2024) further summarizes these recurring characteristics, including multimodality, transfer quality, physical and digital integration, and user inclusivity (Geurs et al., 2023).

While these definitions emphasize the transport and operational features of hubs, our study argues that MMHs should be understood as multifaceted urban systems rather than single transport nodes. In line with the principles of Transit-Oriented Development (TOD) (Cervero, 2012) and the Node–Place framework (Bertolini, 1999), we propose a seamless, replicable definition that connects the transport supply to the spatial and social context in which each hub operates. This perspective situates MMHs as both infrastructural and experiential spaces—points where mobility, land use, and social life intersect. Notably, while our analytical framework builds on the node dimension to quantify accessibility and connectivity, it also allows for the inclusion of complementary dimensions such as the place dimension. It could be extended to what can be defined as a "people dimension", reflecting the broader urban, behavioral, and experiential context.

Accordingly, we define an MMH as: "A collection of closely connected transport nodes that provide seamless transitions among various public and shared mobility services, supported by user-friendly technology and integrated with the surrounding urban environment. By treating these nearby stations and services as one cohesive hub, MMHs maximize accessibility, inclusivity, and multimodality for diverse user needs at both local and network-wide scales."

This definition operationalizes the conceptual duality between the node's technical transport performance and its spatial dimension, as captured in the Node-Place model through measurable indicators. It offers a scalable, transferable framework for identifying and classifying MMHs across diverse metropolitan contexts. It provides a replicable and adaptable foundation, serving as a framework that can evolve with context, data availability, and the changing nature of urban mobility systems. In this sense, our definition aims to pave the way for further studies that seek to refine and expand the understanding of multimodal hubs across different territorial and social conditions.

### 2.2. Locating multimodal mobility hubs: a gap in replicable criteria

Recent literature has highlighted the challenge of systematically identifying and classifying MMHs. Approaches aimed at determining optimal hub locations or configurations are common in MMH studies. Yet they remain highly dependent on case-based criteria and are hardly transferable across different contexts. For instance, studies identify potential locations by integrating various criteria, such as potential demand, implementation costs, and societal impacts, via methods like GIS Multi-Criteria Analysis (MCA) (Blad et al., 2022). Others employ the Fuzzy Analytic Hierarchy Process (AHP) to weigh localized criteria such as public interest, structural suitability, demographics, and accessibility, often based on expert judgments. (Aydin et al., 2022). Similarly, quantitative spatial analysis using Ordinary Least Squares (OLS) regression and Principal Component Analysis (PCA) has been used to identify hotspot areas based on specific factors like micromobility ridership, land-use mix, and network centrality in localized catchment areas (Arias-Molinares et al., 2023).

While these approaches contribute to understanding the spatial determinants of hub development, their reliance on localized factors and subjective weighting makes them less suitable for seamless classification of existing transport nodes across contexts. Consequently, their outputs are typically non-reproducible and challenging to apply across different urban contexts or scales. This limitation underscores the need for a scalable, transparent classification framework that can consistently assess the multimodal potential of existing nodes rather than identify new ones.

### 2.3. MMH typologies

The growing attention to MMHs has triggered several attempts to group hubs into typologies based on a single indicator, such as location, local policy, type, or hierarchy in the structural plan. (Arlington County, 2021; ARUP, 2020; Crowther et al., 2020; Grade et al., 2016; Metropolitan Transportation Commission, 2021) or on multiple indicators that lead to several categories, as mentioned by Blad et al. (2022) and shown in Fig. 1.

In this context, a "typology" refers to a systematic classification of MMHs based on shared attributes. For instance, one typology might distinguish hubs by their location (urban, suburban, or rural). At the

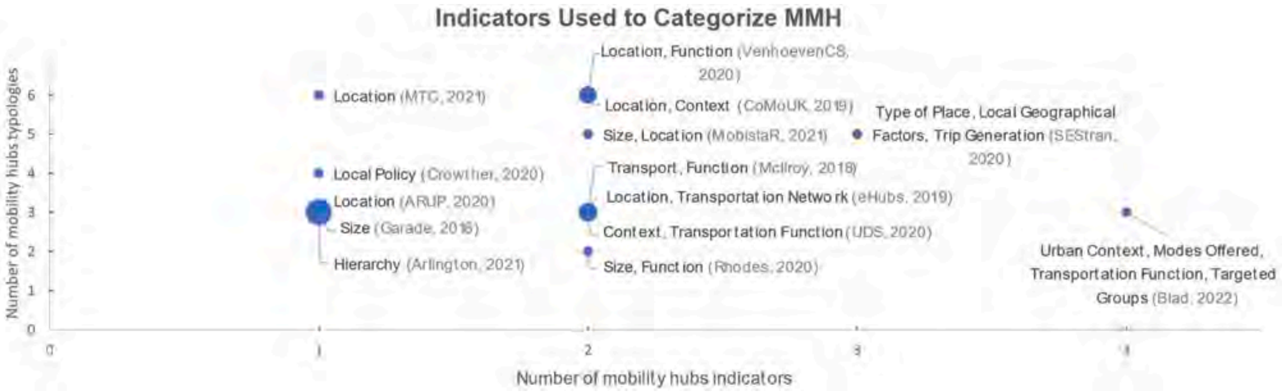

**Fig. 1.** Indicators that are used to create MMHs typologies.

same time, another group could categorize them by the transportation modes they offer (car share, bike share, bus, rail, etc.). However, most existing approaches rely on categorical outputs, which can mask subtler variations in how hubs function.

While grouping hubs into typologies provides a synthetic overview of existing configurations, it often overlooks the hub's evolving relationship with its surrounding context. It is also generally non-scalable, as it remains constrained by current conditions. Acknowledging these limitations, our approach shifts the focus from predefined categories toward the selection and combination of measurable indicators that can capture the multiple dimensions of multimodality and place quality. By adjusting these indicators and their thresholds, the methodology shifts from a fixed categorization to a more flexible, transferable framework that reflects the evolving dynamics of mobility hubs. As a result, this approach is designed to be context-sensitive, replicable, and capable of accounting for future changes, thereby providing a more comprehensive perspective on potential MMH locations.

## 3. Methodology

This methodology aims to classify potential MMHs among existing transport nodes, enabling policymakers to better enhance integration across mobility systems. Building on Bertolini's (1999) Node-Place classification model, each MMH is viewed in terms of both the node (transport supply) and the place (its spatial dimension and surrounding context). It is structured into five main phases (Fig. 2): (i) We begin by identifying potential MMHs through a re-adapted ABC location policy, which locates and primarily classifies nodes that are accessible by multiple means of transport and checks whether the car-related infrastructure is nearby. However, in our re-adaptation of the ABC location policy to the case of public transport MMHs, we deliberately chose not to consider nodes accessible only by car. Once the potential hubs are identified, we calculate an MMH score to classify each hub according to its relative importance within the network. Then, (ii) we assign each potential hub a catchment area that is weighted by its relative importance. This step is essential to operationalize the node-place model in the subsequent phases of the methodology. (iii) We then calculate indicators driven from the literature of Mobility hubs for nodes, such as the number of modes, frequency, transfer time, and Place indicators, such as population density and land use variety, considering current conditions and future forecasts. (iv) After calculating these indicators and based on a hierarchy for transport systems, we cluster any nodes that lie close to each other or share functional linkages into a single MMH, ensuring that physically or operationally adjacent stations are treated as one hub. (v) Finally, we calculate the z-scores of the hubs and compare the results by plotting all MMHs on a Node-Place graph to classify whether they are balanced, stressed, or dependent. By observing any shifts between current and future scenarios, we identify which MMHs warrant interventions, such as enhancing transport supply, redesigning station layouts, or densifying nearby land uses to improve overall multimodality.

Each phase is detailed in the subsequent sections of the paper, which provide an example of the application in the Milan testbed and its first belt.

### 3.1. Spatial identification of (potential) MMHs

Given the provided definition of multimodal mobility hubs, we identify potential hubs based on their proximity to multiple public transport nodes, thereby facilitating seamless transfers. Therefore, the ABC Location Policy and walking-distance criteria were primarily adapted to identify potential MMHs.

#### 3.1.1. Readaptation of the ABC location policy

To select the types of nodes, we re-adapted the ABC location policy, initially proposed by Verroen and Jansen (1992), as a preliminary reference for identifying three types of nodes based on their accessibility and existing infrastructure:

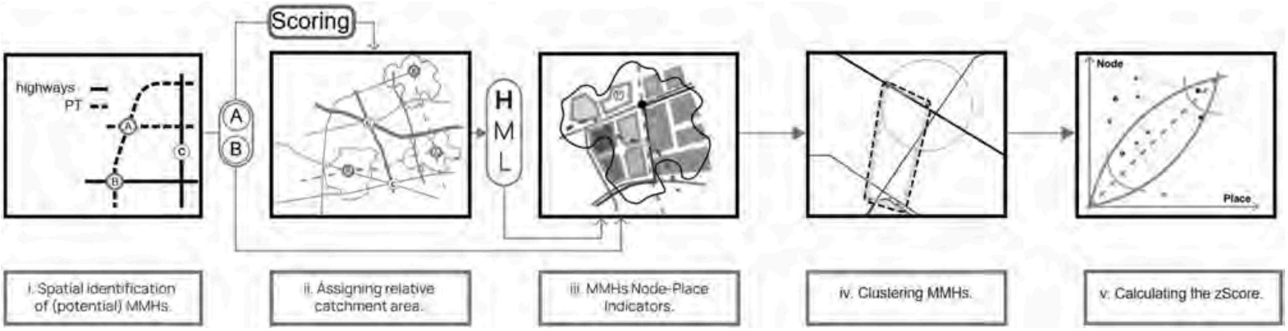

**Fig. 2.** Classification methodology visual summary.

- **Type A locations:** areas highly accessible by public transport, making them prime candidates for MMHs due to their potential to facilitate easy transitions between multiple public transport modes.
- **Type B locations:** feature a mix of public transport options with car-related infrastructure, such as highway exits, large parking facilities, or park-and-ride ($P + R$) sites. Such areas are suitable for MMHs that aim to integrate car users into the public transport system.
- **Type C locations:** characterized by accessibility predominantly via car, these areas are less favorable for MMH development as they are unlikely to support or encourage multimodal practices.

