A Smart Approach for Integrated Land-Use and Transport Planning—An Application to the Naples Metro Station Areas

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Abstract. In recent decades, local and metropolitan authorities worldwide have shown an increasing interest in applying new development strategies that integrate transport and land-use solutions to mitigate the negative consequences of development on the physical and social environment and the economy in urban areas. The progressive application of the smart city paradigm in different urban development sectors from mobility to urban services is influencing decision-makers' and stakeholders' choices. This research proposes a new spatial analysis method to evaluate the "smartness" of land-use and transport integration projects using an updated version of the Node-Place Butterfly model. The method was applied to the 18 stations area of Line 1 of the Naples metro. The results showed significant variation in the level of smartness from the city centre to the peripheral areas, with Node and Place components unbalanced for some stations.

Keywords: GIS · Land use · Geographical analysis · Naples (Italy)

1 Introduction

In 2021, more than 51% of the total global population was living in urban areas. Recent forecasts suggest that by 2050 this figure will exceed 66% [1].

The current 'congestion crisis' that affects most urban areas is undoubtedly a consequence of the lack of coordination of strategies, tools and measures for integrating transport and urban systems. The lack of a holistic vision has often led to the design and construction of transport infrastructure geared mainly to private transport, with inevitable negative consequences for the environment. Transport planning has been oriented towards satisfying an unconditional demand for mobility without foreseeing the impact that transport interventions may have on the urban system and city users, in terms of monetary and generalised costs. Several interesting urban models have been developed in recent decades in order to handle the challenges of today and tomorrow, among which the interactions between transport systems and urban development have received considerable critical attention [2].

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Transport and land-use planning have a significant role in promoting accessibility. At the same time, accessibility is an important component of urban systems and plays a key role in guiding more sustainable and inclusive land use and transport decisions [3]. The concept of accessibility refers to the ease with which people can reach necessary/desired activities—such as goods, services and occupations—within a reasonable travel time. Ensuring high levels of accessibility and sustainable development is, therefore, one of the primary objectives of urban management in order to minimise negative impacts and improve the quality of life in the urban environment.

The transit-oriented development (TOD) approach promotes, through the implementation of eight design principles [4], the gentrification and functionalisation of transit station areas. The alignment of residential and economic densities with public transport capacity and network characteristics, encouraged by TOD principles, is key to improving urban accessibility in cities. Such an approach makes it possible to reduce the need to travel long distances (and thereby reduce greenhouse gas emissions), while promoting a more inclusive urban model.

The literature recognises the role of station areas as major determinants in the organisation of urban systems, mainly because of the strong potential generated by the interactions between the characteristics of nodes and urban places that coexist in such spaces [5, 6]. Thus, the public transport network becomes an opportunity to reorganise settlement patterns, direct growth processes, launch projects for new stations, if necessary, or conduct urban redevelopment in outlying or degraded areas.

The implementation of new technologies in urban living, such as the Internet of Things and information and communication technologies (ICTs), has led to further promising developments in the context of the smart city paradigm. The combination of hardware digital infrastructure and software elements, where city users take an active role as both "detectors" and "diffusers" of data and information, is the cornerstone of urban smartness [7].

Although several studies have recognised the main advantages of both TOD and smart city models, research has yet to systematically investigate the effect of their integration in urban planning practices. To date, there is a notable paucity of evidence-based literature describing the impact of smart and transit-oriented development.

This paper seeks to fill this gap by proposing a new methodology based in GIS (Geographical Information System) environment to assess the smartness and the transit-oriented readiness of station catchment areas. The methodology takes its cue from Bertolini's Node-Place (NP) model [3] and extends it, both in terms of the calculation procedure and the way in which the results are represented. Moreover, our paper examines a significant case study: the transit network of the city of Naples.

The manuscript begins with an overview of TOD and smart city models, with an evaluation of the main advantages and drawbacks of both. The method and materials are then presented. The third section describes the case study and its results. Finally, the concluding section summarises the potential for implementing urban development strategies that combine both approaches. In addition, some ideas for future lines of research are presented for the identification of a range of interventions to support policymakers and stakeholders.

