DEPARTMENT OF REGIONAL AND URBAN STUDIES AND PLANNING

MASTER’S DEGREE PROGRAMME IN

TERRITORIAL, URBAN, ENVIRONMENTAL AND LANDSCAPE PLANNING

CURRICULUM PLANNING FOR THE GLOBAL URBAN AGENDA

Implementing Transit-Oriented-Development in Low Density Urban Areas. The Case Study of Turin-Torre Pellice

Supervisor

Prof. Luca Staricco

Candidate

Anahita Pak Bin

Academic Year 2020/2022

Abstract

Transit-Oriented Development (TOD) is believed to be an effective way to integrate transportation and land use (LUTI), through concentrating urban development around existing station areas. Within its principles, TOD values democratic, pedestrian and cycle friendly neighbourhoods with high density and mixed land uses. As the TOD concept gained popularity in western countries, some studies attempted to measure the "TODness" around existing station areas. Among different methodologies, the Node-Place model has been widely used, and enhanced in the literature related to TOD. However, as original principles of TOD dictate, most of these studies focus on the stations located in the high-density city core, neglecting potential stations in rural and suburban areas may possess for TOD projects. This thesis focuses on such possibilities in rural and suburban stations located on Turin-Torre Pellice railway network, using node-place methodology. The thesis also attempts to enhance the model based on findings in theoretical frameworks. The application of the methodology proves the necessity of adopting a context-sensitive approach that considers unique characteristics of different stations, as well as the importance of vertical coordination between different levels of governance in TOD considerations.

Keywords: *Transit-oriented development, TOD, Low density urban areas, Node-Place Model, Land Use and Transport Integration, Catchment Areas*

Acknowledgements

First, I would like to express my immense gratitude to my supervisor, Professor Luca Staricco, who guided me through the path of writing this thesis. Reaching this point would have been far-fetched without his insights, expertise, and patience.

I also gratefully recognize the help of Mr. Francesco Fiermonte for his technical support, providing me with the valuable data, which I used in this analysis.

I am thankful to Politecnico di Torino for allowing me to dive into this academic adventure. I am also grateful for the friends I have met throughout this master course, with whom I shared many moments of both anxiety and joy.

Most importantly, I am forever indebted to my dearest Iman, who patiently stayed by my side through the two most troublesome years of my life, and always believed in me even in the moments I did not believe in myself. Thank you all.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION AND THEORETICAL FRAMEWORK

1.1 PREFACE

Throughout the urbanization history, there has always been a distinct relationship between city morphology and means of transportation. In fact, we can divide the evolution of cities into three stages based on dominant means of transportation. First, the walking/horsecar era (1800-1890), when the dominant means of getting around was foot and cities were compact. During this time, new means of transportation emerged as small nodes, physically separated from the city itself and one another. Transit era (1890-1920) came with the invention of electric traction motors that revolutionized urban travel. The city spread out around the nodes of the new suburban railway lines, where densities were reduced to between 50 and 100 people per hectare. Land use patterns reflected social stratification where suburban outer areas were typically middle class while the working class continued to concentrate in the central, mixed used and dense city. Finally, the Automobile era (1920 onward) began with the introduction of automobiles in European and North American cities (Muller, 2004; Rodrigue, 2020). Muller (2004) even adds the fourth stage as Highway era (1945) that indicates post WWII massive highway extensions especially in North America, this process also happened in Europe but to a lower extent. Eventually, As the car ownership rate increased rapidly, the land development went on a different path. Developers became more attracted to green-field areas located between the suburban rail axes, and the public was attracted to these single-use zones in order to avoid industrial cities (Newman and Kenworthy, 1989). Indeed, Vehicle ownership has changed the shape of urban areas and even the way we live our lives, encouraging decentralization of activities from city centers and promoting patterns of lower density developments which sometimes is unable to serve adequate public transport choices to support sprawling suburbs (Newman and Kenworthy, 1989). City centers remain highly dense, containing many important financial, cultural, and recreational services and activities. These issues highlight the critical role of transportation in the ways we use lands the context where there is an increasing demand for transportation systems that move people and goods from low density peripheries to high density central areas.

During past years, there has been a great deal of interest of western cities in reversing the process; to reshape the city so that it is once again conducive to public transport (Cervero, 2002). Challenges regarding traffic congestion and pressure for development have resulted in a growing interest in *integration between land-use and transportation* (LUTI). Among numerous projects that have been conducted in North America, Europe, Asia, and South America, "Transit Oriented Development" (TOD) stands out as one of the popular approaches. It aims to concentrate mixed and moderately dense, and pedestrian- friendly development around stations that promotes transit riding, increase walking, bike travel and other alternatives to private cars (Cervero, 2006) as the principles of TOD are mainly focused on what is called 3Ds: Density, Diversity and Design (Cervero and Kockelman, 1997). Literature about TOD is relatively abundant (see for instance: Bertolini 1997 and 1999; Calthorpe, 1993; Cervero 1996 and 2004) however, there is still a gap between theory and practice of TOD. Moreover, within its principles, TOD strives for a high-density design, which has resulted in a focus on high-density urban areas in present literature, neglecting suburbs and rural station areas where same strategies cannot be implemented. Another reason for such tendency could be due to the generally accepted "the denser a city is, the less petrol is used per capita". But this also means a higher usage of private cars in low density peripheries and rural territories (Newman and Kenworthy, 2006). Theory has been proven in the case of Italy (where the case study is located) as well. According to the Italian Observatory on Mobility (ISFORT, 2018), in the large cities, the share of public transport is close to 30% of motorized journeys (double the average), while in municipalities with less than 50,000 inhabitants hardly reaches 4%. This wide gap poses serious problems on how to optimally organize collective mobility (covering the needs of demand in an economically sustainable way) from dense urban areas to less populated and more dispersed inland areas. The issue becomes more critical since about two out of three Italians live in municipalities with less than 50,000 inhabitants and these citizens' usage of public transportation is very little, even when they have to move towards the major poles. In this thesis, I focus on the stations located in low density areas of the Metropolitan city of Turin. I believe implementation of the strategies that promote more sustainable transportation in suburbs and rural areas, are as important as high-density urban areas.

1.2 STRUCTURE OF THE THESIS

Presented thesis is divided in six chapters. Chapter 1 and Chapter 2 have been progressed simultaneously, focusing on one hand, on building a theoretical framework for TOD, and on the other hand, understanding the introductory definitions and topics related to transportation and land use integration and what has been done so far. Chapters 3, Chapter 4 on methodology and application of node-place model for a holistic analysis on the selected railway line. Chapter 5 selects the rural stations from case study railway as the main focus for deeper investigation in potentials and conditions of TOD implementation. Following paragraphs give more detail about the content of each chapter:

The following part of Chapter 1 continues with a brief introduction to Transit-Oriented-Development (TOD) background, outlines the challenges related to TOD, both in the literature and implementations. After this, chapter points the main questions. The theoretical framework has been built on basis of the main questions and the selected keywords. Cited articles are categorized based on result of the search engine which is Google Scholar. Methodology and the outcomes of each paper has been documented in different tables.

Chapter 2 deals with literature review, presenting the topics that are necessary to consolidate the understanding Transit-Oriented-Development (TOD). Chapter begins with more general definitions related to sustainable mobility that is in fact the starting point of the discussion related to integrated land use and transportation planning. Then, reviews the sustainability challenges associated with transportation and the way it negatively effects land use as well, chapter continues with objectives of the sustainable mobility, then shifts to the concept of land use and transport integration as an accepted strategy for tackling the challenges discussed earlier and delivering sustainable mobility, reviewing the definitions and the evolution to the discussion to the point that TOD gained popularity. Chapter continues with the evolution of TOD and its principles, approaches to TOD measurements, planning and classification. At this point, the *Node Place* model introduced by Bertolini (1999) is adopted as the selected methodology for the thesis, briefly reviews it for a further elaboration in following chapter. Next section discusses the implementation of TOD in Europe and then Italy, where the case studies are located. Final part is later added and discuss the mobility situation after COVID-19 emerges, this part is added to understand the possibility of re-thinking transit stations and TOD in a pandemic situation. The chapter closes highlighting the latest findings and discussions related to future of TOD after pandemic.

Chapter 3 goes deeper in the main interest of the thesis that is low density suburbs and rural stations, starting with the context definition. Considering different approaches to classify urban settlements with tools provided by European commission as well as Italian definition measurements to understand the situation of case study municipalities. Second section of the chapter explains the adopted Node-Place methodology, starting with the station catchment area and the methodology to obtain them. To enhance the model, a set of new indicators are added. These indicators are extracted from cited articles in theoretical framework and the final list of indicators that are presented in the chapter. The method to translate indicators with different measures to indices is then explained. Finally, a three-step analysis have been adopted to measure the result based on the article by Nigro et. al (2019).