Our research considered only types A and B, as points accessible only by car (Type C) do not encourage sustainable multimodal behavior.

### *3.1.2. Scoring MMHs*

The refined application of the ABC Location Policy enables the classification of transport nodes, such as train, metro, tram, and bus terminals. Type A locations include large public transport interchanges, while facilities that combine car parking with public transportation, such as Park and Ride ($P + R$) setups, are designated as Type B nodes. Conversely, large parking lots and highway exits are identified as Type C locations, and are not assigned a score, as they are excluded from the calculation. This classification underscores that Type A and B points possess the potential to function as MMHs. A scoring system is applied to each station based on its transport type to facilitate preliminary prioritization within these categories. This scoring system assigns higher values to more permanent and less relocatable transport options, reflecting their significant impact on promoting multimodal behaviors.

To derive the comprehensive score for each potential MMH, assessing the available transport options within a feasible transfer distance is crucial. While there is no consensus on the size or distance between transport options within a hub, there is a general agreement that hub elements should facilitate seamless transitions between different modes of transport (Arnold et al., 2023; Heddebaut & Di Ciommo, 2018). Tran and Draeger, p. (2021, p. 2739) recommend 350 m (5 min of walking for adults) as an adequate walking distance between transport options.

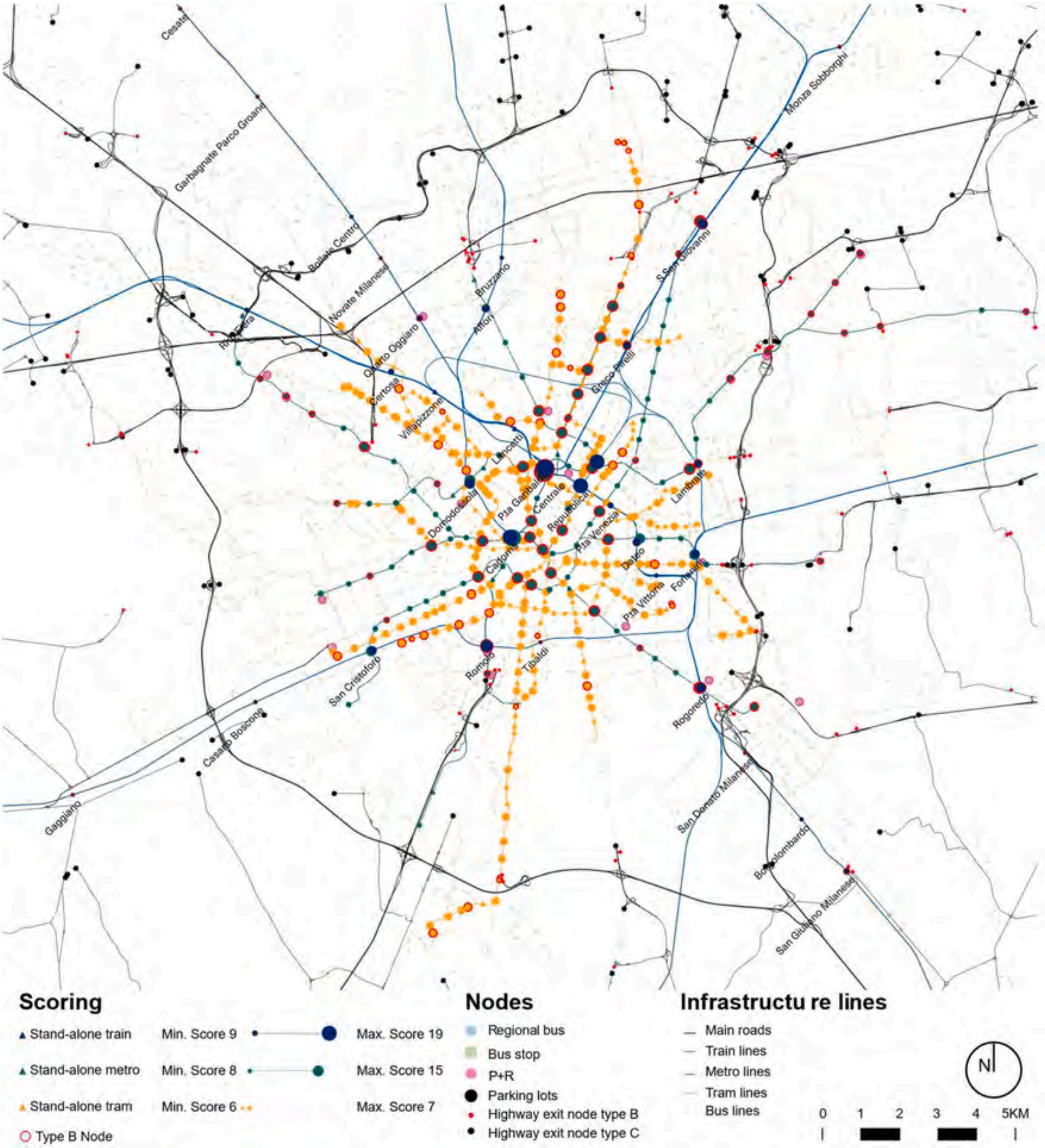

**Fig. 3.** Scores of Milan's transport nodes based on the re-adaptation of the ABC Location Policy.

Conversely Hadas, p. (2013, p. 115) proposes 100 m as the maximum walking distance between stops that can serve as mobility hubs.

For Milan, considering the notably shorter average walking distance (Moovit, 2024), with a mean distance of about 300 m, we opted for a 125-meter radius buffer (roughly two minutes of walking time) to define MMH zones primarily.

The final score of a potential MMH is based on the sum of the available transport options within the selected radius, in addition to the score of the node itself. The final score of the station should be calculated based on the following formula:

$$H_S = H_{intial\ score} + \sum_{i=1}^{n} S_i$$

Where $H_S$ is the Hub Score.

$S$ as the sum of the initial scores of all unique transport types.

$Si$ is the initial score of the $i^{th}$ unique transport type within the buffer, and $n$ is the total number of unique transport types.

$H_{intial\ score}$ is the initial score of the hub. Fig. 3 shows the Hs of the potential MMHs in the study area of Milan. MMHs located in the central area receive the highest scores compared to those in the outskirts.

### 3.2. Assigning a relative catchment area

The $H_S$ (Hub Score) serves as a crucial indicator for defining the appropriate catchment area for each MMH and is required to implement the Node-Place classification model, suggesting that catchment sizes should vary depending on the spatial characteristics of the study context.

In many Node-Place model applications focusing on inner-city contexts, 700 m (about 8–10 min' walking time) is frequently used as an upper threshold for a node's catchment area (Chorus & Bertolini, 2011; Lyu et al., 2016; Reusser et al., 2008; Vale, 2015; Zemp et al., 2011). Building on this threshold, the methodology assigns the largest catchment radius to the node with the highest score. The formula for determining a node's catchment area is:

$$Hub\ Catchment\ area\ = \frac{H_s \times H_{s.max}}{700}$$

Where $H_{s.max}$ represents the highest Hub Score observed in the analysis.

Calculating the catchment area for all mobility options in the first belt area is computationally intensive, so a simplification of the assigned catchment area has been applied for this extensive case study. Every type of transport was divided into three equal groups (high, medium, and low), and each node was assigned the group with the highest catchment area based on the stations' highest-score band.

For the score band $H_{sg,\ max} = max\{H_{s1}, H_{s2}, H_{s3},\ \ldots,\ H_{sn}\}$ where $H_{sg,\ max}$ is the highest hub score per the three categories.

$$Hub\ Catchment\ area\ = \frac{H_{sg.max} \times H_{s.max}}{700}$$

The aim of re-adapting the ABC location policy and extending it to the scoring mechanism is to prepare MMHs for evaluation in the Node-Place classification model, where nodes are predefined, and their catchment areas are justified.

### 3.3. The MMH node–place indicators

The Node-Place model (Bertolini, 1999) provides a framework for public transport-oriented development by examining a station's transport function (node value) and its spatial context (place value). The node value represents accessibility, or the "potential for physical human interaction," while the place value reflects the intensity and diversity of nearby activities or the "actual realization" of that potential. The model also identifies five ideal-typical station-area situations, indicating a node's position within the broader regional system.

This is a dynamic model because the performance of each station can evolve based on the criteria of the land use–transport feedback cycle (Lautso & Wegener, 2007). The transport provision (the node value) of a location can increase by improving the transport supply in terms of frequency or lines, which creates favorable conditions for the further reach of the location. In turn, the development of an area (the place value) due to potential growth in the demand for transport generated by the new settlers creates favorable conditions for the further development of the transport system.

Based on this, the Node-Place Classification model is an effective tool for identifying opportunities to intensify and differentiate urban activities around public transportation nodes, or for recognizing situations in which a reorganization of the public transport network is needed to enhance the accessibility of disconnected places.

The model has been tested and used in different contexts and applications (Nigro et al., 2019), which have contributed to the elaboration of an 'extended version' of this approach in terms of parameters considered and processed (Caset, Boussauw et al., 2018; Lyu et al., 2016; Reusser et al., 2008; Vale et al., 2018; Zemp et al., 2011). In particular, the main additional contributions have analyzed access to stations considering different modes, therefore adopting various radii for defining the catchment area of each station (Caset, Vale et al., 2018), as well as testing specific analytical tools such as the 'design index', implemented to investigate the factors that influence pedestrian accessibility of station catchment areas (Vale et al., 2018).

The model has been selected based on Wang et al. (2021), which reinterprets the Node–Place framework through a flexible composition of indicators describing both transport supply and land-use conditions. This formulation allows its application across different spatial scales and contexts and provides a reference for adapting the model to evaluate the degree of multimodality in Milan's first belt area using indicators derived from the literature on MMHs.