2 Towards Smart and Transit-Oriented Cities

There are different approaches to transit-oriented development and smart cities in the literature. However, these two development paths are usually investigated as alternatives rather than as complementary. Some cross-sectional studies suggest an undeniable link between them—the common urban development objectives underlying the two urban models. The aim of our study is to propose some advances in the scientific panorama of this discussion by developing a methodology to assess the performance of transit nodes where both TOD and smart city principles have been implemented. In this section, the main traits of the two urban models are highlighted. In particular, concerning urban smartness, some of the most common gateways to the smart city model are summarised. TOD principles and some of the methodologies for analysing transit strategies are also presented.

2.1 Smart Cities

The smart city model has been widely studied but rarely deployed in real-world practices. The smart city aims to support spatial decision-making processes with the combined use of the latest scientific knowledge and ICT solutions in order to steer the development of cities towards greater economic, social and environmental sustainability [8–11].

The use of the smart approach, therefore, is proposed as a possible path to improving the efficiency, competitiveness and sustainability of urban systems in order to offer a better quality of life to citizens and more opportunities for stakeholders and entrepreneurs [12]. Smartness is also linked to the ability to foster integration and interoperability between the different components of a city. Furthermore, the concept of smartness is associated with the achievement of urban efficiency in the economic development, environmental, social, cultural and e-governance fields [13]. However, numerous researchers argue that without a real commitment to collaborating and cooperating from public institutions, the private sector and individual citizens, an adequate level of smartness cannot be achieved [14, 15].

Studying the relationships between smartness and urban development can contribute to a better understanding of those features of the smart city model that significantly contribute to improving the quality of life and well-being of citizens. Academics, practitioners, companies and public administrators, despite the commonalities in the theoretical and practical development of the smart city, have over time developed different ways of defining urban smartness.

Much of the scientific literature agrees that smart solutions in urban areas are effective only if they are developed holistically [16, 17]. The interest in improving urban smartness that has developed over the years has mainly been related to the use of new technologies to support services and infrastructure. However, substantial evidence proving that these types of interventions can provide comprehensive answers to the challenges that cities face has not yet emerged [18].

Mora et al. [19] point out that the knowledge necessary to understand the process of designing effective smart cities in the real world and the tools for supporting the actors involved in this development have not yet been produced. The innovation processes needed should be based on the interaction between different sectors and actors,

in order to give rise to horizontal and vertical transformational interventions. This holistic approach to urban smartness would affect multiple components of the city system, including entrepreneurship, design, technology, public policy, urban development, social challenges and climate change adaptation.

From a marketing perspective, smartness is used to emphasise the potential of using new technological equipment to improve the well-being and safety of individuals [20, 21]. Regarding the development of new technologies, smartness refers to the capabilities of hardware and software devices to self-configure, self-repair, self-protect and self-optimise the urban system depending on the conditions that occur [22]. Within the field of urban services planning and management, smartness is associated with the use of ICTs to improve the productivity and efficiency of a city's infrastructure and resources [23, 24]. From the perspective of urban planners, the smart city model is oriented towards the development of strategies and choices that enable a quick understanding of and adaptability to the needs of urban actors and events intrinsic and extrinsic to the urban system [25].

Theoretical studies on the topic of urban smartness are numerous and constantly evolving. This phenomenon suggests that a full understanding of the concept has not yet been achieved. Moreover, until now, all the efforts made to find a synthesis capable of identifying the main elements and phenomena influencing urban smartness have not been unanimously supported by scientific evidence.

Overall, the reviewed studies suggest that ICTs are important in improving the level of urban smartness. However, it has emerged over the years that collaboration and partnerships between the different components of a city are also fundamental to achieving the desired results. In this regard, Ahvenniemi and Huovila [26] identified three different classes of urban smartness, taking into consideration the level of collaboration between the various players (public and private) involved in implementing smart projects.

2.2 Transit-Oriented Cities

TOD was formalised in 1993 by Peter Calthorpe in his book "The Next American Metropolis" [27], which expounded urban planning practices in support of travel by transit. TOD is a planning and design strategy to develop a compact, multifunctional, safe urban environment for pedestrians and cyclists, closely integrated with local public transport hubs. The idea promotes the use of soft mobility and the development of active communities. Although TOD principles were theorised for American urban environments, they found wide dissemination and application in European contexts also, across cities large and small, with great variation in outcomes. Moreover, not all station areas in the same city can support a compact urban layout with a high density of housing, employees and activities.