Chapter 4 describes a step-by-step implementation of the methodology for thirteen stations on the *Torino-Torre Pellice* railway line. The obtained node and place values for each indicator is presented in different tables. Place values are differentiated by the catchment areas related to four transportation modes (walking, cycling, bus and car). Through an averaging method, the node and place values have been translated into the node and place indices, from which so the final node and place scores are obtained. The scores then applied on three different diagrams: a general node place diagram, four detailed node place diagrams differentiated by the catchment areas related to each transportation modes, and finally radar diagrams for each station. Final section of this chapter compares the situation of each station on node-place model with and without additional indicators related to COVID-19 pandemic, to understand if the model can communicate a meaningful comparison between two scenarios.

Realizing the limitations of the model, and with regards to the context, Chapter 5 selects the stations in rural towns as the focus and compares the results obtained by node place analysis, for walk and bike catchment areas to the development framework of in-force planning tool of each municipality. The objective of this chapter is to realize the feasibility of TOD planning for the analyzed station. Chapter starts with a municipality analysis, identifying the development potentials based on PRG. Then, in a final table the findings are compared with the planning strategies obtained from the holistic analysis.

Chapter 6 sums up what has been done throughout the thesis process. Highlights the findings, discuss the shortcomings of the methodology, and finally, presents suggestions of further research of the topic.

1.3 RESEARCH BACKGROUND

This section briefly highlights the structure by which the evolution of the Transit-oriented development concept can be explained. It is necessary to highlight these topics before reaching to the main questions. As said earlier, TOD strategy is part of a wider discussion about Integration of Land-Use and Transportation (LUTI) that gained most of its popularity after sustainable development gained international attention. Given the fact that urban development and transportation are two main contributors to CO2 emission-today, LUTI has become more important and is considered to achieve sustainable transport and development goals. In European context, the report of the European Conference of Ministers of Transport (2001:19) for example, states that more sustainable policy making for urban travel requires a more holistic approach in which transport, land-use and the environmental decisions are made together, not in isolation from each other (Greelings, Stead, 2002). To this date, various policies were designated, and projects were funded by the European Commission with the objective Land-use and transport integration, promoting more sustainable urban planning and transport (see for instance, Geerlings & Stead, 2002 and 2005).

The term transit-oriented development was first introduced by Peter Calthorpe, in the late 1980's, and clearly defined and published later in his book *"The New American Metropolis"* (1993), aiming to build a compact, more walk and bike friendly urban environment around transit nodes. Even though TOD was born in the 90s', this name can be considered as a rebranding of older concepts such as Ebenezer Howard's idea of Garden City. When discussing TOD, Calthorpe himself has mentioned other related concepts such as Pedestrian Pockets, Traditional Neighbourhood Development, Urban Villages and Compact Communities (Calthorpe, 1993). Calthorpe discusses in detail what urbanism could look like in a more suburban context. The book itself is divided in three parts, The Next Metropolis; Guidelines and Projects that support his claims. Calthorpe argues the increasing migration to less expensive city peripheries and decentralization of jobs have resulted in drained and unappealing cities, pointing out pollution, congestion, loss of affordability and isolation as outcomes of this trend. Later, he mentions two strategies: an anti-sprawl regional plan that channels developments back in the city, and green belt strategy to preserve open areas around the cities. Calthorpe criticizes contemporary car-oriented developments, as he calls private vehicles “the ultimate segregation of our culture” (Calthorpe, 1993, p. 27). As opposed to this approach, he puts transit as the centre of the American metropolis arguing that transit -unlike car- strives for a more integrated, dense urban area.

There is a lot of emphasis on the essentiality of regional development in Calthorpe’s view of urban growth. He mentions obstacles and challenges regarding both local development and planning at the state and federal level that caused uncontrolled development to remote areas in the former and ineffectiveness and complexity of land use planning and growth in the latter, both of these levels are unable to address regional issues in his opinion. Later in the “guidelines for growth”, Calthorpe says “the regional structure of growth should be guided by the expansion of transit and a more compact urban form; second, that our ubiquitous single-use zoning should be replaced with standards for mixed-use, walkable neighbourhoods; and third, that our urban design policies should create an architecture oriented toward the public domain and human dimension” (Calthorpe, 1993, p.41).

Calthorpe points TOD as the most effective strategy for growth that is defined by “moderate and high-density, along with complementary public uses, jobs, retail and services [...] concentrated in mixed-use developments at strategic points along the regional transit system” (Calthorpe, 1993, p.41). While they can differ in terms of feature, each TOD must have at least, retail, housing, and public spaces, providing an adequate and attractive mix of lands adjacent to the station in order to create a link between land use and transit. However, the size of these spaces may vary in each TOD. It can also have a secondary area with lower density and a different street network with the aim of providing a direct connection to TOD’s core commercial centre and transit stops. Calthorpe warns that the commercial uses in the secondary area must not overlap with the ones in the TOD area. Interestingly, despite being written in the 90s, Calthorpe’s view on urban growth has been reflected in many new discussions. His criticism about urban sprawls and suburban growth are still issues in many developed cities in Europe and North America. So, it comes as no surprise that TOD has been gaining popularity among scholars and several national and local authorities to encourage public transportation and limit the use of cars. As academic journals and authors became more and more interested in the field, transit-oriented development began to achieve worldwide recognition, and the implementation of various projects emerged across the globe, it became clear that TOD is a very complex policy, and its implementation is highly dependent on the context and involvement of various stakeholders. This shift from theory to implementation revealed the challenges associated with this field, and researchers devoted their attention to more aspects of TOD, from planning to implementation and evaluation.

Among these studies, several attempted to classify TOD typologies according to several features of transit nodes and the area around it. These classifications can be useful in many ways, first they can lead to a better understanding of TOD implementation, facilitating the comparisons between different stations, and finally they are ways to identify problems that have been mentioned above. These evaluations are based on different indicators such as accessibility (Bertolini, 1996, 1999; Kamuruzzaman et al, 2014) pedestrian friendliness (Vale, 2015), urban agglomeration (Singh et al, 2014), design characteristics (Lyu et al, 2016) etc. These studies will be reviewed in the theoretical framework part of this chapter. One of the most famous studies is the node-place model, introduced by Bertolini (1999), which positions stations on a XY diagram according to the characteristics of the transit node and the land around it. Second part of this thesis (Chapter 3 and 4) deals with the node-place theory with the aim of evaluating TOD in low density areas. Normally, stations in low density areas are regarded as unbalanced nodes, lacking accessibility or availability of adequate public transport which indeed have a significant negative impact on travel behaviour of residence, environment. Thus, more attention must be paid to such stations. These topics will be more discussed in the literature review chapter (Chapter 2).

1.4 Challenges to TOD

As said, the complex nature of the TOD approach brought up several planning barriers. Many of these barriers s stem from disciplinary boundaries between Land use and transport (Staricco and Vitale Brovarone, 2018), and their conflicting interests that can be political, institutional, financial, legal, technical, cultural, or educational. Probably one of the main challenges is the question of TOD’s international transferability since it is important to consider the socio-economic and environmental aspects that are unique in different contexts. With this in mind, the challenges to TOD differ based on the location of the projects. Chapter 4 of the book *"Transit Oriented Development: Making It Happen"* (Curtis et. al, 2009) for example, focuses on challenges related to TOD. Curtis brings up the case study of "Network City" in Perth, Australia, where there are implementation challenges such as: lack of nationally adopted policy, lack of adapting planning tools and practices between plan and previous planning tools, poor coordination of planning for different activities, heterogeneity in different element of plans, weaknesses in the actions of transport agencies, improper functional classification of the roads and conflicts between different stakeholders.

In the European context, Pojani and Stead (2014) identify institutional, financial and even social challenges in Dutch TOD development and find out ideas, interest and institution connectors simultaneously play a role in this outcome. They list challenges as: inopportune timing due to economic crisis, weak strategies taken by Dutch municipalities, low stakeholders' interest, poor image of past TOD efforts that influenced community opinion combined by widespread usage of bikes that sets much higher standard of distance for non-motorized travel. They also mentioned inappropriate institutional strategies and even opposing actions of Dutch institutions as the main reasons for hesitation of TOD implementation and finally, isolation and ineffective actions of TOD lobby members and local politicians contributed to implementation becoming even less likely.

In another study about the United States Cervero et. al (2004) divide barriers to TOD in three basic categories which are: A) *Fiscal* which means factors that detract from financial feasibility of TOD projects such as questionable market viability and lack of conventional financing; B) *Organizational* such as structural impediments lodged in the institutional structure of transit agencies and other governmental entities responsible for projects; C) *Political:* land-use policies and NIMBY forces that impede multifamily housing and infill development more generally. Aside from this generic classification, the authors also mention unique barriers such as congestion issues, conflict between node and place, parking issues, weak realization of mixed-uses. The study goes further and provides a ranking of the most serious TOD barriers according to five public-sector stakeholder groups. The result shows a car dependent environment, lack of interests, expertise, market demand, local zoning issues, community opposition are among the most serious obstacles of TOD implementation.