To apply the model, we selected indicators based on two main criteria. First, we included indicators quantified from standard data sources, such as OSM and GTFS, with support of open data within the study context, specifically data available at the station level for the Node dimension and within catchment areas (typically ranging from 150 to 700 m) for the place dimension. Some Node-level indicators describing station physical performance (e.g., accessibility for people with limited mobility) rely on locally published transport-provider data and may not be consistently available across cities. Other indicators frequently used in different studies, such as job density (Reusser et al., 2008; Vale et al., 2018) were excluded because the available datasets could not be spatially disaggregated at the catchment scale. These criteria guided the selection of the indicators listed in Table 2, together with the sub-indicators used to operationalize them quantitatively. The Node–-Place framework is designed to remain flexible, allowing for the inclusion of additional indicators, such as those related to digitalization or democratic participation, when relevant data at the station level becomes available or can be applied to different scales and contexts. In doing so, this study advances previous approaches by providing a transferable, open-data-based framework that can be replicated across diverse urban contexts to support consistent classification and comparison of multimodal hubs.

In this study, the Node–Place model is adapted to assess multimodal mobility hubs rather than single transport stations. While Bertolini (1999) framework evaluates the interaction between land use and accessibility; our approach incorporates multimodality-related indicators such as transfer time, shared mobility availability, and the Inclusive Accessibility by Proximity Index (IAPI). This adaptation transforms the model into a transferable analytical framework for classifying clusters of multiple nodes using open and replicable data.

#### 3.3.1. The node dimension of the MMH model

In this study, the Node-Place model is utilized to assess the performance of MMHs, explicitly focusing on the "node" dimension. This dimension is crucial for evaluating the characteristics of MMHs that potentially enhance multimodal mobility behavior.

In this study, selected indicators refer to Milan and its first belt of surrounding municipalities. Indicators were derived from transport providers' GTFS (General Transit Feed Specification) data and other open-source portals. We treat trains, metros, trams, and the 90/91 trolleybus corridor as the core of MMHs, without disregarding other mobility services, which are considered complementary within our framework.

*3.3.1.1. Indicator N_1: multiple modes.* This indicator counts the types and numbers of public transport options available within the defined buffer area described in Section 3.1.2. In this step, the indicator sums the initial scores for all available options within a 125-meter buffer.

$$N_1 = \sum_{i=1}^{m} S_i$$

- Where $N_1$Represents the total sum of all initial scores in the 125-meter buffer.
- And $S_i$ is the initial score of the i$^{\text{th}}$ transport instance.
- *m* represents the total number of transport instances within the buffer.

*3.3.1.2. Indicator N_2: transfer to the closest station.* Transfer to the closest mode or interchange of transport options often happens when public transport offers no direct route for the desired trip (Zhuk et al., 2022). This indicator measures the connectivity between transport stations and their nearest alternatives. To effectively quantify transferability between nodes in a transport network, the following steps are applied:

1- **Walking distance to the closest station (N2_1)**: Calculate the linear distance between the node and the nearest transport station. This step identifies the physical proximity required for mode transfer.
2- **Time estimation**: Utilize an average walking speed of 4.5 km/h to estimate the walking time between the node and the closest station. This calculation provides an approximate understanding of the time required to move between nodes.
3- **Arrival time calculation**: Upon determining the walking time from step 2, use the stop_times file from the GTFS to determine the next arrival time at the new station for the same day.
4- **Transfer's waiting time to the closest station (N2_2)**: This represents the idle time spent at the station, calculated by subtracting the commuter's arrival time (determined by walking speed) from the next scheduled service arrival in the GTFS data.

*3.3.1.3. Indicator N_3: public transport supply.* Public transport serves as the critical infrastructure of the MMH. The efficacy of public transport within MMHs has been the subject of considerable academic study. For this analysis, it is essential to measure public transport's strength from the node's perspective, which is central to the MMH's effectiveness. This study adopts the multidimensional criteria developed by Hawas et al. (2016) which assesses public transport using three key aspects:

- **Route diversity**: This evaluates the number of destinations accessible from a single transport point without the need for transfers, reflecting the direct connectivity offered by the transport node.
- **Transit coverage**: This aspect measures the furthest distance that can be reached directly from a transport stop, indicating the spatial reach of the transport service.
- **Transit supply**: This involves assessing the frequency of public transport services at a station, which is a critical indicator of service reliability and capacity.

An advantage of this approach is the ability to use GTFS data, enabling these indicators to be seamlessly applied and replicated across different contexts and scales. This standardized method ensures that public transport performance can be consistently and accurately assessed, facilitating comparisons and benchmarking across various urban settings.

The calculation of the three parameters N_3–1 (frequency of arrivals), N_3–2 (routes per stop), and N_3–3 (longest route per stop) should be done through a uniform service timetable. This is done by considering variations such as weekends, holidays, working days, seasonal schedules, and a consistent time of day (e.g., morning rush hour, end of business day, night service) for all measurements. This standardization ensures comparability across different times and conditions.

*3.3.1.4. Indicator N_4: shared mobility.* Shared mobility refers to a transportation strategy that enables users to have short-term access to a mode of transportation as needed (Shaheen & Cohen, 2019). Shared mobility, particularly bike and scooter-sharing points, can help address first- and last-mile challenges (Ashraf et al., 2021).

A systematic literature review by Oeschger et al. (2020) underscores the importance of infrastructural elements in integrating bike-sharing services with public transport systems. Critical infrastructural features identified include the number of available bike parking spaces and the accessibility of these facilities within walking distance.

Various free-floating micromobility services are available in Milan, but integrating them into the calculation is hindered by the lack of publicly available data on service operations and system characteristics. Due to their ubiquity and the presence of vehicle-return policies in numerous designated parking areas that are not necessarily located near other transport modes, these services cannot be reliably assessed. By contrast, BikeMi, the city's official bike-sharing system, stands out by providing open-source data on its stations. This data, which details each station's location and capacity, is essential for evaluating how well the bike-sharing system integrates with the broader public transport network.

To quantify shared mobility's effectiveness, two specific indicators are used:

- N_4–1: The distance between the hub and the closest bike-sharing station, measuring physical accessibility.
- N_4–2: The capacity of the nearest bike-sharing station, which reflects its ability to serve a significant number of users.

*3.3.1.5. Indicator N_5: physical conditions for access.* This indicator measures the physical properties of a node that support people with reduced mobility in accessing it. Further, it investigates whether the node is protected against weather conditions.

In the specific context of Milan, the primary service providers offer detailed information on station accessibility features. Service maps specify which stations and lines are equipped with elevators, escalators, or ramps, thus facilitating access for individuals with reduced mobility. This aspect of the physical integration indicator focuses on the presence and adequacy of such facilities.

For the second aspect of this indicator, protection against weather conditions, data from OpenStreetMap (OSM) are used to establish whether stations are adequately sheltered. This evaluation includes checking whether stations have covered areas or other forms of shade that protect users from rain, sun, and other environmental factors.

The N_5–1 (accessibility for people with reduced mobility and N_5–2 (protection against weather conditions) together define the physical conditions of the MMH. This dual assessment ensures that the MMH is not only accessible but also provides a comfortable, user-friendly environment for all transit users (Fig. 4).

### 3.3.2. *The place dimension of the MMH model*

The Place dimension of the MMH classification model is designed to identify the density of people living near the MMH, the available daily services, and the density of activities associated with the MMH. To calculate the Place dimension, we use the catchment area of each node, which is pre-calculated in Section 3.1.2. Therefore, the Place dimension sums the population and activity densities within the node's catchment area.

*3.3.2.1. Indicator P_1: the population density.* Transport demand at nodes is correlated with the population living or working near the node. The pre-calculated isochrones were used to sum the number of registered population in Milan and the first-belt municipalities surrounding the city, as reached by the local public transport network (ISTAT, Istituto Nazionale di Statistica, 2023) to count how many people are living in the catchment area of each node, we used the ISTAT census data (Istituto Nazionale di Statistica, 2023).

*3.3.2.2. Indicator P_2: the availability of activities and functions in proximity to the node.* The second indicator within the Place dimension assesses the availability of activities and functions near the MMH, mainly focusing on essential daily services linked to high-priority movement patterns. This analysis re-adopts the Inclusive Accessibility by Proximity Index (IAPI) proposed by Lanza et al. (2023).

IAPI measures accessibility levels in active modes for a basket of daily services, considering the physical conditions of sidewalks and open spaces that influence walkability. In the IAPI approach, accessibility is a function of walkability, as a comfortable, walkable environment can reinforce active mobility and local access to activities and opportunities. In this application, IAPI has been applied to assess how many services are available in the catchment area of each node, following these steps:

1- **Pedestrian graph calculation,** finalized to generate a pedestrian graph for the Milan first-belt area, weighted according to the objective conditions affecting the walkability of each arc of the graph.
2- **Service mapping,** for mapping a basket of selected daily services (Moreno et al., 2021) as public and open spaces, commercial activities, and services to the public, gathering and cultural spaces, sports, health and social care, and educational spaces.