In order to adapt TOD strategies to different territorial and urban contexts, it is necessary to know the physical, functional and socio-anthropic characteristics of transit station areas. Starting from the planning experiences of some cities, researchers have developed a number of methodologies to study the characteristics of station areas and support public decision-makers in making transit-oriented choices for governing transformation. One of the methodologies to support the governance of urban transformations is the Bertolini

NP model [5]. It allows for an assessment of the level of integration between transport and land-use development policies.

The NP method is based on indices that numerically and synthetically define the "node" and "place" characteristics of stations and their surrounding areas. The node indexes take into account the features of transport infrastructure, while the place indexes refer to the urban characteristics of the station areas. According to this model, the stronger the integration between the node and place value, the better the transit node performance is [28, 29].

The main purpose of the NP model is to assess the functionality of a transit node by analysing the relationship between the properties of the node and the quality of its location. The NP model is based on the reasoning of the land-use feedback loop [30]: Improving the transport supply (or node value) of a place through improved accessibility creates favourable conditions for further development of the place. In turn, the development of an area (or its place value) will create favourable conditions for the further development of the transport system due to increasing demand for transport. The NP model cannot predict developments, but it can help identify where actions can be taken to improve certain aspects.

The NP model helps determine where improvements are needed; therefore, this model lends itself well to identifying which aspects that characterise transit nodes require intervention to increase their accessibility. The model, as developed by Bertolini, is not uniquely applicable to different territorial contexts; it needs to be adapted according to the type of application to take into consideration differing physical-functional characteristics and the varying availability of data useful for calculating the indicators. Although this dynamism and adaptability of the model can be considered a strength, the consistency and quality of the results depends on the type and number of indicators that can be selected.

Hence, a large body of scientific literature has developed enhanced NP models to best suit ad hoc case studies and development objectives. Balz et al. [31] proposed one called the NP Butterfly. It resembles the shape of a butterfly as its final diagram is composed of two wings: a left wing that includes all indicators related to the 'ode' and a right wing that includes 'place' indicators. Each wing is divided into different dimensions: The node wing includes the accessibility of the station to people walking, cycling, using public transport or driving cars, while the place wing includes the proximity of the station to the city centre, the intensity of use by city users (inhabitants, employees and visitors) and the degree of functional diversity.

Another development of the original NP model includes indicators that assess the design of the environment [32–34]. This extension of the model makes it possible to assess not only aspects of land use ('place') and transport ('node') but also the ways in which the design of the built environment stimulates pedestrian and cycling conditions to support access to and from the station.

The quality of a transit node is relative, which means that the quality is determined by the other transit nodes in a network or a selection of them. By normalising the scores for each criterion, the relative score of a specific transit node can be calculated in relation to the others [29].

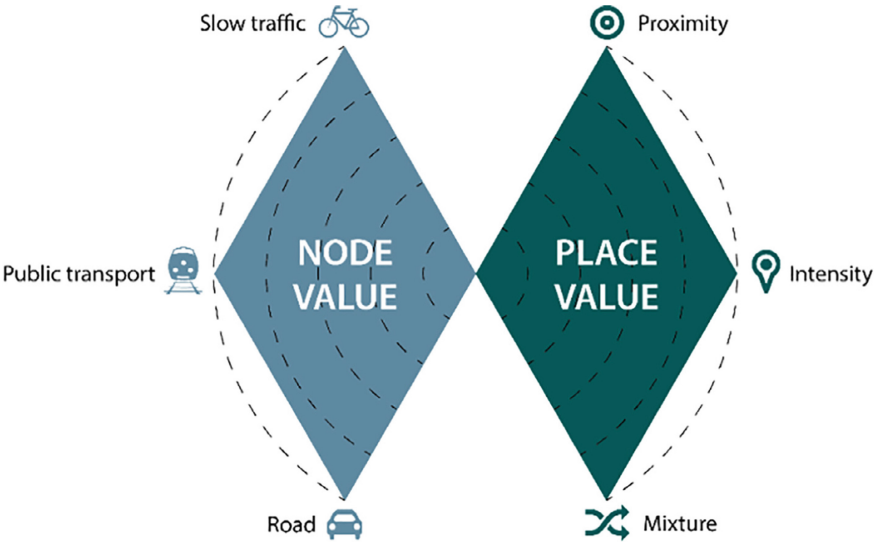

Fig. 1. Application of the vereniging deltametropool node-place method.