In an attempt to explore TOD transfer and its implementation in Netherlands, Bertolini and Thomas (2014) discuss economic crisis, absence of an academic and political consensus, weak regional governance institution, an office space surplus and a mismatch between the supply and demand of areas for the residential development, fragmented ownership of the lands, land contamination, node's weak design, and area's unattractiveness (Thomas and Bertolini, 2014), later they listed three criteria of TOD "Critical Success Factors" (divided in three categories: Plans and Policies; Actors; and Implementation) consisting of sixteen factors derived from the barriers that their shortcomings, can negatively affect a TOD project. These factors are Policy consistency; Vision stability; Government support; Political stability at national level; Political stability at local; Actor relationships; Regional land use-transportation body; Intermunicipal competition; Multidisciplinary implementation teams; Public participation; Public acceptance; Key visionaries; Site-specific planning tools; Regional-level TOD planning; Certainty for developers; Willingness to experiment. In a complimentary study, Thomas and Bertolini (2015), analyse these 16 critical factors on 11 international case studies, the result show that political stability at national level, relationships between actors in the region, interdisciplinary teams used to implement TOD, and public participation are the most significant success factor in TOD implementation (Thomas and Bertolini, 2015). Some authors like Belzer and Autler discuss the challenges stem from relative stakeholders in most TOD projects. They first point out the lack of clarity in definition of TOD as a reason for unsuccessful projects in the USA, stating that the objective of projects can conflict with each other and since many actors are involved, some of their goals may be incompatible, for this reason, a careful balancing between objectives is required. Many of these incompatibilities reflect the basic tension between place and node as the result of the multitude of actors and goals, making the integration of node and place (which is strongly crucial in TOD projects) even more complicated. An example of transit agencies reluctance in the stations as anything but nodes and citizens who claim for more parking spaces find their needs in contrast with those who complain about increased traffic in the neighbourhood (Belzer and Autler, 2002, 21). Moreover, Belzer and Autler mention financial complexity due to mixed used characteristics of TOD, different real estate types have different levels of risk and require different financing strategies, lenders, and investors. Financial challenges happen to be more extreme in suburban areas where land is inexpensive and neither local governments nor transit agencies have enough incentives. Another issue brought up by the authors is the lack of coordination between different actors and finally, transit agencies overestimation of the land value brought by TOD projects.

1.4.1 TOD Classification Challenges and Research Gaps

Previous paragraphs discussed the academic focus on TOD classification based on features of the station and surrounding area. The classifications can be an effective evaluation tool for stations and have advantages such as: enhancing the planning process and strategies developed by TOD policy makers, increasing efficiency and effectiveness of projects, reducing complexity of TOD and identifying the success factors (Kamruzzaman et. al, 2014), however, most of the relative studies have discussed only high-density urban stations in large cities. Typically, *"Density, Diversity, and Design",* also known as the 3Ds introduced by Cervero and Kockelman (1997), are the main features of a TOD in most of the cases. Later 3Ds (Cervero and Edwing (2010) have been extended to 5Ds (density, diversity, design, distance to transit, and destination accessibility). Yet, these are not the only criteria that affect TOD, and in many areas, suburban and rural stations are examples of low density and diversity cases that, at the same time, suffer from more car dependency and consequently lower *"TODness"*, leaving Low density areas out of the TOD discussion (Staricco and Vitale Brovarone, 2018). Some studies however, suggested more site specific, context-based approaches to TOD typology (e.g., Conesa 2018; Lierop et al., 2017; Staricco and Vitale Brovarone, 2018; Lyu, Bertolini and Pfeffer, 2016; Thomas et al., 2018). Staricco and Vitale Brovarone (2018) for instance, discuss the potential and constraints of implementing TOD around suburban and rural areas along an entire line in Italy by assessing the potential change of 3Ds values for each station within a 750m buffer and the urbanized land. This study shows several shortcomings in the typical TOD classification, the first issue is the station buffer (which is usually 700-800 m, corresponding to 10 minutes' walk to/from the station) that is typically considered in TOD classification. According to the authors, this approach can work in urbanized areas however, in less urbanized areas, the urban fabrics that are located outside the buffer also affect the TOD potential of the inside area. Second issue is related to the definition of TOD and 3Ds evaluation; many suburban areas are below the minimum threshold suggested by TOD. Moreover, land use in these buffers is mostly residential and the infrastructure for secondary or tertiary activities are not available. Design of the road network is on the other hand, not very pedestrian and cycle friendly. However, many of these seemingly not suitable stations can in fact become a good choice of development. The authors suggest a wider, more context sensitive approach with more attention to sociocultural aspects (lifestyles, travel and housing demand, demographics etc.) for low density areas (Staricco and Brovarone, 2018). In another study, Nigro et. al. (2019) follows the same idea as Staricco and Vitale Brovarone (2018) applying the 'Node-Place model' (Bertolini, 1999) in a non-metropolitan context. Authors discussed despite the evolution of TOD classification studies since the 90s, the present literature still lacks an explicit focus on TOD in non-metropolitan context or land-use and transport integration in a wider catchment area. The paper attempts to extend node place analysis for a railway line in Italy, consisting of six municipalities classified as Town and Suburbs by Eurostat. In this analysis, the authors take into account the role of different transport feeders as an indicator alongside node and place indicators. According to the paper, this opens a new debate about LUT integration because these feeder modes need to be considered in low density areas in order to capture the interaction of the main transport node with the destination outside (Nigro et. al., 2019). Same as the previous paper, the authors emphasize on the necessity of considering a wider catchment area for suburban and rural stations. This topic will be further discussed in Chapter 2.

1.5 Main Question

From the discussions in section 1.4, the main questions form as follow:

How Transit-Oriented-Development potentials can be evaluated for existing transit stations located in low-density urban areas?

Therefore, the major concepts generated from the question are:

- *Transit stations:* Stations can be considered as logistical nodes that people or vehicles use for accessing transit. At the same time, stations are places where daily life of communities happens. Node and place are both preconditions of a successful TOD and this thesis is built on the assumption that transit station's functionality is in a node-place spectrum.

- *Low density areas;* are the focus of the thesis. As mentioned in the TOD challenges, the discussion is often neglected by TOD.
- *Transit-Oriented-Development (TOD)* is defined as a mixed-use, high density, pedestrian-oriented development around transit node (bus or train) with the aim of its general increasing public transport use and to improve the quality and liveability of neighbourhoods.
- *TOD evaluation:* There are various methods to evaluate a transit node. For instance, TOD can be evaluated according to Calthorpe (1993) neighbourhood/urban definition or 3Ds proposed by Cervero and Kockleman (1997) or the Node-Place model developed by Bertolini (1999). As it was mentioned earlier, these evaluations can be an effective tool to support TOD planning.

1.6 THEORETICAL FRAMEWORK

As the first step of building a theoretical framework, four articles related to TOD literature were cited based on the suggestion of the supervisor. Table1-1 shows the full list of initial sources in the order of publishing date:

Table 1-1 Initial group of articles (elaborated by author)

Title	Author	Methods	Outcome	Year
Promoting TOD through regional planning. A comparative analysis of two European approaches	L. Staricco E. Vitale Brovarone	Descriptive analysis	This paper focuses on the role of regional planning for TOD by analysing its benefits, tools, and barriers, both theoretically and through two European case studies in Netherlands and Italy. The analysis reveals that despite different results stem from two planning style, the main issue remains the deep coordination of land use and transport, which is hard to achieve despite dedicated efforts.	2018
Implementing TOD around Suburban and Rural Stations: and Exploration of Spatial	L. Staricco E. Vitale Brovarone	Regression Analysis	implementation, using cervero's 3Ds. The paper concluded the importance of a regional approach to TOD, pursuing the objectives on an	2018

Potentialities and Constraints			entire train line, defining the role of each station. Rethinking the statues of 3D in the context where higher density cannot be achieved, and finally emphasizing to the process of governance and a cooperative approach in planning development	
Transit-Oriented Development: A Review of Research Achievement and Challenges	A. Ibraeva G.H.A. Correia C. Silva A.P. Antunes	Literature review	Comprehensive research on TOD research achievements and Challenges, covering 330 articles from 1990s to 2018	2018
Land Use and Public Transport Integration in Small Cities and Towns: Assessment Methodology and Application	A.Nigro L.Bertolini F.D. Moccia	Analytic Tool (Extended Node-Place Model)	The paper investigates the relations between land use and public transport specifically focused on 'non-metropolitan' contexts (low density areas) through node-place model considering the role of different feeder transport modes in the consideration of node-place model for stations in small towns.	2019

Second set of articles have been extracted from references of initial articles. Selection is based on the importance the papers in arguments made by first group of articles. Articles are listed on basis of the publishing date:

Table 1-2 Second group of articles

Title	**Author**	**Methods**	**Outcome**	**Year**
Travel Demand and the 3Ds: Density, Diversity and Design	R. Cervero K. Kockelman	Descriptive statistics, Regression Models	Analysis of 50 neighbourhoods in the San Francisco Bay Area shows that compact, mixed-used, pedestrian friendly designs can decrease vehicle trips, reduce VMT per capita and encourage non-motorized travel.	1997
Spatial Development Patterns and Public Transport: The Application of an Analytical Model in Netherlands	L. Bertolini	Analytic Tool (Node-Place model), Multi Criteria Analysis (MCA)	Introduction of the analytical tool to offer a conceptual framework for development potentials in railways stations in Amsterdam and Utrecht in the Netherland	1999

An Application of the Node-Place Model to Explore the Spatial Development Dynamics of Station Areas in Tokyo	P. Chorus L. Bertolini	Node place model. Correlation analysis	The paper is based on the Reusser et al. (2008) study, the result shows even though the model illustrates development dynamics in station areas, and the transport and land-use factors responsible for such developments, discovering suitable positions for developments however, it comes with several the shortcomings for instance some of the balancing suggestions may not be realistic and also other important factors such as government policies must be taken into account.	2011
Advance Transit Oriented Development Typology: Case study in Brisbane, Australia	M.Kamruzzaman D.Baker S.Washington G.Turrell	Literature review, Two-step Cluster Analysis, Multinomial Logistic Regression model	Typologies of TOD neighborhoods in Brisbane, to assess their potential for different types of TODs built around six indicators. The result was four TOD clusters: residential TODs, activity center TODs potential TODs, and TOD non-suitability	2014
Beyond the Case Study Dilemma in Urban Planning: Using a Meta-matrix to Distil Critical Success Factors in Transit-Oriented Development	R. Thomas L. Bertolini	Meta-analysis	Meta-analysis of 11 TOD case studies implementation in order to identify critical success factors of TOD implementation. The authors developed 16 criteria which are: policy consistency; vision stability; government support; political stability (national); political stability (local); actors' relationships; regional land-use transport body; intermunicipal competition; multidisciplinary implementation trams; public participation; key visionaries; site specific planning tools; regional level TOD planning; certainty for development; willingness to experience	2014

Third group of articles are selected based on searching the keyword *TOD evaluation* that has been extracted from the main question. The search engine used for this thesis is Google Scholar. The searching process took into account the entire text and not title only. Table1- 3 shows the result:

Table 1-3 Selected articles result of TOD Evaluation key words (elaborated by author)

Title	Author	Methods	Outcome	Year
TOD: Developing a Strategy to Measure Success	J.L. Renne	Literature Review; Web-Based Survey	The paper offers strategies to evaluate the potential success of transit-oriented development by identifying 10 most useful indicators that impact TOD. Transit ridership; Density; Quality design of the streets; Quality of mixed- useness; Pedestrian activity/Safter; Increase in property value/ Tax revenue/ Public perception/ Mode connections to transit/ Parking configurations. The author believes the collection of the data for some of these indicators is not easy to achieve.	2005
Gaining Insight in the Development Potential of Station Areas: A Decade of Node-Place Modelling in the Netherlands	G.J. Peek L. Bertolini H. De Jonge	Node-Place Model with two extensions	Authors conclude that the success of node-place models depends on their ability to capture the synergy opportunities of integrated transport and land use development at station areas. However, their evolution points at the need of more closely relating the analysis to the views of the actors involved.	2006
Measuring transit-oriented development: a spatial multi criteria assessment approach for the City Region Arnhem and Nijmegen	Y.J. Singh P. Fard M. Zuidgeest M. Brussel M. van Maarseven	Spatial Multi Criteria Analysis (SMCA)	The study developed and calculated two TOD indices: Actual TOD index and Potential TOD index. Actual TOD index can represent the existing level of TOD for an area. Using the results of the Actual TOD Index scores, clusters were identified, and locations recommended for transit connectivity. Potential TOD Index can identify and map areas where urban development has High TOD level.	2014
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	D.S. Vale	Node-Place model	Combining Node-Place model with an evaluation of the pedestrian connectivity of stations in land-use, transportation, and walkability aspects. Author believes a balanced node-place does not indicate a TOD or vice versa and complementary analysis of both is needed to identify and classify the station area.	2015
Decision Support Framework for TOD	K.C. Strong M.E. Ozbek A. Sharma	Multicriteria decision analysis/AHP	The purpose of this research was to develop a flexible decision support framework which can be used by different transit agencies when	2017

	D. Akalp		choosing a TOD site to develop or build by incorporating and assessing unique success factors and their weights. Implementation of the framework showed differences in results when it comes to assigning weights of the factors.	
Measuring TOD Around Transit Nodes- Towards TOD Policy	Y.J. Singh A. Lukman J. Flacke M. Zuidgeest M. van Maarseven	Multiple Criteria Analysis (MCA)/ Spatial Multi Criteria Analysis (SMCA)	This paper proposed a methodology to measure the existing levels of TOD in terms of a TOD Index, within walkable distance of a transit node, by measuring various criteria that define TOD. The result of this study can improve the accuracy of TOD Planning proposals. The case study was 21 train stations in Arnhem and Nijmegen, the Netherlands and for each station, identified TOD characteristics that can be improved.	2017
Evaluating TOD on Station Area and Corridors Scales	F. Alarcon Y.J.J. Degerstrom A. Hartle R. Sherlock	TOD scoring tool	According to the authors, this guide presents a universal evaluation method for TOD. The framework conceptualizes the importance of travel behavior, the built environment, and the community strength. This method is also useful in determining how adjacent stations can complement one another and compensate for characteristics that a certain station lacks.	2018
Urban sustainability assessment: The evaluation of coordinated relationship between BRTS and land use in transit-oriented development mode using DEA model	R. Khare V.G.K. Villuri	Data envelopment analysis (DEA)	The study has been done to simulate the Coordinated relationship between BRTS and land-use in the city for 16 TOD station areas that are surrounded by BRTS stations using DEA methodology. According to authors CR input can be useful for planners who wish to plan TOD in the regions to understand whether the coordination between transit system and land-use are balanced or not. This method is highly dependent on the indicators so it can be applied to other public transportation systems as well.	2020

In fourth step, a search on keywords, *TOD Typology and TOD Typologies* have been performed. The reason for choosing them is the number of times they were repeated in the cited articles. Again, the searching process took into account the entire text and not title only. Selected articles are extracted as shown in Table1- 4:

Table 1-4 Selected articles/chapters from TOD Typology search results (elaborated by author)

Title	**Author**	**Methods**	**Outcome**	**Year**

Classifying Railway Stations for Sustainable Transitions	D.E. Reusser P. Loukopoulos M. Stauffacher M. Scholz	Descriptive Statistics; Multiple Imputation (for missing data)/ Extended Node-place model/Questionnaire and Repertory Grid Interview / Two-step Clustering Analysis	Enhancing Node-Place model imitation by taking into account more indicators relevant to sustainability and defining operationalized classification of the stations. According to author, this method achieved a better fit for Swiss data than original Bertolini Node-Place model (1999) better capturing the existed difference	2008
Performance-Based Transit- Oriented Development Typology Guidebook	M. Austin D. Belzer A. Benedict P. Esling P. Haas G. Minaitis E. Wampler J. Wood L. Young Z. Sam	Performance-Based Assessment	A guidebook for evaluating the performance of transit zones in neighbourhoods and towns by identifying the number of miles the typical household within each transit zone will travel in a year and whether that area is primarily residential, employment or a balance of the two. The result is a spectrum with which transit zones in a region can be compared to one another. The guidebook created 15 categories to describe various levels of TOD potential development sites.	2010
The geography of advance transit-oriented development in metropolitan Phoenix, Arizona, 2000–2007.	C. Atkinson-Palombo M.J. Kuby	Cluster analysis	Five typologies were identified for light-rail transit stations in Phoenix, Arizona: Middle-income area types; Transportation nodes; High population/rental areas; Urban poverty areas. Authors believe these quantitative geographical variables may be useful for policy makers since they give insights about income, housing tenure, whether land uses are compatible with TOD or not	2011
Classifying railway stations for strategic transport and land use planning Context matters!	S. Zemp M. Stauffacher D.J. Lang R.W. Scholz	Cluster Analysis	1700 Swiss railway stations have been classified based on context factors. Typologies vary in terms of density and land use. The result suggests that common passenger frequency is an insufficient indicator for station qualifications, on the other hand, a systematic classification based on contextual elements will	2011