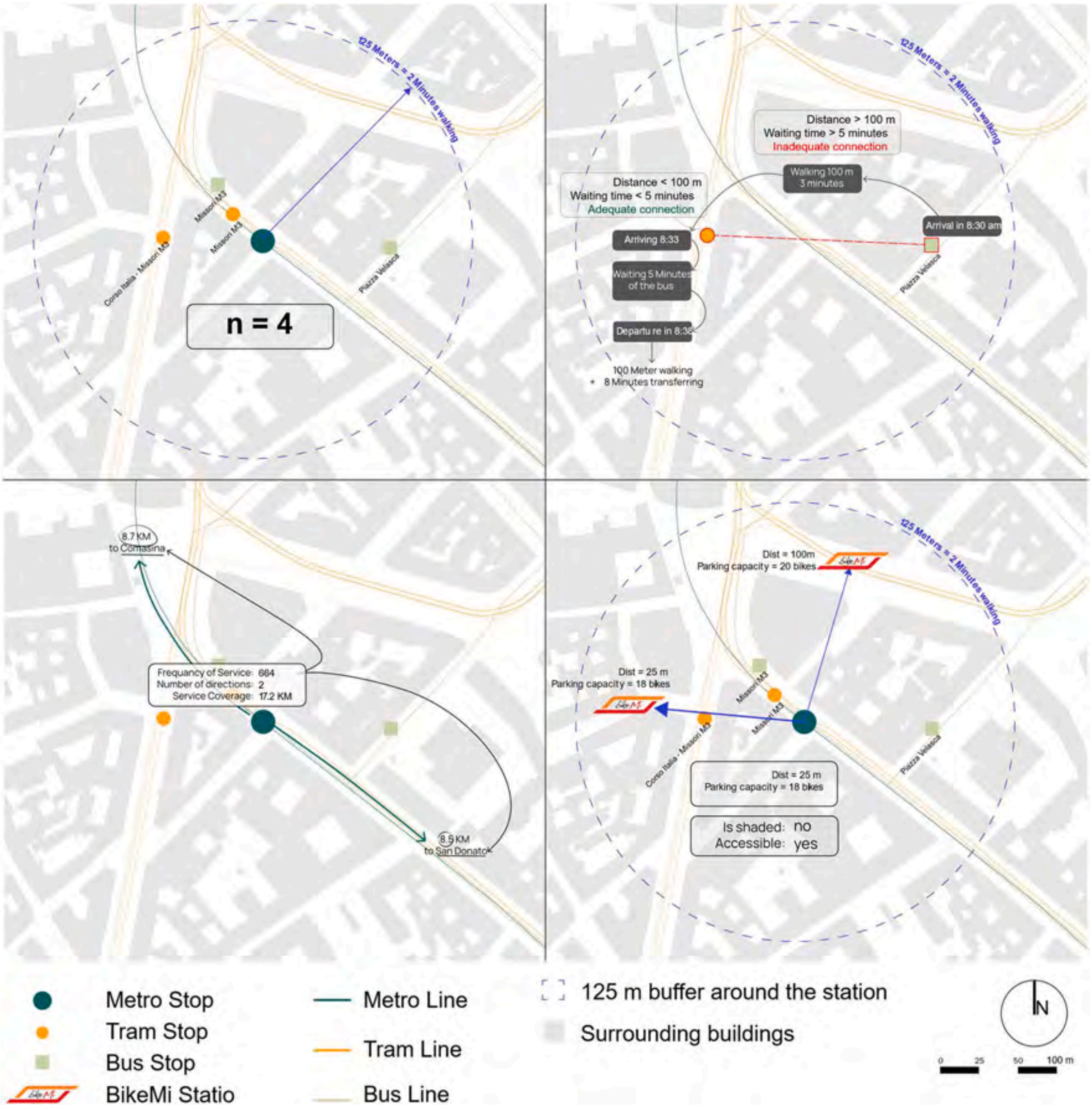

**Fig. 4.** From the Top left in the Clockwise direction, exemplification of the calculation process for Indicators N_1, N_2, N_3, and N_4 &N_5.

3- **Walking isochrones calculation**: Isochrones for 5-, 10-, and 15-minute walking distances are calculated for each service using the weighted graph as a simulation base. The aggregated results of these calculations are then clustered into hexagons of 250 m, approximating the size of a city block in the study area.

Finally, the predefined isochrones of the Place dimension were used again to sum up the results of the IAPI application for each node.

### 3.4. *Clustering the MMHs*

Upon calculating indicators for each potential node, the methodology aims to identify nodes in proximity and group them under a single hub. Clustering begins with stations that have a high initial score and then selects stations that meet two conditions: they are located within a 125-meter buffer or partially share the same name. Many hubs that combine trains and metros are not situated near each other; however, they still function in relation to one another.

The clustering of MMHs is based on the four transport modes selected for each MMH. It begins by clustering MMHs by train stations; for unselected stations, the process is repeated for metro, tram, and bus stations. This order corresponds to the initial hub score, facilitating the evaluation of MMHs. For instance, Fig. 5 shows the train station as a core node for the MMH, and within a 125-meter buffer, another tram station is connected. However, in proximity to the train station, a metro station, and tram stations share the same name as the main node of the hub. Although the stations are located apart, in our methodology, we treat them as part of a single hub. In the example shown, there is also a tunnel linking the train station to the underground metro station.

In this framework, the centroid and the catchment area of each cluster are defined by the node with the highest hierarchy in the initial score (see Table 1). This denotes the maximum performance of an MMH.

### 3.5. *Calculating the z-score*

To realize the Bertolini (1999) Node–Place results, the raw data from the previous steps must be processed into single composite values for the Node and Place dimensions. This allows for a clear understanding of each MMH status within the model. The following steps were employed to achieve this:

**Table 1**
Extending the ABC location policy into scoring.

| Transport type | Location type | Initial score |
|---|---|---|
| Train | A | 6 |
| Metro | | 5 |
| Tram | | 4 |
| Bus | | 3 |
| Regional bus | | 2 |
| *P* + *R* | B | 1 |
| Highway exit | C | |
| Parking lots | | |

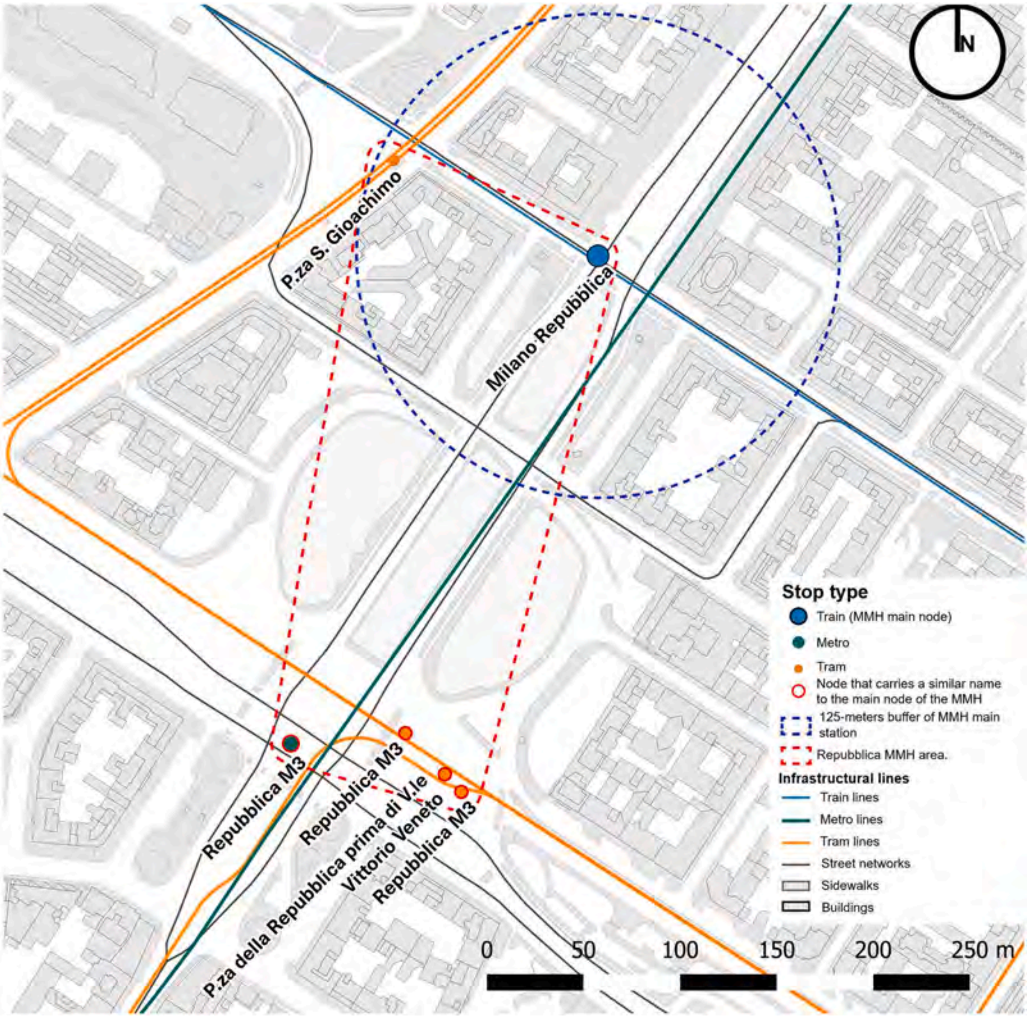

**Fig. 5.** Repubblica MMH Cluster.

**Table 2**
The Node–place classification model indicators.

| Indicator type | Index | Indicator | No. of mentions in the literature | Subindex | Sub-indicators (Unit) |
|---|---|---|---|---|---|
| Node | N_1 | Multiple Modes | 34 | N_1 | The number of transport options within 125 m. |
| | N_2 | Transfer to the closest station | 32 | N_2–1 | Walking distance to the closest station (meters). |
| | | | | N_2–2 | Transfer's waiting time to the closest station (minutes). |
| | N_3 | Public Transport Supply | 20 | N_3–1 | Frequency of arrivals (stops/day). |
| | | | | N_3–2 | Routes per stop (destination/stop). |
| | | | | N_3–3 | Longest route per stop (km). |
| | N_4 | Shared Mobility | 23 | N_4–1 | Distance to closest BikeMi station (m). |
| | | | | N_4–2 | Capacity of the closest BikeMi station (bikes). |
| | N_5 | Physical conditions for access | 18 | N_5–1 | Accessibility for people with reduced mobility [yes/no] |
| | | | | N_5–2 | Protection against weather conditions [yes/no] |
| Place | P_1 | Population | - | P_1 | Population (no. of registered residents) |
| | P_2 | Index of Accessibility by Proximity | - | P_2 | IAPI index |

1- **Indicator Alignment:** First, indicators were treated according to the rules in Table 3 to ensure their values are correctly computed. Specifically, for indicators where high values represent poor performance, a "Max (Inverted)" rule was applied. For example, walking distances (N_2–1, N_4–1) and transfer time (N_2–2) were inverted by subtracting the original value from the maximum so that higher scores consistently reflect better accessibility.
2- **Sub-Index Normalization:** All individual sub-indicators were normalized separately to a 0–1 range. This step harmonizes units such as meters, minutes, and counts into a standard format.
3- **Composite Aggregation:** The normalized sub-indices were then summed to produce a single, unified value for the Node and Place dimensions, respectively.
4- **Z-score Calculation:** A Z-score was calculated for these unified values. This step allows a comparative analysis of the performance of different MMHs relative to the dataset's mean**.**