3 Materials and Methods: The Smart Spatial Indices of the Node-Place Model

This section describes the phases of the GIS-based spatial analysis methodology to support the evaluation and definition of priority transformation projects in station areas from a smart perspective. It is an integrated approach capable of relating the level of smartness of a station node to the level of smartness of the station surrounding the urban context. This methodology can be applied to any rail transport network by using open data to overcome the difficulties related to low availability of data necessary to define the synthetic indexes of "node" and "place".

Before selecting NP indicators, we identified the five smart dimensions that best contribute to defining integrated transport-territory development policies for station areas. These smart dimensions, obtained from previous studies, are described below.

Smart Economy refers mainly to the ability of a station area to create the best possible environment to encourage the development of businesses. The presence of commercial activities, public and private companies and an adequate functional mix represents the economic dynamism of a station area.

Smart Mobility has as its starting point the problems related to traffic congestion, which increasingly pose the question of how to move people and goods in the urban environment and ensure more efficient levels of service, while reducing the negative externalities that burden citizens. Therefore, the goal is not only to optimise transport infrastructures but also to improve the mobility of people and, in particular, the development of new ecological and sustainable mobility solutions in a station area.

Smart Environment focuses on environmental protection, which mainly involves good management of natural resources (including soil resources), and on the quality of

the station environment. These aspects are essential to create the conditions for an urban environment that is oriented to improving citizens' quality of life.

Smart Living and People concerns the ability of a station area to favour a "user-friendly" transport system, which is necessary to encourage people to use the railway system while also guaranteeing greater accessibility for the elderly and people with reduced mobility. This dimension also refers to the potential of a station environment to advance urban liveability by improving the services offered to citizens. Therefore, we can refer to enhancing cultural heritage and using it more intelligently through services supporting tourism, culture and free time.

Smart Technology refers to the enormous potential of technology to facilitate a station's operation and help improve the urban environment around it. Interactive terminals are an important source of information for passengers arriving at an unknown station, and digitisation makes it possible to increase the reliability of the information provided to users.

To enable the application of the methodology in different urban contexts, we selected a set of 32 indicators (19 for the Place component and 13 for the Node component). The indicators were defined to assess the degree of smart development of a station environment and its surrounding urban environment. Table 1 shows the list of indicators for each smart component.

Specifically, the indicators were chosen based on their ability to effectively describe an aspect consistent with the dimension to which they belong, the availability of data for the Italian context, the level of detail of the data acquired, and the availability of data for the two reference areas, namely the Node and the Place.

The main phases to apply this GIS-based methodology for the smart spatial analysis of railway station areas are:

Phase I—Data collection. For the data sources, we refer to the open databases provided by national statistical agencies and national and regional official portals.
Phase II—Creation of the GIS geodatabase. This involves the development of a relational data database (geodatabase) that is usable in the GIS environment and contains all the alphanumeric and spatial data necessary to calculate the selected indicators.
Phase III—Calculation of smart indicators. This entails evaluating the numerical value of each indicator and normalising from 0 to 1.
Phase IV—Graphic representation of the results. A quantitative analysis graphic model was developed based on the NP method proposed by Vereniging Deltametropool [35] as a fundamental support for defining priority interventions in station areas. This method proposes an innovative representation of transit nodes assessment which resembles the shape of a butterfly. It presents two wings: a left wing that includes all node indicators, and a right wing that presents 'place' features.

Table 1. The set of node-place indicators for each smart category.