			generate an interpretable, multi-perspective objective strategic planning. for railways.	
Latent Class Method for Classifying and Evaluating the Performance of Station Area Transit-Oriented Development in the Toronto Region	C.D. Higgins P.S. Kanaroglou	Latent Class Based Clustering	Latent method was applied to 372 existing and planning rapid transit station in Toronto, Canada, and the result was 10 typologies: Urban commercial core; Urban mixed-use core; Inner urban neighbourhood; Urban neighbourhood; Outer suburban neighbourhood; Suburban neighbourhood; Suburban centre; Outer suburban park; and Airport. The Authors believe this method reduces the complexity associated with complexity of TOD typology studies.	2016
Developing a TOD typology for Beijing Metro Station Area	G. Lyu L. Bertolini K. Pfeffer	Extended Node-Place Model/Literature Citation/ Citation/ Principal Component Analysis (PCA)/Cluster Analysis	The study tries to find TOD typology in China with a context-based approach. By extending the *oriented* dimension to quantify the degree of orientation of transit and development components towards each other. The result was six clusters (typologies) that reflected a context specific measurement.	2016
Transit-Oriented Development Among Metro Station Areas in Shanghai, China: Variation, Typology, Optimization and Implications for Land-use Planning	Z. Li Z. Han J. Xin X. Luo S. Su M. Weng	Extended Node-Place model/ Analytic Hierarchy Process (AHP)/ Self-Organising Map (SOM)	The aim of the study was to incorporate the oriented characteristics that represent morphological and functional ties between transport and land-use. Authors identified four typologies: Integrated; Functionally place-developed; Morphological node-developed; And dispersed	2019
Incorporating the travellers' experience value in assessing the quality of transit nodes: A Rotterdam case study	L.Groenendijk J. Rezaei Gocalo. Correia	Extend node-place model Node-Place-Experience (NPE) Multi criteria analysis (BMW method)/ Survey/ Interview	According to the authors, due to the shortcomings of the original node-place model in measuring the quality of transit mode, this method has been applied in Rotterdam, Netherlands in order to assess the quality of stations in travalleres' perspective. For the additional experience dimension in NPE models, the authors proposed a method to find criteria (based on literature, interviewing experts,	2018

			policy makers and users) and weighted (multi criteria analysis) the experience value to apply to different transit nodes. Authors believe this method results in a more accurate prioritization of transit nodes where improvements are necessary.	
Urban Networks Special Issue: Measuring the Accessibility of Railway Stations in the Brussels Regional Express Network: a Node-Place Modeling Approach	F. Caset D.S.Vale C.M. Viana	Extended Node-Place model	The paper performed a node place analysis on 144 railway stations in Brussels Regional Express railway network. The methodology consists of two recent extensions of the node-place model: butterfly model and the second one is the original node-place with additional indicators related to the design of the built environment. These	2018
Classifying railway station catchment areas. An application of node-place model to the Campania	R.Papa G.Carpentieri	Adjusted Node-Place Model Cluster Analysis	The application of the cluster analysis at the selected indicators for the 291 railway stations determined six types of station groups. Each group is distinguished by specific characteristics of infrastructure, the transport service, socio-economic conditions, and geographical location. These results from the application of the proposed procedure are useful for pre-selecting stations or corridors needing further investigation in the transport and land-use planning process.	
Planning for Nodes, Places, and People in Flanders and Brussels an Empirical Railway Station Assessment Tool for Strategic Decision-Making	F. Caset B. Derudder F. Witlox F.M. Teixeira K. Boussauw	Extended Node-Place Model / Cluster Analysis	The paper added some analytical improvement to original node-place model as: the proposed methodology was tested on Flanders and Brussels in Belgium which resulted in two typologies	2019
Using Walkability Measures to Identify Train Stations with the Potential to Become Transit Oriented Developments Located	D. Jeffery C. Boulange B.Giles-Corti S. Washington L.Gunn	Two Step Cluster Analysis	This paper explores walkability of 230 train stations in Melbourne, Australia using 14 different walkability measures. Result was three clusters: Most walkable (inner city area); least walkable (middle or outer suburban areas) and stations with highest potential for development as TOD that have the same walkability feature as cluster	2019

in Walkable Neighborhoods			1but more parking facilities compared to cluster 2.	
TOD Planning Analysis by GIS Approach	N. Mohd Noor	GIS MCDM Technique	The paper analyzed TOD development potentials for 17 stations in Shah Alam City Council, Malaysia. The research involved three analyses: land-use; TOD potential and TOD typology. The stations ranked in four typologies: Highest TOD intensity; Second Highest TOD intensity; Third Highest TOD intensity; Specialized TOD.	2020
Considering Context and Dynamics: A Classification of Transit-Oriented Development for New York City	Y. Liu A. Singleton D. Arribas-Bel	Self-Organizing Map (SOM) / Temporal Cluster analysis (k-means clustering)	The authors attempted to identify TOD typologies outside of D variable notions. Four salient TOD clusters were extracted for NYC. The methodology was applied for the second time and stations were classified in five unique clusters: Typical-work-oriented; Home-work mixed; Entertainment and work; Off-peak average; And typical home-oriented	2020

1.6.1 COVID 19 Pandemic and Public Transport

At this point of the research, COVID-19 had been already affected many nations across the globe. So, this part is added (later) to investigate in the effects of the pandemic on public transportation (the topic is discussed in literature review chapter, section 2.4). Here, the keywords *Public Transportation* and *COVID-19* are searched together. The result is shown in table1-5:

Table 1-1-5 Selected articles about public transport in relation with COVID-19 pandemic

Title	Author	Methods	Result	Year
Transportation in the Mediterranean during the COVID-19 pandemic era	D.Tarasi; T. Daras; S.Tournaki;T.Tsoutsos	Two phase questionnaires (online survey);	The article asked 308 (1st phase) and 193 (2nd phase) participants from two cities in Greece about travel mode choice. The result shows a difference between the factors that influence travel choice for each gender. For instance, women consider “road safety” and “personal safety” most crucial. Travel cost and flexible departure time were other	2020

			important factors for both genders.	
Physical mobility and virtual communication in Italy: Trends, analytical relationships and policies for the post COVID-19	C.Caballini; M.Agostino; B.DallaChiara	SWOT analysis	This paper analyses the relationships and mutual impacts between physical and virtual communications trends - in relation to different travel purposes in Italy before and during the health emergency, a SWOT analysis is elaborated to highlight pros, cons, future opportunities, and possible threats of virtual mobility. The ultimate objective is to provide policy indications in relation to different segments of mobility, considering various governance levels. Three scenarios are proposed with different levels of virtual mobility influence on physical mobility (low, moderate, and high). Among the proposed policy indications an integrated approach between physical and virtual mobility, improvement and regulation of physical mobility through ICT technologies to reduce negative externalities associated with transport, rethinking the timing and services of human activities, smarter and safer transportation infrastructure like providing real time , the adoption of solutions for co-modality and flexible transport services over long distances, encouraging the usage of MaaS through ITS are mentioned.	2021
Extent to which COVID-19 will affect future use of the train in Israel	W. Elias; S.Zatmeh-Kanj	Online survey	This study focuses on the attitudes and beliefs towards train use after COVID-19 pandemic. Two surveys have been conducted with a gap of seven months with 237 and 149 participants respectively. Study results also demonstrate the relation between trip purpose and the decision to use public transportation. The study results highlight the importance of many attributes favourably associated with train travel, including saving time, reliability, and comfort. According to this study, the most effective measures for encouraging people to keep traveling by train required mask use, preventing people with	2021

			flu-like symptoms from traveling by train, and fining those who do not comply.	
COVID-19 Impact on Transport: A Paper from the Railways' Systems Research Perspective	A.Tradivo; A.C. Zanuy; C.S.Martin	Action research method	This paper focuses on the impacts of COVID-19 on the transport sector specially railways. The article mentions the advantage of rail transport compared to road and air due to the composition of wagons, speed and efficiency, lower costs and being safer with respect to social distance measures. With the chance of reversing the impact of transport on the environment, the paper emphasizes on the necessity of developing new green mobility. It mentions "5R" s as a solution: resilience, return, reimagination, reform and research as necessary steps the rail sector needs to address. Among the measures proposed, automation such as electronic ticketing systems, enhancing maintenance, deeper interconnection with micro mobility sectors (scooters and bicycles), passenger tracking, installation of thermal cameras, rethinking length of the trains, night trains for long-distance travels.	2021
Impacts of COVID-19 and pandemic control measures on public transport ridership in European urban areas – The cases of Vienna, Innsbruck, Oslo, and Agder	S.Rasca K.Markvica B.P.Ivanschitz	Online uvery Descriptive analysis	Comparing the data for two small towns and two metropolitan areas: Vienna (Austria), Innsbruck (Austria), Oslo (Norway), and Agder (Norway) for the whole period considered (February 2020 – February 2021), the negative impact on PT patronage was extremely strong during the first pandemic wave (between 67 and 82 percent loss of patronage), despite the low number of infections. Full recovery of PT patronage did not occur in any of the cases. During the second and third wave, PT faced a milder drop in all the cases. The authors conclude that the length and variation in severity of the pandemic itself were decisive regarding the PT ridership variations, with the beginning of the pandemic registering stronger impacts due to the "fresh fear" effect	2021
A region-wide survey on emotional and	T. Campisi; S. Basbas;	Online survey	The study examines the PT demand characteristics during the various	2020