**Table 3**
Calculating the indicators for the clustered MMHs.

| Index | Indicator | Subindex | Description | Selection Rule |
|---|---|---|---|---|
| N_1 | Multiple Modes | N_1 | The number of transport options within 125 m. | Sum |
| N_2 | Transfer between Modes | N_2–1 | Walking distance to the closest station [meters]. | Max (Inverted) |
| | | N_2–2 | Transfer waiting time to the closest station [minutes]. | Max (Inverted) |
| N_3 | Public Transport Supply | N_3–1 | Frequency of arrivals [stops/day]. | Sum |
| | | N_3–2 | Routes per stop [destination/stop]. | Sum |
| | | N_3–3 | Longest route per stop [km]. | Maximum value |
| N_4 | Shared Mobility | N_4–1 | Distance to closest BikeMi station [m]. | Max (Inverted) |
| | | N_4–2 | Capacity of closest BikeMi station[bikes] | Average |
| N_5 | Physical Characteristics | N_5–1 | Accessibility for people with limited mobility [yes/no] | Average |
| | | N_5–2 | Weather protection [yes/no] | Average |
| P_1 | Population | P_1 | Population [no. of registered residents] | Maximum |
| P_2 | Index of Accessibility by Proximity | P_2 | IAPI index | Maximum |

5- **Final Normalization**: A final normalization was applied to bring the values back to a 0–1 range. This ensures the results fit within the standard Bertolini (1999) Node–Place model, allowing for a clear visual interpretation of each station's status.

## 4. The results of the classification

The methodology was systematically applied to assess both the current situation and the future transformations of MMHs in Milan. Land-use forecasts are derived from the PGT, the local urban development plan (Comune di Milano, 2022), where information on the number of potential residents in an area can be extracted. Which directly impacted P_1 in the place dimension.

Planned changes to the metropolitan transport system are based on the Sustainable Urban Mobility Plan (SUMP) (Comune di Milano, 2018). From this document, information on new station locations, types, and planned network extensions was extracted, and service attributes such as frequency and line length were estimated where possible. These elements directly influence the classification node dimension.

The node–place classification framework identifies five MMH statuses: Balanced, Stressed, Dependency, Unbalanced Node, and Unbalanced Place. This distinction allows for the differentiation of MMH types. It supports the identification of context-specific mobility policies, as interventions suitable for an unbalanced train-based MMH may differ substantially from those required for an unbalanced bus-based MMH. Finally, the comparison between current and future scenarios enables the identification of MMHs whose status is affected by planned transformations, either positively or negatively.

The Node–Place model distinguishes five main station-area conditions according to the balance between transport accessibility (Node) and land-use intensity (Place). These conditions are summarized in Table 4.

### *4.1. Assessment of the current situation of Milan's MMHs*

Our Node–Place results align closely with an external mobility hub

**Table 4**
MMH node–place classification and interpretation.

| Condition | Node–Place Relationship | Characteristics | Potential Planning Implications |
|---|---|---|---|
| Dependent MMH | Node ≈ Place (low values) | Both transport and activity levels are weak. | Consider targeted accessibility improvements or integration with the nearby context. |
| Balanced MMH | Node ≈ Place (medium values) | Transport accessibility and land-use intensity are developed in proportion | Indicates a well-functioning multimodal hub; maintains integration between transport and surroundings quality. |
| Stressed MMH | Node ≈ Place (high values) | Both transport and surroundings are strong, generating capacity and quality pressures. | Focus on management, service quality, and public-realm enhancement to sustain demand. |
| Unbalanced Node MMH | Node > Place | High transport supply relative to surrounding activities. | Prioritize land-use intensification, mixed-use development, and pedestrian accessibility. |
| Unbalanced Place MMH | Place > Node | High concentration of activities but insufficient transport provision. | Improve multimodal connections, service frequency, and accessibility. |

typology that differentiates hub roles by two determining properties: the quantity and complexity of urban services and facilities, and the quantity and complexity of transport modes (Weustenenk & Mingardo, 2023). The typology orders hubs from community and neighborhood to city district and city center, with location and scale treated as supportive dimensions rather than determinants. Fig. 6 shows this correspondence on the Node–Place results. Milano Centrale occupies the upper ranges of both axes and matches the city-center type, with the highest modal complexity and a broad service ecosystem. Porta Genova aligns with the city-district type, combining several modes with district-level public spaces and everyday amenities. Stations with modest modal supply but dense daily-life service clusters in the neighborhood zone match the typology's ideal types and are consistent with its separation of Place and Node properties.

Fig. 7 translates these positions into the current spatial distribution and the intended transformation. Corridors with multiple stressed or unbalanced hubs indicate where frequency, reliability, and interchange quality should be addressed at this scale, while isolated unbalanced nodes or places call for station-scale upgrades to the transport offer or the service ecosystem. The visual and conceptual correspondence between our Milan results and the independent framework provides external validation of the present-day classification and supports the credibility of using the same Node–Place approach to assess future transformations, even though future outcomes cannot yet be observed.

### 4.2. Assessment of future transformations of Milan's MMHs

Based on the land-use and transport indicators updated using the PGT and the SUMP, the node–place classification was recalculated to assess future transformations. The classification based on land-use and transport forecasts indicates significant improvements for several train-based MMHs outside Milan's first-belt boundaries. Fig. 7 illustrates the model's output, depicting the type of MMH in both the current situation and future transformations. It also identifies the primary transport supply that constitutes each MMH and evaluates whether the MMH's status has changed positively or negatively in response to the proposed transformations.

To evaluate whether an MMH undergoes a positive or negative change, we compare its status before and after the implementation of land-use and transport transformations. A change is classified as positive when an MMH that was previously unbalanced shifts toward the equilibrium line, namely to the dependency, balanced, or stressed categories, or when an MMH transitions from stressed or dependency to a balanced condition. Conversely, changes that move an MMH away from the equilibrium line or reinforce an unbalanced condition are classified as negative.

To quantify the magnitude of change, we measure the euclidean distance between the MMH's positions in the place–node space across the two scenarios. Larger distances indicate stronger shifts in status and are used to identify transformations with a more pronounced impact, particularly in cases of negative change where prioritization may be required.

### 4.3. Policy implications of unbalanced MMHs

The classification of Milan's MMHs reveals not only their internal balance between Node and Place characteristics, but also broader spatial patterns that determine how planners should act upon them. To translate the analytical findings into actionable insights, the results were clustered according to two dimensions: geographical configuration and functional condition. This yielded three recurrent typologies of unbalanced MMHs (corridors, junctions, and stand-alone hubs), each associated with specific policy implications and intervention strategies (Table 5; Fig. 8).

#### 4.3.1. Unbalanced corridors

An "unbalanced corridor" occurs when a sequence of hubs along the same transport line (bus, tram, or metro) consistently shows either a high node value but weak surrounding land uses, or vice versa. These situations often reflect structural rather than localized inefficiencies. As the imbalance is spatially continuous, interventions should operate at the corridor scale rather than at individual stations.

Typical strategies include:

- **Increasing public transport frequency and reliability,** along the entire line to ensure that service capacity matches the density and land-use mix of the served areas.
- **Upgrading stop and station quality**. such as shelters, accessibility for people with reduced mobility, and digital information systems to harmonize user experience and reduce perceived distance between hubs.
- **Coordinating land-use actions** along the corridor, such as promoting mixed-use developments or densifying residential and commercial functions near underutilized stops.

For instance, tram-based corridors. such as Line 27 (see Fig. 8) in Milan. exhibit a recurring place imbalance, in which land-use density and diversity exceed the transport supply. In such cases, increasing service frequency or improving transfer conditions along the entire line would generate a shared benefit across multiple hubs simultaneously. Hence, corridor interventions are systemic and collaborative, aiming to improve network performance and user experience collectively.

#### 4.3.2. Unbalanced junctions

A second pattern concerns "unbalanced junctions." These are junctions where multiple transport modes converge spatially but fail to operate as coherent hubs. Although these nodes are close in distance (often within 200–400 m), the transfer experience remains fragmented because of discontinuous pedestrian paths, poor signage, or mismatched schedules.

In these contexts, improvements should focus on integrating modes rather than expanding individual services. Two complementary dimensions are essential:

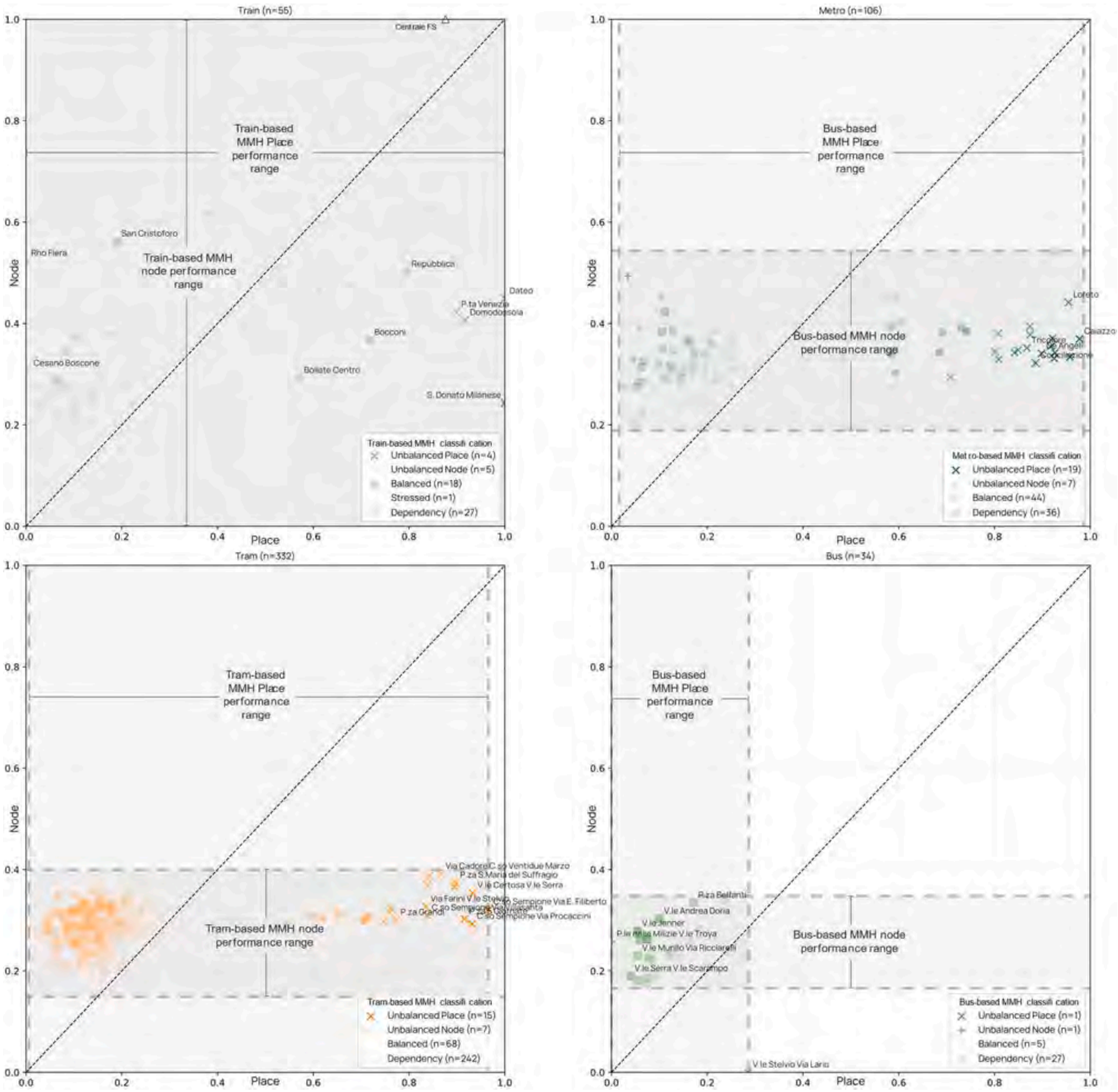

**Fig. 6.** Scatter plots of the Node–Place classification for train-, metro-, tram-, and bus-based MMHs in the current situation.

- **Spatial integration:** creating clear, comfortable, and legible pedestrian links between modes through shaded walkways, tactile paving, weather protection, and continuous surfaces. Where possible, station forecourts can be reorganized to visually signal multimodal continuity and reduce users' cognitive effort.
- **Temporal integration:** aligning schedules and service frequencies to minimize waiting times and avoid missed connections. When physical redesign is constrained (e.g., between a metro and tram stop), even modest timetable coordination or real-time digital information can significantly enhance perceived network integration.

Addressing such conditions transforms disjointed clusters into genuine multimodal gateways, improving both efficiency and user comfort.

### 4.3.3. Stand-alone unbalanced hubs

The third typology includes “stand-alone” hubs, typically found in suburban or peri-urban areas where a single, often rail-based, node functions in relative isolation from the rest of the network. These hubs face challenges related to limited first- and last-mile accessibility and low land-use intensity within their catchment areas.

Interventions at stand-alone hubs are localized and focus on expanding the hub’s functional reach rather than its immediate transport capacity. Key strategies include:

- **Integrating shared micromobility** (bike- or e-scooter-sharing) and secure parking facilities to bridge gaps between the hub and surrounding neighborhoods.
- **Introducing demand-responsive or feeder services** that connect residential clusters or industrial areas to the mainline station.
- **Reorganizing station forecourts** as small intermodal platforms accommodating drop-off zones, parcel lockers, and safe pedestrian crossings to increase comfort and perceived safety.

By improving first- and last-mile connections and small-scale amenities, stand-alone hubs can evolve from isolated rail stops into local

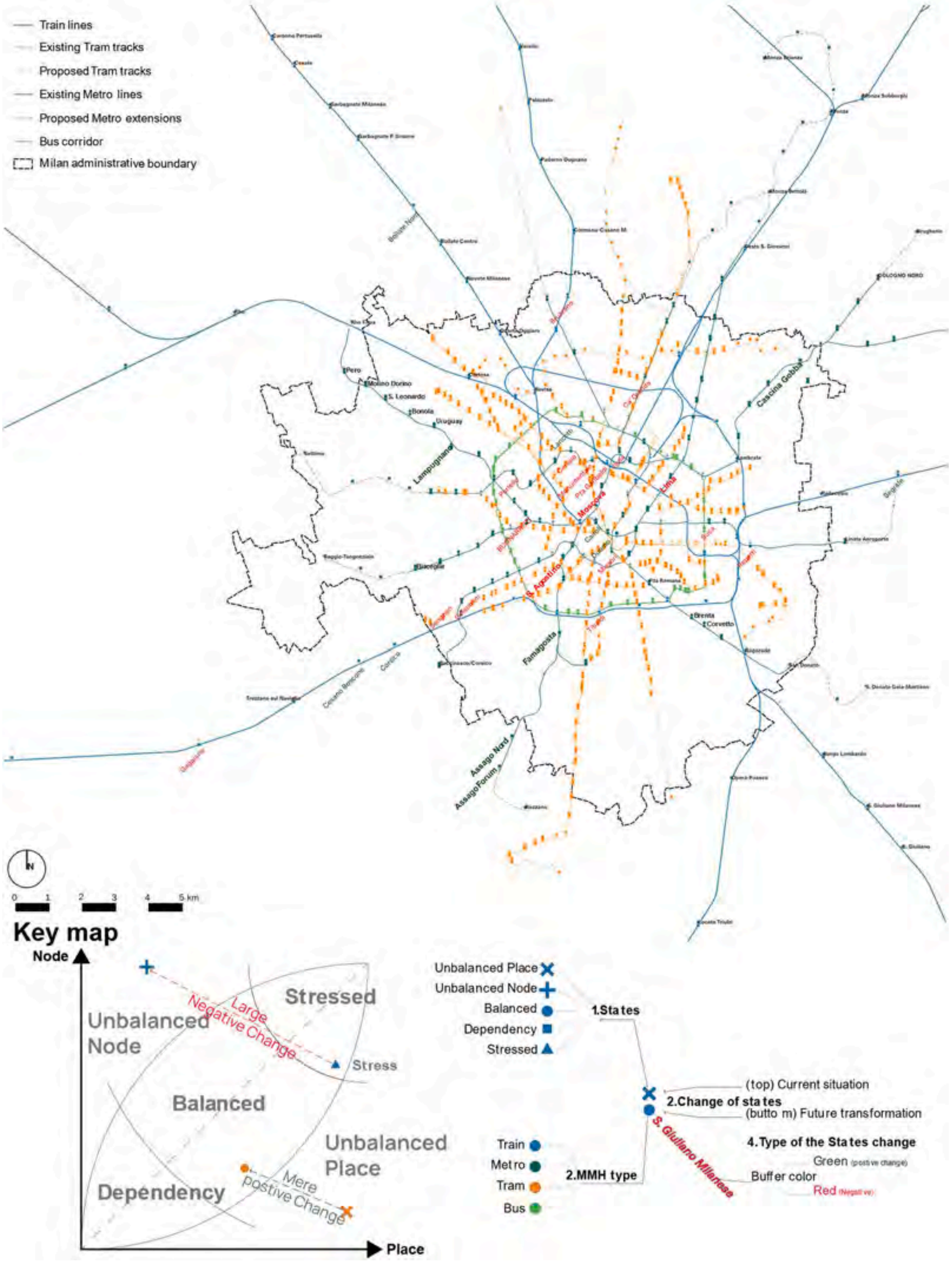

Fig. 7. Mapping the MMHs in the study area for the current situation and future scenario.

**Table 5**
Types of unbalanced conditions.

| Cluster Type | Description | Planning Focus |
|---|---|---|
| Unbalanced Corridors | Several contiguous hubs along the same line display similar imbalances. | Corridor-wide interventions on service frequency. |
| Unbalanced Junctions | Different imbalanced MMHs are located nearby but are physically or temporally weakly connected. | Strengthening spatial and temporal integration between hubs through adequate transfers and shared spaces. |
| Stand-alone Hubs | Isolated MMH located in sub- or peri-urban contexts, typically rail-based. | Enhancing first- and last-mile accessibility through shared or flexible mobility options. |

access points within a wider multimodal network, supporting inclusion and reducing car dependency in peripheral municipalities.

## 5. Discussion and conclusion

The classification results in a scalable, transferable approach for evaluating the MMHs in the current and planned conditions, supporting evidence-based urban mobility policies that enhance the performance of MMHs. The classification pinpoints MMHs affected by changes in transport supply and available land uses. It can be used as a policy decision-support system for effective land-use and transport integration, thanks to its characteristics. In particular, the tool can prefigure multiple planning and development scenarios to promote sustainable urban