Smart category	Component	ID	Indicators
Smart economy	Place	01	Number of private entrepreneurships
		02	Number of public education buildings
		03	Employment rate
		04	Population density
		05	Employment territorial distribution
	Node	06	Number of commercial activities
		07	Number of tourist attractors
		08	Number of smart economic activities
Smart mobility	Place	09	Bike lanes
		10	Parking spaces for electric mobility
		11	Surface of walking areas
		12	Density of road intersections
		13	Parking spaces for bikes
	Node	14	Number of park and ride spaces
		15	Number of tourist bus parks
		16	Infomobility services
		17	Level of intermodality
Smart environment	Place	18	Green areas
		19	Built areas
		20	Urban design
	Node	21	Safety of the station environment
		22	Station average attendance rate
Smart living and people	Place	23	Hotel facilities
		24	Cultural activities and entertainment
		25	Housing
		26	Public services
	Node	27	Level of disabled accessibility
		28	Station facilities
Smart technology	Place	29	Wi-Fi connectivity
		30	Smart roads
	Node	31	Transport information systems
		32	Video surveillance cameras

4 The Case Study

To apply the methodology, we selected the case study of the urban metropolitan railway (Line 1) in the city of Naples. Line 1 was preferred due to the fact that the municipality of Naples owns it, which could represent a strength in choosing and applying integrated interventions on both the Place and Node. Moreover, since the beginning of service, even partial, of the line, the city of Naples has experienced, in various forms, the strong influence of the station nodes, both in the central areas, since the stations themselves became touristic poles, and in outlying areas, finally reconnected to the entire urban structure (Fig. 2).

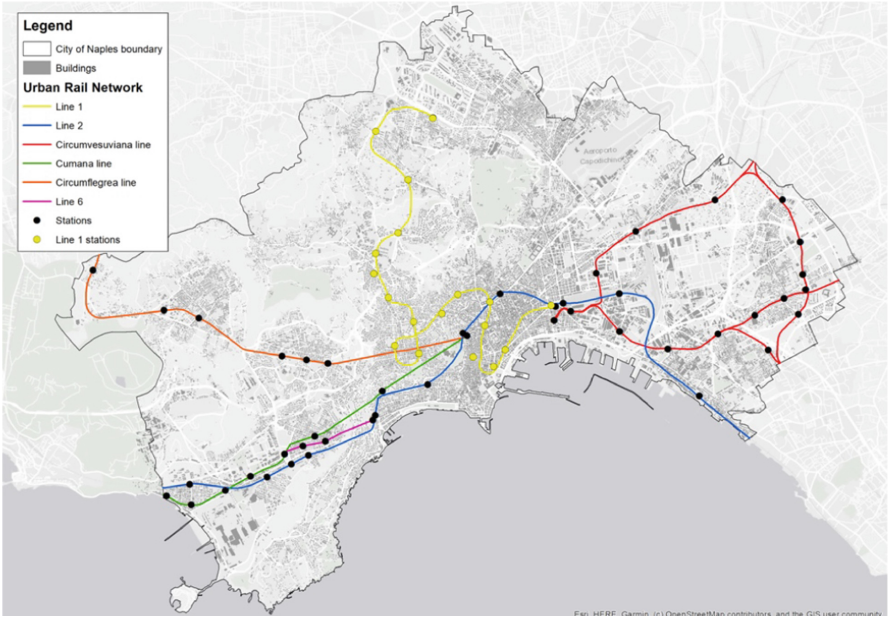

Fig. 2. The urban railway network in the city of Naples.

Line 1 is managed by Azienda Napoletana Mobilità and it includes 18 stations: Piscinola, Chiaiano, Frullone, Colli Aminei, Policlinico, Rione Alto, Montedonzelli, Medaglie d'Oro, Vanvitelli, Quattro Giornate, Salvator Rosa, Materdei, Museo, Dante, Toledo, Municipio, Università and Garibaldi.

The current operational section, which goes from the Piscinola district to Piazza Garibaldi, has an average frequency of one run every nine minutes. The line is 18 km long with a travel time of 33 min. The first two sections, from Vanvitelli to Colli Aminei, and from Colli Aminei to Piscinola, were activated in 1993 and 1995 respectively, while the remaining part was completed from 2001 to 2013. Of the 18 stations that make up the line today, 11 of them have been called "Art Stations" in which particular attention was paid to making the environments beautiful, comfortable and efficient to redevelop large areas of the urban fabric. The Art Stations are: Garibaldi, Università, Municipio,

Toledo, Dante, Museo, Materdei, Salvator Rosa, Quattro Giornate, Vanvitelli and Rione Alto.