psychological impacts of COVID-19 on public transport choices in Sicily, Italy	M.A. Al-Rashid; G. Tesoriere; G. Georgiadis	Inferential statistical tests Descriptive analysis	phases of the COVID-19 pandemic in Sicily. A series of inferential statistical tests were applied to assess the correlation of psychological aspects with socio-demographic variables and modal choice habits (trip frequency). From the point of view of the land transport offer, the buses, trams, trains, and metro services have been characterized by a 50% capacity reduction of onboard users. The travel restriction has also led to a reduction in the number of journeys and left some areas relatively inaccessible. Empirical findings showed that users' emotional perceptions led them to restrict certain travel choices. The empirical results obtained from the first step of the survey carried out through the present research show weak or moderate correlations between people's emotions and the frequency of use of PT maybe because they remained captive users or they had certain incentives to do so or because specific conditions in Sicily created a more favourable environment for PT use during the pandemic. Considering transport supply, the paper suggests Demand Responsive Transport (DRT) and complementary modes and consideration of MaaS.	
Behavioural changes in transport and future repercussions of the COVID-19 outbreak in Spain	E. Echaniz A.Rodríguez R. Cordera J. Benavete B. Alonso	Survey MNL model	This paper investigates the behavioural change in the transport sector of region Cantabria (Spain) during the lockdown through a survey of 478 participants. The results show that citizens are wary of using PT due to the risk of contagion, and an increase in the use of private vehicles is also reported.	2020
Building back better: The COVID-19 pandemic and transport policy implication of a developing megacity	M. Hasselwander T. Tamagusko J.F. Bigotto A.Ferreira A. Mejia		The study used aggregated open-source cell phone and GPS data from two sources that provide a comprehensive representation of the mobility behaviour of the Metropolitan Manila population before and during the lockdown. The result shows the PT shows the largest drop (-74.5%). The paper concluded that the people who relied on PT are the most to be affected by	2021

	lockdown, and with the PT being unable to deliver the service, a shift is happening towards active mobility (walk and bike)	

2 LITERATURE REVIEW

2.1 INTRODUCTION TO SUSTAINABLE DEVELOPMENT AND SUSTAINABLE TRANSPORTATION

To shed a light on TOD as a model for transportation and land use integration, it is important to understand more general concepts as a framework that changed views on transportation and led to the emergence of aforementioned discussions. 'Sustainability' or 'Sustainable Development' initially defined in Brundtland Report as a development that 'meets the needs of the current generation, without compromising the ability of future generations to meet their own needs and choose their lifestyle' (Hauf, 1987, p. 16). As it shows in the figure, it is necessary to make a balance between economic, social, and environmental priorities in order to achieve sustainable development (Figure 2-1).

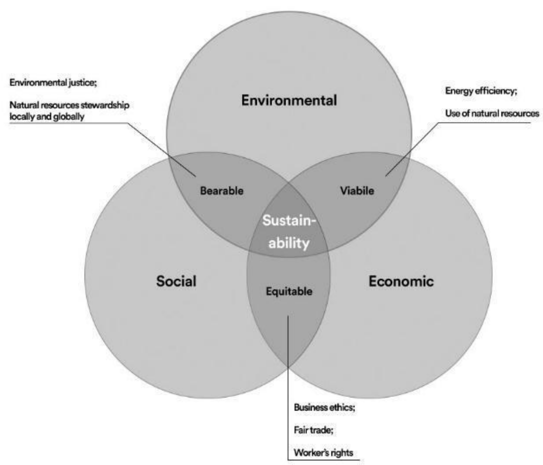

Figure 2-1 Sustainability diagram based on the sustainability definition in Brundtland report (elaborated by author)

The current transportation system is not by any means sustainable as the report of the Sustainable Mobility Project of the World Business Council for Sustainable Development (WBCSD) claims: 'mobility is not sustainable today and it is not likely to become so if present trends continue' (WBCSD 2004). There are various reasons that make the current system unsustainable such as, high dependency on fossil fuel, safety issues and accidents caused by motor vehicles, air and noise pollution, congestion, and urban sprawl. In fact, transportation is one of the most problematic challenges of sustainability especially from the environmental perspective and is heavily linked to climate change and global warming since emission from motorized vehicles exacerbates greenhouse gas emission. From 1973 to 2010, CO_2 emissions from the transport sector nearly doubled, from 3.4 to 6.7 billion tons (Millard Ball, 2016). This linkage between transport and sustainable development -although not in a separated chapter- was mentioned three times in the Brundtland report, putting greater attention to this relation. As a result, during the 1990s, the notion of sustainable development heavily influenced the discussion about transportation and raised the awareness about negative impacts of automobile dominance on global warming issues.

Applying the imperative of sustainable development to the transport sector has led to several concepts denoted by terms such as: sustainable mobility, sustainable transport, sustainable transportation, and sustainable transport systems (Holden, 2007) and went beyond environmental concerns and include economic and social aspects as well. This trend was followed by authorities on different levels to implement policies and strategies aiming to change priorities to more sustainable and low impact transport options, such as the pioneering National Environmental EU Green Paper on the Impact of Transport on the Environment (CEC 1992), 2001 White Paper of the European Commission on the Common Transport Policy and so on. These strategies and actions, although still insufficient, are part of the sustainable transport (ST) agenda which is yet to improve.

Considering the main issue of this research, while sustainable development calls for a more holistic approach to different aspects of development, the integration of land-use and transport planning, through comprehensive regional and local policies, could help facing for all [sustainability] issues leading to more dense and mixed development areas and to prevent further habitat and farmland degradation and promoting healthier, safer and more sustainable transport modes (Calthorpe, 2011). This chapter tries to clarify major elements, starting with the sustainable transport concept, its historical background and relative challenges, then moves to more related topics.

2.1.1 Sustainability Challenges of Transportation

It is better to begin ST discussion with the components of unsustainable transport and how they make the current transportation system unsustainable. To do so, the author analyzes the history of transportation and how car dominance culture led to various sustainability issues, then moves to the definition of sustainable transport.

The increasing role of transportation in urban development dates back to the first half of the 19th century with the beginning of the 'Railway Era' when a revolution in transport systems was accompanied by industrial revolution. The invention of the steam engines seemed to be an answer to the fast-growing population of European and North American cities and gradually changed the perceptions of distance and travel hardships. The first commercial rail line linked Manchester to Liverpool in 1830 (Rodrigue et al., 2006) and soon, the construction of new railways paved the path for moving huge amounts of goods and people at a significant speed compared to previous modes of transport such as horses as a result, the railway network expanded tremendously. By the end of the nineteenth century, international transportation undertook a new growth phase, especially with improvements in engine propulsion technology and a gradual shift from coal to oil in the 1870s (Rodrigue et al., 2006). This new, successful mode of transport along with engineering improvement to waterways was one of the earliest pollutions of the transport sector. Still, during this century, the impact of transportation on the environment remained localized. Over the years of the 20th century the railroad industry has done its share of polluting through the use of various petroleum products as lubricants; by using polychlorinated biphenyls (PCBs) in brake boxes to keep them from overheating; and, by using chemical defoliants along their rights-of-way (Black, 2010).

It was during the 'Fordist Era' (1920-1970) when the real impact of transportation on the environment and land emerged as the popularity of automobiles grew in western Europe and the United States. Compared with steam engines, internal combustion engines have a much higher efficiency and use a lighter fuel: petrol. The internal combustion engine permitted an extended flexibility of movements with fast, inexpensive, and ubiquitous (door to door) transport modes such as automobiles, buses, and trucks. Mass producing these vehicles changed considerably the industrial production system, notably by 1913 when Ford began the production of the Model T car using an assembly line (Rodrigue et al., 2006). By the eve of World War I the development of mechanized and motorized transportation modes was well under way, with the automobile in the lead and the truck, small by today's standards, close behind. This led to increased demands for improved and expanded roads. Moreover, Fordism led to the availability of relatively affordable and useful automobiles for rural folks, family physicians and city dwellers. The bicycle and the automobile had emerged as modes for elites but soon became available to a wide range of social classes in many countries. During this period, several European nations undertook large highway and motoring projects while public transportation systems were under siege by automobility and automobile interests, (Preston et al., 2010) and gradually, cars became the icon of the twentieth century and experienced an extensive increase of the production in the second half of the century (Figure 2-2). In 1950, there were about 50 million cars on the world's roads, 76% of them in the United States (WBCSD, 2001). From this point, modal share of public transport began to decrease and even city planning's favored to maximize car accessibility. This 'car culture' results not only in negative environmental challenges such as congestion, air and noise pollution, but also in emergence of urban sprawl as a result of highway system expansion and suburbs.