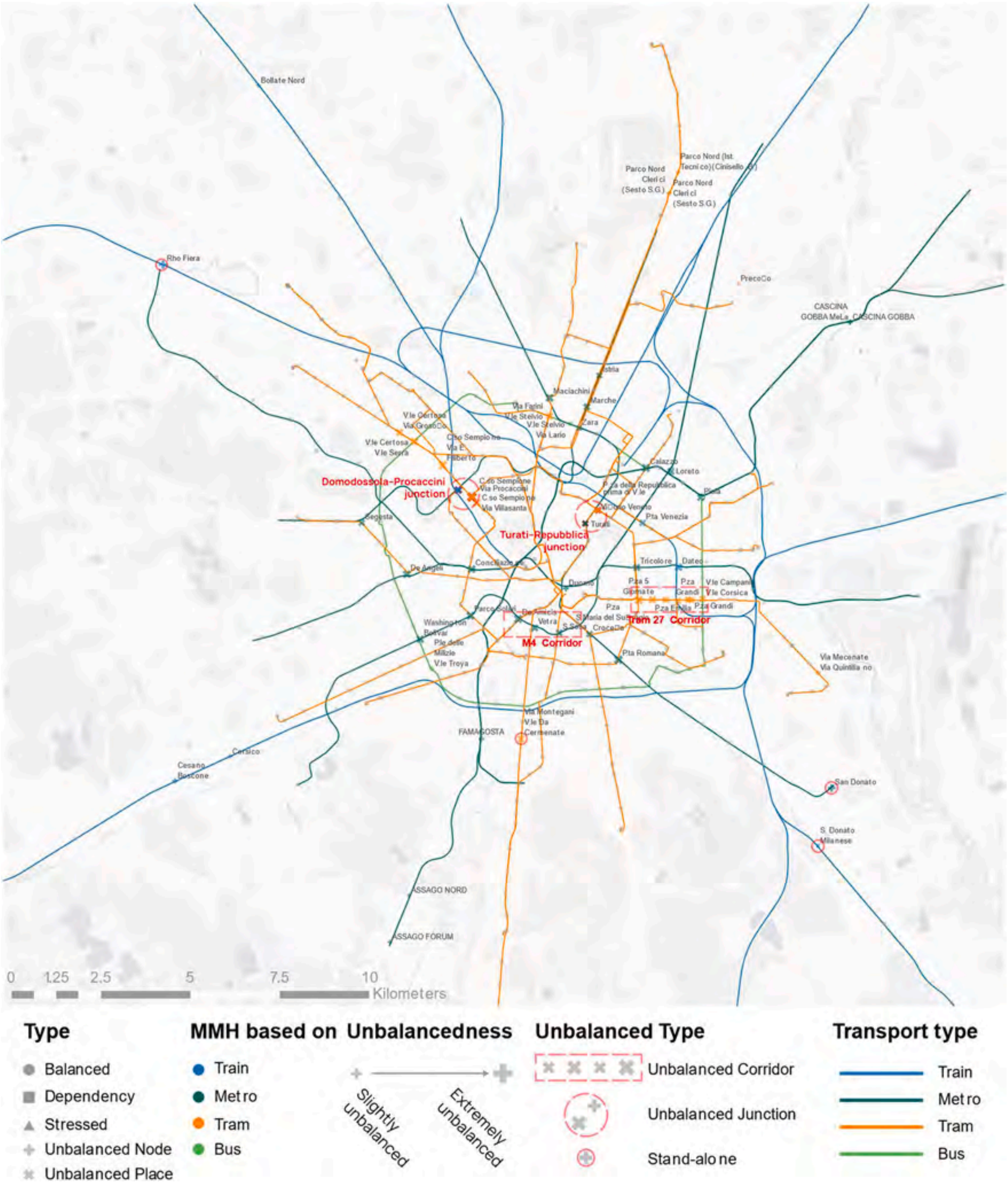

**Fig. 8.** Mapping Milan's unbalanced clusters.

mobility by identifying the potential for improvement in transport nodes and the mobility options they provide access to, and by guiding a more efficient localization of new settlements and urban functions.

Despite these strengths, the model presents several limitations. First, the identification of MMHs is currently based on fixed public transport stops (rail, metro, tram, and bus), while other mobility services are not explicitly represented. Shared mobility options, such as bike sharing, car sharing, or pick-up and drop-off services, can serve as complementary or alternative access layers to public transport, particularly in contexts where fixed services are inefficient or costly. Still, their inclusion is constrained by limited availability and a lack of standardized spatial data. On the other hand, the Place dimension is currently underrepresented, with only two indicators (population density and basic services accessible by active mode over a given time frame). This limitation reflects the availability and resolution of open data capable of describing the multiple dimensions of the spatial conditions. The Place dimension depends strongly on the spatial resolution of available datasets, which must align with the MMH catchment areas. Several relevant indicators, such as job density, could not be included because the corresponding data are not available at this fine spatial scale. Similarly, information on digitalization (such as whether stations are equipped with bright information screens or real-time systems) is not consistently available across transport modes. These data limitations have restricted the inclusion of potentially valuable indicators but also highlight opportunities for future improvements to the framework as more granular and multimodal datasets become accessible.

Moreover, all indicators were treated equally during normalization, without assigning weights or priorities. While this approach ensures transparency and comparability across contexts, it may not fully capture the relative relevance of different indicators in shaping MMH performance. Future developments could introduce weighting schemes based on surveys of users and mobility experts to reflect the perceived importance of each indicator and to strengthen the model's interpretative capacity. Also, this work could deepen the results of transfer time by moving from objective waiting time to perceived waiting time, as argued in Lagune-Reutler et al. (2016). This would allow the framework to better account for how environmental factors, such as tree cover or traffic exposure, distort the user's perception of time spent at the station. Planned transformations and transport improvements also require further interpretation. While planning documents specify new stations and service extensions, they often lack detailed information about future transport supplies and the characteristics of proposed land uses. These limitations have constrained the ability to comprehensively simulate future accessibility and population changes.

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## CRediT authorship contribution statement

**Mohamed Elgohary:** Writing – review & editing, Writing – original draft, Visualization, Validation, Resources, Methodology, Formal analysis, Data curation, Conceptualization. **Paola Pucci:** Writing – review & editing, Writing – original draft, Supervision, Resources, Methodology, Conceptualization. **Giovanni Lanza:** Writing – review & editing, Methodology.

## Declaration of competing interest

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

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## References

Aquilué Junyent, I., Martí Casanovas, M., Roukouni, A., Moreno Sanz, J., Roca Blanch, E., & Correia, G. H. D. A. (2024). Planning shared mobility hubs in European cities: A methodological framework using MCDA and GIS applied to Barcelona. *Sustainable Cities and Society, 106*, Article 105377. https://doi.org/10.1016/j.scs.2024.105377

Arias-Molinares, D., Xu, Y., Büttner, B., & Duran-Rodas, D. (2023). Exploring key spatial determinants for mobility hub placement based on micromobility ridership. *Journal of Transport Geography, 110*. https://doi.org/10.1016/j.jtrangeo.2023.103621

Arlington County. (2021). *Mobility Hubs Guidebook and Pilot Concept Design*.

Arnold, T., Frost, M., Timmis, A., Dale, S., & Ison, S. (2023). Mobility hubs: Review and future research direction. *Transportation Research Record: Journal of the Transportation Research Board, 2677*(2), 858–868. https://doi.org/10.1177/03611981221108977

ARUP. (2020). *Future Mobility Hubs Supporting the transition towards sustainable journeys*.

Ashraf, M. T., Hossen, M. A., Dey, K., El-Dabaja, S., Aljeri, M., & Naik, B. (2021). Impacts of bike sharing program on subway ridership in New York City. *Transportation Research Record: Journal of the Transportation Research Board, 2675*(9), 924–934. https://doi.org/10.1177/03611981211004980

Aydin, N., Seker, S., & Özkan, B. (2022). Planning location of mobility hub for sustainable urban mobility. *Sustainable Cities and Society, 81*, Article 103843. https://doi.org/10.1016/j.scs.2022.103843

Banister, D. (2008). The sustainable mobility paradigm. *Transport Policy, 15*(2), 73–80. https://doi.org/10.1016/j.tranpol.2007.10.005

Banister, D. (2011). *Cities, mobility and climate change.* 1538–1546. https://doi.org/10.1016/j.jtrangeo.2011.03.009.

Baum, C. L. (2009). The effects of vehicle ownership on employment. *Journal of Urban Economics, 66*(3), 151–163. https://doi.org/10.1016/j.jue.2009.06.003

Becker, T., & Gerlach, J. (2012). *The true costs of automobility: external costs of cars.* https://core.ac.uk/display/236374862?utm_source=pdf&utm_medium=banner&utm_campaign=pdf-decoration-v1.

Bell, D. (2019). Intermodal mobility hubs and user needs. *Social Sciences, 8*(2), 65. https://doi.org/10.3390/socsci8020065

Bertolini, L. (1999). Spatial development patterns and public transport: The application of an analytical model in the Netherlands. *Planning Practice and Research, 14*(2), 199–210. https://doi.org/10.1080/02697459915724

Hamburg-Nor, B. (2023). *Carsharing-Ausbau im Bezirk umsetzung 32 neuer hvv switch Punkte in Hamburg-Nord.* Hamburg.De. https://www.hamburg.de/hamburg-nord/pressemitteilungen/17843834/carsharing-ausbau-hvv-switch/.

Blad, K., Homem de Almeida Correia, G., van Nes, R., & Anne Annema, J. (2022). A methodology to determine suitable locations for regional shared mobility hubs. *Case Studies on Transport Policy, 10*(3), 1904–1916. https://doi.org/10.1016/j.cstp.2022.08.005

Bösehans, G., Bell, M., Thorpe, N., Liao, F., Homem de Almeida Correia, G., & Dissanayake, D. (2023). eHUBs—Identifying the potential early and late adopters of shared electric mobility hubs. *International Journal of Sustainable Transportation, 17*(3), 199–218. https://doi.org/10.1080/15568318.2021.2015493

Caset, F., Boussauw, K., & Storme, T. (2018). Meet & fly: Sustainable transport academics and the elephant in the room. *Journal of Transport Geography, 70*, 64–67. https://doi.org/10.1016/j.jtrangeo.2018.05.020

Caset, F., Vale, D. S., & Viana, C. M. (2018). Measuring the accessibility of railway stations in the brussels regional express network: A node-place modeling approach. *Networks and Spatial Economics, 18*(3), 495–530. https://doi.org/10.1007/s11067-018-9409-y

Cervero, R. (2012). Transit-oriented development and land use. *Encyclopedia of sustainability science and technology* (pp. 10923–10934). New York: Springer. https://doi.org/10.1007/978-1-4419-0851-3_269

Chorus, P., & Bertolini, L. (2011). An application of the node place model to explore the spatial development dynamics of station areas in Tokyo. *Journal of Transport and Land Use, 4*(1), 45–58. https://doi.org/10.5198/jtlu.v4i1.145

CoMoUK. (2019). *Mobility hubs guidance.* www.como.org.uk.

Comune di Milano. (2018). *Piano urbano della mobilità sostenibile: Valutazione ambientale strategica, rapporto ambientale.* Comune di Milano. https://www.comune.milano.it/aree-tematiche/mobilita/pianificazione-mobilita/piano-urbano-della-mobilita.