In Table 2, we provide a list of alphanumeric and spatial open data selected for the application of the GIS-based methodology to Line 1 in the city of Naples.

Table 2. Data source for the calculation of selected node-place indicators.

Data	Source	Year
Population	ISTAT	2011
Census track	ISTAT	2011
Walking network	Open street map	2021
Transport stops	Open street map	2021
Railway urban network	Open street map	2021
Buildings	Geoportale Nazionale	2011
Companies	ISTAT	2011
Public offices	ISTAT	2011
Urban services	Open street map	2021
Urban green areas	Municipality of Naples	2021
Hotspot Wi-Fi	Google Maps	2021

The results show that most of the Line 1 stations are localised in the balanced part of the NP diagram. This distribution of stations reveals an optimum condition, with a substantial balance between the Node and Place indices for the analysed stations. The stations located in the central part of the diagram close to the middle line have a higher level of accessibility than the outermost stations.

The 14 stations included in the balanced part of the diagram have very different values for their NP indices, from 0.25 to 0.54 for the Node index and from 0.29 to 0.63 for the Place index. In these balanced stations, we identify two main subgroups: subgroup 1 includes Colli Aminei, Policlinico, Rione Alto, Montedonzelli, Quattro Giornate, Salvator Rosa, Materdei and Museo; and subgroup 2 includes Medaglie d'Oro, Vanvitelli, Dante, Toledo and Municipio. The stations with low NP indices values are in subgroup 1, while subgroup 2 contains the stations with higher values.

Table 3. Data source for the calculation of selected node-place indicators.

	Node					Place					Node	Place
	Economy	Mobility	Environment	People and living	Technology	Economy	Mobility	Environment	People and living	Technology		
Piscinola	0.079	0.243	0.333	0.300	0.012	0.035	0.047	0.305	0.157	0.210	**0.193**	**0.151**
Chiaiano	0.023	0.186	0.000	0.200	0.000	0.113	0.018	0.736	0.263	0.065	**0.082**	**0.239**
Frullone	0.023	0.222	0.455	0.373	0.000	0.150	0.001	0.324	0.267	0.000	**0.215**	**0.148**
Colli Aminei	0.015	0.080	0.560	0.456	0.181	0.591	0.029	0.337	0.321	0.195	**0.258**	**0.295**
Policlinico	0.142	0.124	0.495	0.517	0.177	0.572	0.026	0.360	0.307	0.290	**0.291**	**0.311**
Rione Alto	0.087	0.054	0.636	0.542	0.163	0.550	0.036	0.476	0.328	0.194	**0.296**	**0.317**
Montedonzelli	0.087	0.083	0.617	0.570	0.238	0.563	0.024	0.472	0.333	0.161	**0.319**	**0.311**
Medaglie d'Oro	0.578	0.125	0.929	0.717	0.358	0.410	0.119	0.389	0.466	0.568	**0.541**	**0.390**
Vanvitelli	0.404	0.198	0.936	0.682	0.349	0.409	0.163	0.653	0.529	0.635	**0.514**	**0.478**
Quattro Giornate	0.182	0.250	0.508	0.565	0.247	0.422	0.087	0.321	0.445	0.700	**0.350**	**0.395**
Salvator Rosa	0.175	0.125	0.495	0.517	0.330	0.343	0.132	0.443	0.408	0.468	**0.328**	**0.359**
Materdei	0.293	0.125	0.553	0.552	0.346	0.231	0.045	0.419	0.403	0.244	**0.374**	**0.268**
Museo	0.309	0.202	0.728	0.557	0.212	0.289	0.486	0.279	0.727	0.358	**0.402**	**0.428**
Dante	0.420	0.317	0.598	0.499	0.254	0.359	0.813	0.247	0.769	0.710	**0.418**	**0.580**
Toledo	0.277	0.365	0.670	0.662	0.278	0.591	0.769	0.340	0.632	0.839	**0.451**	**0.634**
Municipio	0.499	0.405	0.618	0.631	0.398	0.601	0.668	0.421	0.527	0.934	**0.510**	**0.630**
Università	0.143	0.500	0.540	0.384	0.092	0.848	0.758	0.307	0.740	0.819	**0.332**	**0.694**
Garibaldi	0.968	0.846	0.910	0.846	0.997	0.323	0.250	0.482	0.268	0.490	**0.914**	**0.363**

The Università station is out of the balanced area, and it is unbalanced for the Node index (Smart Economy and Smart Technology). The Università station deserves separate consideration as it is located outside the central spindle, as visible from the NP diagram in Fig. 3. Its decentralised position towards the right part of the graph reveals notable development regarding the Place indicators and lower values for the Node indicators.