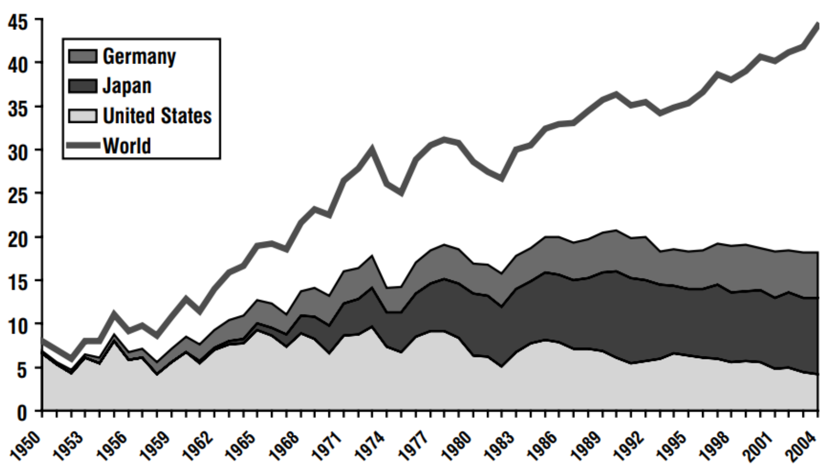

Figure 2-2 Automobile production, United States, Japan, and Germany, 1950–2004 (in millions) (Source: Worldwatch Institute; International Organization of Motor Vehicle Manufacturers, http://www. oica.net)

It was in the 1980s' when the environmental issues associated with highway and street expansion finally got worldwide recognition. During this time, the link between emissions from the transport sector and global warming became obvious as almost all the transport activities were dependent on oil. From this point, Governments began to promote low impact transport actions and policies such as: increasing investments in public transportation, refinement of urban transit systems, pedestrianization, traffic control, investment in bicycle facilities, and regulatory efforts. In Europe, Transport and Environment Reporting Mechanism (TERM) has been monitoring the progress of the integration between environmental objectives and transport policy since 2000. However, so far, the actions appear to be insufficient as every country still faces transportation sustainability challenges, albeit to different extent. In the EU-28 for instance, transport (including air transport emissions) was responsible for 24.6 % of total emissions in 2017 (The largest after the Energy Industry sector) this means a 2.2% increase compared to 2016 and 11% compared to 1990. Moreover, according to the European Environmental Agency (2015) transport is the only one among the main economic sectors that had an increasing trend in GHG emission during 1990-2013. Having said that, it is also important to note that each transport mode has its own environmental consideration and more importantly, there is a significant difference in the degree of emission between different transport modes. For instance, railway is one of the most sustainable, energy-efficient, and least polluting modes for moving people and goods – especially when electrified (Preston et al., 2010). So, a distinction can be made between more consuming or less safe transport modes such as private vehicles and more efficient ones such as bus, train. Here, the question is, what components make the current transportation systems unsustainable? Probably David Banister (2005) gives the most precise answer to this question as 'Ten Principles of Sustainable Development and Transport', which are as follows:

1. *Growing congestion* in many urban areas has been increasing in its duration and intensity. On average, speeds in cities have been declining by about 5 per cent per decade (EFTE, 1994), and the severity of congestion increases with city size (Dasgupta, 1993).

2. *Increasing air pollution* has resulted in national air quality standards and those recommended by the World Health Organization being exceeded in many cities. Air pollution affects health, impairs visibility, and damages buildings and local ecology – it reduces the quality of urban life.

3. *Traffic noise* affects all city life, and it is estimated by the OECD/ECMT (1995) that about 15 percent of the population in developed countries is exposed to high levels of noise, mainly generated by traffic. Disturbance is also caused by vibration, particularly from heavy lorries, and night-time deliveries.

4. *Road safety* is a major concern in cities and elsewhere. Worldwide, traffic accidents result in 250,000 deaths and about 10 million injuries each year (Downey, 1995). The accident rates are now declining in some countries (with high levels of motorization) but increasing in others (with low levels of motorization). This is a very high cost 'accepted' by society,

5. *Degradation of urban landscapes* results from the construction of new roads and transport facilities, the demolition of historic buildings, and reductions in open space. Transport contributes to the decaying urban fabric and neglect of central city areas, as well as urban sprawl (Ewing, 1997).

6. *Use of space by traffic* facilitates the movement of the motorist but reduces the accessibility of others as transport routes become barriers, as parked vehicles form obstacles for pedestrians, cyclists, and those with disabilities. Car dependency results in traffic domination in urban areas, sometimes splitting communities.

7. *Global warming results* from the use of fossil fuels. Transport (2016) accounts for 28.9 percent of CO2 emissions and this level is rising in relative terms as well as in absolute quantities. Transport is almost wholly dependent on oil, and this is a non-renewable energy source.

And three land-use related factors need to be added to this list

1. *Decentralization of cities* has been facilitated by the car, in combination with efficient public transport. This has resulted in a substantial growth in trip lengths and patterns that are dispersed rather than concentrated on the city centre. This in turn increases car dependence and reduces the possibilities of promoting efficient public transport
2. *Development pressures* have taken place around car accessible locations which are not accessible to all people (including the edge city developments). The spatial segregation of activities in urban areas again increases trip lengths and has strong distributional consequences. High land and property prices are symbolic of a buoyant economy, but they are also socially exclusive, particularly in terms of access to low-cost city centre housing
3. *Globalization* and the relocation of industry (including the information economy) have resulted in new patterns of distribution and the transport intensity of freight has increased globally, regionally, and locally (Banister, 2005).

In another study by Holden et al. (2019), authors add excessive consumption of energy and material resources to the list above. Around 31.6% of the world's final energy in 2016 was mostly non-renewable energy resources (IEA. 2018). Moreover, motor vehicles consume 7% and 3% of ferrous metals. Metal demand in OECD regions is likely to grow by a factor of 2.2 to 3.5 between 2017 to 2060 (OECD, 2019). Looking at these principles and facts, it is obvious that current transportation systems are in contradiction with all three aspects of Sustainable development. the unsustainability of the transport system will continue well towards the end of this century (Holden et al., 2019). Realization of such impacts led to emerging Sustainable Transportation which will be discussed in the following part.

2.1.2 What is Sustainable Mobility?

As mentioned in previous paragraphs, sustainable transportation and sustainable mobility concepts emerged as a response to the sustainability challenges related to transportation. In present literature, these terms are used interchangeably, the former is commonly used in North America while the latter is more present in European studies (Black, 2003). It has been said already that Brundtland Report (1987) can be considered as the starting point of this discussion and even though there is no explicit section under sustainable transport title, it has been mentioned in some parts of the report. The European Commission was one of the first legislative bodies to respond, and attempted to put together transportation and sustainable development concepts as 'sustainable mobility' in the Green Paper on Transport and Environment (CEC,1992):

'This Green Paper [....] presents a Common strategy for "sustainable mobility" which should enable transport to fulfil its economic and social role while containing its harmful effects on the environment' (CEC, 1992).

It was the first time that the term sustainable mobility appeared in an international agenda, covering the issues of environmental protection, safety and security, consumer protection, labour rights and social policy, and the external costs of transport, and ever since, the concept has gradually evolved in the literature. In an article Holden et. al (2019) presents a literature review on concept evolution since the early 1990s and how the concept- according to the authors- extends different dimensions over four generations since its emergence. The review shows that the methodological approach and theories related to ST transitioned from revolving around environmental impact assessment, quantitative modelling, and regression in the first generation, to more qualitative modelling, institutional and historical analysis in the second, and later, to transition management; sociotechnical transition and technological innovation system. (Holden et al., 2019). Similar to CEC 1992, many authors attempted to define it by applying sustainability principles of Brundtland report to the transport discourse (Black, 2010; Kennedy, 2005; Banister, 2005; Schiller and Kenworthy, 1999). These definitions are mostly based on the three dimensions of sustainable development (environment, economy and social), commonly referred to as 'triple bottom line' (Pei et al., 2010). Black (2010) simply defines ST as a "transportation that satisfies the current transportation and mobility needs without compromising the ability of future generations to meet those needs" (Black, 2010). Maybe a more objective oriented definition was presented by the University of Winnipeg's Centre for Sustainable Transportation which defines an ST as a system that:

- allows the basic access needs of *individuals* and *societies* to be met safely and in a manner *consistent with human and ecosystem health*, and with *equity* within and between *generations*.
- is *affordable*, operates *efficiently*, offers choice of transport mode, and supports a vibrant *economy*.
- *limits emissions and waste* within the planet's ability to absorb them, *minimizes consumption of non-renewable resources*, *limits consumption of renewable resources* to the sustainable yield level, *reuses and recycles* its components, and *minimizes the use of land* and the *production of noise* (Preston et. al, 2010).

Some other studies attempt to identify applicable frameworks to achieve a sustainable transport, for instance, Banister (2008) outlines four sustainable mobility paradigms by which sustainable transport can take place: *(1) reducing the need to travel- substitution; (2) transport policy* *measures- modal shifts*; *(3) land-use policy measures- distance reduction*; *(4) Technological innovation- efficiency increase*. These basic actions are useful to classify policies and projects on sustainable transport. In this regard, Banister's third paradigm is the focus of this thesis. This approach aims to build sustainable mobility into patterns of urban form and layouts, which in turn may lead to a switch to green modes of transport. Intervention can be taking place through increasing densities and concentration, through mixed use development, through housing location, through the design of buildings, space, and route layouts, through public transport-oriented development and transport development areas, through car-free development, and through establishing size thresholds for the availability of services and facilities (Banister, 2008). Following parts of the chapter discusses the relationship between transportation and urban forms.