Comune di Milano. (2022). *Piano di Governo del Territorio.* https://www.pgt.comune.milano.it/pgt-previgente/pgt-milano2030-approvato-05022020/documento-di-piano-approvato-14102019/relazione-norme-e-progetto-di-piano-05022020.

Creutzig, F., Javaid, A., Soomauroo, Z., Lohrey, S., Milojevic-Dupont, N., Ramakrishnan, A., Sethi, M., Liu, L., Niamir, L., Bren d'Amour, C., Weddige, U., Lenzi, D., Kowarsch, M., Arndt, L., Baumann, L., Betzien, J., Fonkwa, L., Huber, B., Mendez, E., … Zausch, J. M. (2020). Fair street space allocation: Ethical principles and empirical insights. *Transport Reviews, 40*(6), 711–733. https://doi.org/10.1080/01441647.2020.1762795

Crowther, J., Mangle, K., Abe, D., & Maines, K. (2020). Mobility hub typology study. *Alta Planning + Design.* https://altago.com/wp-content/uploads/PBOT-Mobility-Hub-Typology_June2020.pdf.

Fanchao, L., & Gonçalo, C. (2020). *Smart Shared Green Mobility Hubs. Deliverable 1.1 State-of-the-art related to eHUBS.*

Geurs, K., Grigolon, A., Münzel, K., Gkiotsalitis, K., Duran-Rodas, D., Büttner, B., Kirchberger, C., Pappers, J., Martinez Ramirez, L., Graf, A., Hansel, J., Gkrava, R., & Klementschitz, R. (2023). The Smarthubs integration ladder: A conceptual model for the categorisation of shared mobility hubs. *Transport Reviews*, 1–28. https://doi.org/10.1080/01441647.2023.2239499

Grade, J., Jansen, H., & Bläser, D. (2016). *Mobilstationen – Bausteine für eine zukunftsfähige Mobilität in der Stadt.* https://core.ac.uk/display/55284861?utm_source=pdf&utm_medium=banner&utm_campaign=pdf-decoration-v1.

Graf, A., Hansel, J., Kirchberger, C., Wien, T.U., Klementschitz, R., & Gkiotsalitis, K. (2022). *A multidimensional mobility hub typology and inventory. SmartHubs Deliverable D 2.1.*

Hadas, Y. (2013). Assessing public transport systems connectivity based on Google Transit data. *Journal of Transport Geography, 33*, 105–116. https://doi.org/10.1016/j.jtrangeo.2013.09.015

Hawas, Y. E., Hassan, M. N., & Abulibdeh, A. (2016). A multi-criteria approach of assessing public transport accessibility at a strategic level. *Journal of Transport Geography, 57*, 19–34. https://doi.org/10.1016/j.jtrangeo.2016.09.011

Heddebaut, O., & Di Ciommo, F. (2018). City-hubs for smarter cities. The case of Lille "EuraFlandres" interchange. *European Transport Research Review, 10*(1), 10. https://doi.org/10.1007/s12544-017-0283-3

Huang, D., Liu, Z., Fu, X., & Blythe, P. T. (2018). Multimodal transit network design in a hub-and-spoke network framework. *Transportmetrica A: Transport Science, 14*(8), 706–735. https://doi.org/10.1080/23249935.2018.1428234

Istituto Nazionale di Statistica. (2023). *Dati per sezioni di censimento.* Istituto Nazionale Di Statistica.

Joseph, I. (1995). *Gare du nord. mode d'emploi* (Editions Recherches). RATP.

Kokoreff, M. (2002). Pratiques urbaines d'un quartier de gare. *Espaces et Sociétés, 108–109*(1), 177–196.

Lagune-Reutler, M., Guthrie, A., Fan, Y., & Levinson, D. (2016). Transit stop environments and waiting time perception: Impacts of trees, traffic exposure, and polluted air. *Transportation Research Record: Journal of the Transportation Research Board, 2543*(1), 82–90. https://doi.org/10.3141/2543-09

Lanza, G., Pucci, P., & Carboni, L. (2023). Measuring accessibility by proximity for an inclusive city. *Cities (London, England), 143*, Article 104581. https://doi.org/10.1016/j.cities.2023.104581

Lautso, K., & Wegener, M. (2007). Integrated strategies for sustainable urban development. *Land use and transport* (pp. 152–175). Emerald Group Publishing Limited. https://doi.org/10.1108/9780080549910-008

Liao, F., Dissanayake, D., & Homem de Almeida Correia, G. (2024). Modelling the complementarity and flexibility between different shared modes available in smart electric mobility hubs (eHUBS). *Transportation Research Part A: Policy and Practice, 190*, Article 104279. https://doi.org/10.1016/j.tra.2024.104279

Lyu, G., Bertolini, L., & Pfeffer, K. (2016). Developing a TOD typology for Beijing metro station areas. *Journal of Transport Geography, 55*, 40–50. https://doi.org/10.1016/J.JTRANGEO.2016.07.002

Metropolitan Transportation Commission. (2021). *MTC mobility hub implementation playbook*.

Minneapolis Metropolitan Council. (2021). *Mobility hub survey analysis results-high-level findings*. https://metrocouncil.org/Transportation/Publications-And-Resources/Planning/MISCELLANEOUS-DOCUMENTS/2021-Mobility-Hub-Survey-Analysis-Results.aspx.

Moovit. (2024). *Moovit insights - Public Transit index*. Moovit. https://moovitapp.com/insights/en/Moovit_Insights_Public_Transit_Index-countries.

Moreno, C., Allam, Z., Chabaud, D., Gall, C., & Pratlong, F. (2021). Introducing the "15-Minute City": Sustainability, resilience and place identity in future post-pandemic cities. *Smart Cities, 4*(1), 93–111. https://doi.org/10.3390/smartcities4010006

Nigro, A., Bertolini, L., & Moccia, F. D. (2019). Land use and public transport integration in small cities and towns: Assessment methodology and application. *Journal of Transport Geography, 74*, 110–124. https://doi.org/10.1016/j.jtrangeo.2018.11.004

Oeschger, G., Carroll, P., & Caulfield, B. (2020). Micromobility and public transport integration: The current state of knowledge. *Transportation Research Part D: Transport and Environment, 89*, Article 102628. https://doi.org/10.1016/j.trd.2020.102628

Portland Bureau of Transportation. (2020). *Mobility hub typology study*.

Raphael, S., & Rice, L. (2002). Car ownership, employment, and earnings. *Journal of Urban Economics, 52*(1), 109–130.

Reusser, D. E., Loukopoulos, P., Stauffacher, M., & Scholz, R. W. (2008). Classifying railway stations for sustainable transitions – balancing node and place functions. *Journal of Transport Geography, 16*(3), 191–202. https://doi.org/10.1016/j.jtrangeo.2007.05.004

Saeidizand, P., Flickenschild, M., Verkennis, N., Martino, A., De Stasio, C., Fiorello, D., Schade, W., Scherf, C., Berthold, D., Stich, M., Öörni, R., Fougeyrollas, A., Dreher, S., Giro, C., & Tozzi, M. (2021). *Study on exploring the possible employment implications of connected and automated driving - Final Report*.

Shaheen, S., & Cohen, A. (2019). *Shared Micromoblity Policy Toolkit: Docked and Dockless Bike and Scooter Sharing*. 1–31.

SmartHubs. (2024). *Smarthubs – website*. https://smarthubs.eu/.

Tran, M., & Draeger, C. (2021). A data-driven complex network approach for planning sustainable and inclusive urban mobility hubs and services. *Environment and Planning B: Urban Analytics and City Science, 48*(9), 2726–2742. https://doi.org/10.1177/2399808320987093

Vale, D. S. (2015). Transit-oriented development, integration of land use and transport, and pedestrian accessibility: Combining node-place model with pedestrian shed ratio to evaluate and classify station areas in Lisbon. *Journal of Transport Geography, 45*, 70–80. https://doi.org/10.1016/j.jtrangeo.2015.04.009

Vale, D. S., Viana, C. M., & Pereira, M. (2018). The extended node-place model at the local scale: Evaluating the integration of land use and transport for Lisbon's subway network. *Journal of Transport Geography, 69*, 282–293. https://doi.org/10.1016/j.jtrangeo.2018.05.004

van Wee, B., vab Wee, B., & Geurs, K. (2011). Discussing equity and social exclusion in accessibility evaluations. *European Journal of Transport and Infrastructure Research*. https://doi.org/10.18757/EJTIR.2011.11.4.2940

Verroen, E. J., & Jansen, G. R. M. (1992). Location planning for companies and public facilities: A promising policy to reduce car use. *Transportation Research Records*, (1364), 81–88. http://worldcat.org/isbn/0309054036.

Wang, Z., Han, Q., de Vries, B., & Dai, L. (2021). Insights into the correspondence between land use pattern and spatial distribution of rail transit services. *Applied Spatial Analysis and Policy, 14*(4), 907–928. https://doi.org/10.1007/s12061-021-09385-4

Weustenenk, A. G., & Mingardo, G. (2023). Towards a typology of mobility hubs. *Journal of Transport Geography, 106*, Article 103514. https://doi.org/10.1016/j.jtrangeo.2022.103514

Xanthopoulos, S., van der Tuin, M., Sharif Azadeh, S., Correia, G. H., de, A., van Oort, N., & Snelder, M. (2024). Optimization of the location and capacity of shared multimodal mobility hubs to maximize travel utility in urban areas. *Transportation Research Part A: Policy and Practice, 179*, Article 103934. https://doi.org/10.1016/j.tra.2023.103934

Zemp, S., Stauffacher, M., Lang, D. J., & Scholz, R. W. (2011). Classifying railway stations for strategic transport and land use planning: Context matters! *Journal of Transport Geography, 19*(4), 670–679. https://doi.org/10.1016/j.jtrangeo.2010.08.008

Zhuk, M., Pivtorak, H., Gits, I., & Kozak, M. (2022). Application of bayesian networks to estimate the probability of a transfer at a public transport stop. *Transport Technologies, 2022*(2), 22–32. https://doi.org/10.23939/tt2022.02.022