In addition, Garibaldi station is located in the "unsustained" part of the diagram, where values for the Place indicators are too low compared with those for the Node indicators. This station obtained the highest Node indicator values of all the stations of Line 1 but low Place indicator values. The stations of Piscinola, Frullone and Chiaiano are located in the lower part of the NP diagram. These stations show a substantial equilibrium between the Node and Place components. However, they have a low degree of development of transport infrastructure and the urban and social characteristics of the station areas. Therefore, it would be advisable to intervene in these stations to reduce the marked differences between them and the remaining stations and improve the average values of Line 1 overall. A possible positive consequence of these interventions would be greater balance, which could trigger greater flows of displacement by railway and increase the attractiveness of the station areas.

Figure 5 shows the Smart Butterfly NP diagrams, as final stages of the methodology, for the four stations previously discussed, comparing the values of their indicators with the average values of the indicators for all the stations. This comparison could be useful to identify in detail the aspects that need to be improved in each station.

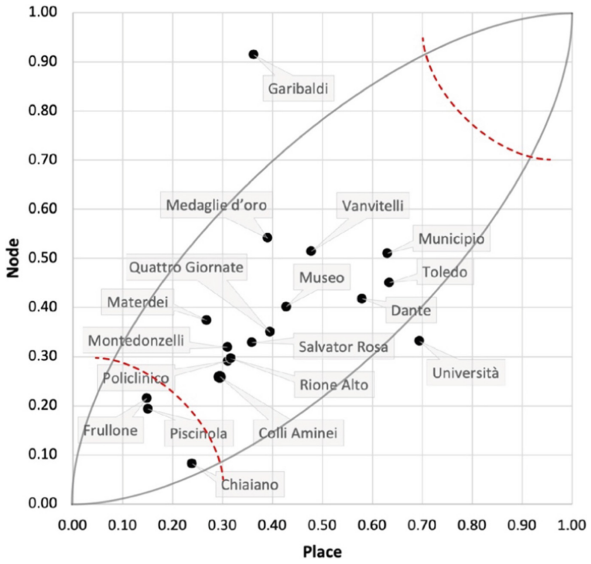

Fig. 3. Node-place diagram for the stations of Line 1.

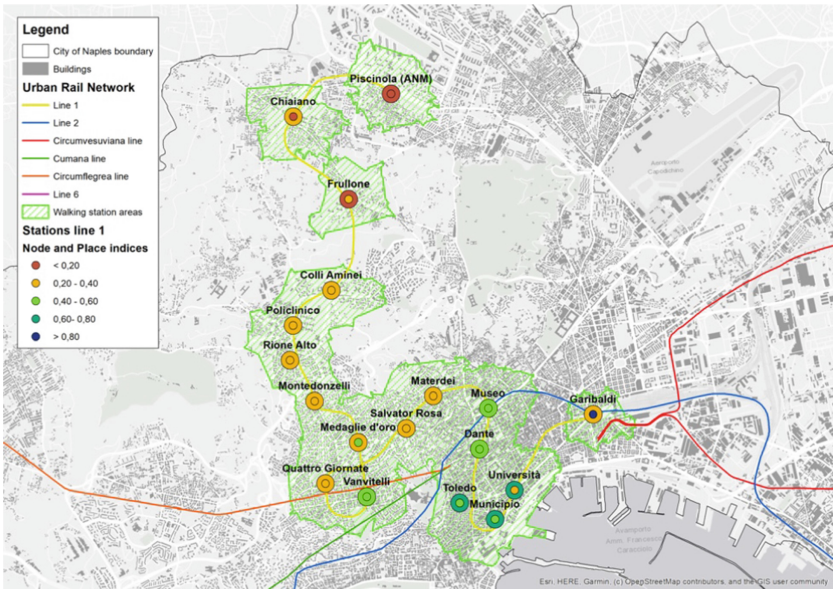

Fig. 4. The Node and place indices for the stations of Line 1.

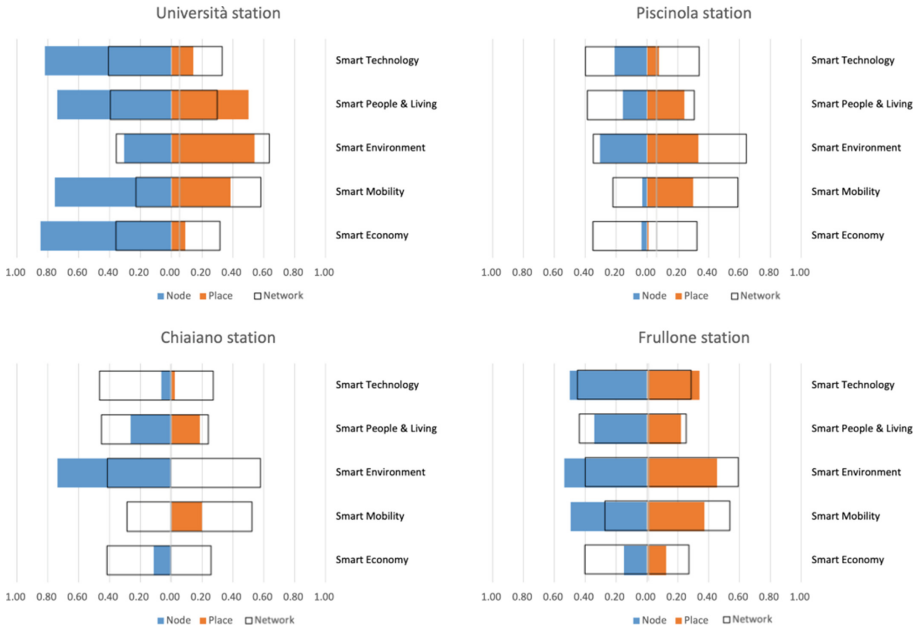

Fig. 5. The Smart butterfly node-place diagram for the stations of Università, Frullone, Piscinola and Chiaiano (in blue, the average value of indicators for Line 1 and in yellow, the value of indicators for the single station). (Color figure online)

5 Conclusion

This first application of the Smart Butterfly NP model to Line 1 of Naples as a preliminary step of our research attempts to define integrated land-use and transport methodologies and guidelines to improve the transit orientation strategy of station areas. In line with the scientific literature on smart cities, for this study, we considered five different categories of smartness (Smart Economy, Smart Mobility, Smart Environment, Smart Living and People and Smart Technology) to collect the indicators for the Node and Place components. The selected set of indicators (13 components for Node and 19 for Place) was obtained through an in-depth study of the scientific literature on the interaction between land use and transport and smart cities, but also through expert knowledge and the availability of open data.

The results showed that the stations of Line 1 are generally balanced, with the exceptions being some peripheral stations (Frullone, Chiaiano and Piscinola) and the station of Università (in the central area of the city). These unbalanced stations have deficiencies in all smart categories for the Node and Place components, and policymakers and technicians will need to implement specific solutions to improve them. Garibaldi station is an interesting case: its values for the Node component are very high because of its spatial proximity to the transport services of Naples railway central station.

A further result of this research concerns the methodological advancement of the Node-Place model and its integration with smart-city dynamics, in order to assess the performance of transit nodes as urban and, potentially, smart places. The integration

of transit-oriented development and smart city principles may be a solution for more sustainable and inclusive urban planning practices.

In our opinion, further developments should focus on increasing the number of indicators selected, applying a correlation analysis to choose the final set of indicators, defining a set of planning strategies for each group of stations and proposing specific transport and land-use planning solutions to increase the balance between the Node and Place components of the stations in each group.

Acknowledgments. The work, of which this paper is a product, although the result of a common reflection, was divided as follows. Carmen Guida: Introduction (1) and Towards smart and transit-oriented cities (2). Gerardo Carpentieri: Materials and methods: the smart spatial indices of the Node-Place model (3), The case study (4), Conclusion (5). John Zacharias: supervision.

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