2.2 LAND USE AND TRANSPORT INTEGRATION

Even though the studies about the interaction between land-use and transportation date back to the 60s, prior to the popularity of sustainable development in the research and policy discourses, land-use and transport were mostly considered as two different domains. Fortunately, recognition of the environmental aspect of sustainable development has led to the popularity of LUTI since both land-use and transportation contribute to global warming with a high share of CO2 emission. It is important to note however, unlike the transport sector which contributes directly to environmental degradation, land use (or urban form) has both direct and mediated impacts on the environment. Directly, a change in land use pattern (e.g., from vegetation to urban) is a major factor of climate change. Indirectly, urban form influences the way people travel and thereby the level of CO2 emissions (Yigitcanlar, Kamruzzaman, 2014).

Many scholars believe that a sustainable urban form has the potential to reduce energy consumption for transport by reducing the travels and increase accessibility for low mobility groups to public transport (see for example Barton et al., 1995; Banister and Marshall, 2000; EMCT-OECD, 2002; Banister 2005; Holden, 2007). On the other hand, there have been some disagreements on what urban form should be considered as sustainable? Generally, there are two opposing theories: the compact city and the dispersed city theories. Each is claimed to be the superior urban form by its proponents (Holden, 2007). Having said that, today there is a convergence among many planners and policy makers about the crucial role of integrated land-use and transport policies in planning practices as it has become one of the priorities in policy making as an answer to negative effects of rapid urbanization on climate change, and in order to achieve sustainability especially in the case of sustainable mobility. The report of the European Conference of Ministers of Transport (2001) for instances, states:

"Sustainability requires that policy-making for urban travel be viewed in a holistic sense: that planning for transport, land-use and the environment no longer be undertaken in isolation one from the other… Without adequate policy coordination, the effectiveness of the whole package of measures and their objectives is

compromised" (EMCT, 2001).

New integration policy instruments that have been designed in Europe paved the path for further research activities. Some studies attempted to classify such integration policies; one example could be the analysis published by Stead et. al (2003) that identifies four types of integration policies, all of which are claimed to be crucial for achieving sustainable development:

(1) Vertical integration: policy integration between different levels of government.

(2) Inter-sectoral integration: policy integration between sectors or professions within one organization.

(3) Inter-territorial integration—policy integration between neighbouring authorities or authorities with some shared interest in infrastructure and/or resources.

(4) intra sectoral integration between different sections or professions within one department (integration between different environmental sectors such as air quality and noise or biodiversity, for example, or integration between different transport sectors such as roads, public transport, cycling or walking) (Greelings and Stead, 2003).

In the same study, the authors perform a literature review on the European integration policies documents and research activities. and summarized another classification as:

- *Policy cooperation that simply implies dialogue and information*

- *Policy coordination, policy coherence and policy consistency, these terms are considered similar and imply on cooperation and transparency with some attempt to avoid policy conflicts*
- *Policy integration and joined-up policy which include both co-operation and co-ordination policy as well as joint working and creating synergies between policies and use of same goals to formulate policy* (Greelings and Stead, 2003).

In the first article of the special issue of International Journal of Environmental Science and Technology on Transport, Land-use and Environment, Yigitcanlar and Kamruzzaman (2014) classify integration policy specifically aimed at reducing transport/ land-use impact on the environment to "push" and "pull" measures. The former policies include changing travel behaviour through reducing the attractiveness of cars by increasing the taxes and latter includes increasing the attractiveness of public transport through improving the services, design more walkable roads. Same scholars suggest other classification as soft/psychological (e.g., campaign, individualized travel planning, teleworking, and carpooling) and hard/structural (i.e., modification in infrastructure or legislation) interventions (Yigitcanlar and Kamruzzaman, 2014). Despite all these European policy interventions, the land-use, transport, and environmental policies are still not coordinated. So, it seems that more attention needs to be paid to various aspects of integrated policies.

2.2.1 History of Land-use and Transport Integration in Academic Literature

First attempts to study the relationship between land-use and transportation were made in the US during the 1950s, probably by Mitchell and Rapkin (1954) that considered traffic as a function of land-use. Moreover, Hansen (1956) in the paper "*How accessibility shapes land use*" for Washington, DC. introduced the concept of *accessibility* as an important factor in land-use and transport interrelation. Using a gravity model, he claimed that the locations with good accessibility have more potential to be more developed. He defined accessibility as *"the potential of opportunities for interaction"* (Hansen, 1956). Based on this view, the idea spread among American planners and the concept 'land-use transport cycle' became a commonplace in the

American planning literature (Wegener and Fu¨rst, 2004) and later presented by Wegener (1999) as follows (see also figure 2-3):

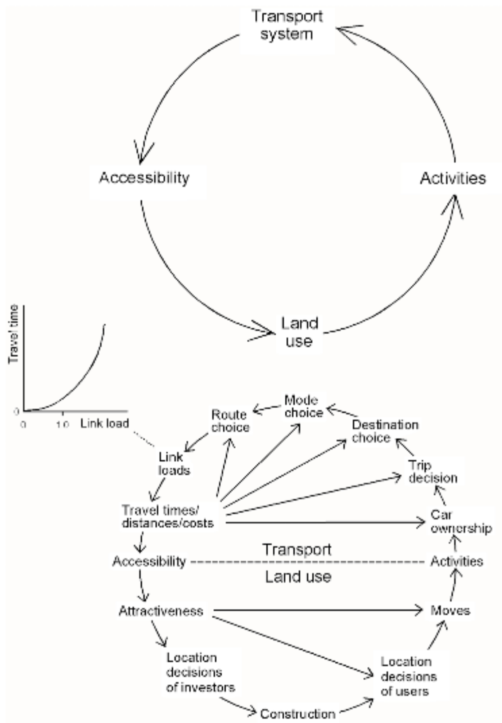

Figure 2-3 "land-use transport feedback cycle" (Source: Wegener, 2004, p.6)

- *The distribution of land uses, such as residential, industrial, or commercial, over the urban area determines the locations of human activities such as living, working, shopping, education, or leisure.*
- *The distribution of human activities in space requires spatial interactions or trips in the transport system to overcome the distance between the locations of activities.*
- *The distribution of infrastructure in the transport system creates opportunities for spatial interactions and can be measured as accessibility.*
- *The distribution of accessibility in space co-determines location decisions and so results in changes of the land-use system* (Wegener and Fu¨rst, 2004).

Hansen analysis has become a source of inspiration for further studies and accessibility became one of the most recurring themes in the studies of two-way interaction of land-use and transport developments (e.g., Koenig, 1980; Wachs and Kumagai, 1973; Handy and Niemeier, 1997;

Blumenberg and Ong, 2001). Aside from theoretical and conceptual research, lately there are some studies that focus on the implementation of accessibility (Halden, 2011; Proffitt, Bartholomew, Ewing, and Miller, 2015). Starting from the 50s' another group of studies related the relationship between land-use and transport started to focus on the integrated land-use and transportation models by using mathematical and statistical methods. Wegener (1994) performed an extensive analysis on land-use and transport modelling studies (van Lierop et al., 2017).

Travel behaviour is another theme of research related to LUTI which emerged simultaneously with the research on accessibility. This group of research attempts to understand and predict travel flows in order to better plan the transportation and land-use system to meet the demand. Mode choice studies that specifically focus on investigating travel patterns from and individual's perspective (Hurst, 1969) became predominant discussion in travel behavior studies and later, modal split models have been developed to capture the diversity of factors that influence mode choice and land-use characteristics have been included in later models (van Lierop et al., 2017). The most recent group of research is focused on understanding how to best integrate land-use and transportation infrastructure, with the goal of sustainable development. These studies first focused on an inner-area revitalization to keep urban growth closer to the city centre, a good example of such strategies would be "*Smart Growth*". Later, more attention was given to LUTI at the neighbourhood level which led to the "*New Urbanism*" movement in the early 80s' in the US with the aim of creating compact, pedestrian-friendly, and more liveable communities by including vibrant public spaces amenities located at the centre of the development, and a transit station or stop (Burchell et al., 2000; Leccese and McCormick, 2000). Following smart growth and new urbanism movements, Transit Oriented Development started to gain popularity in the early 90s' (van Lierop et al., 2017). As mentioned in the previous chapter, TOD is a strategy that strives for a more sustainable community by reducing the use of private cars, enhancing walkability and bikeability of neighbourhoods and promoting public transport. At the same time successfully implemented, TOD will not only result in emission reduction but has the potential to reduce the urban sprawl as TOD promotes more compact neighbourhoods and focuses mostly on already built areas. So, it can be said that TOD could integrate spatial planning with transportation systems. Next section of the chapter focuses on TOD literature review.

2.3 TOD

In the previous sections, the potential of public transportation in reducing sustainability challenges related to transportation and the necessity of taking a holistic approach toward land-use and transportation policies has been highlighted. The combination of public transport investment and sustainable urban development can be found in the strategy of Transit-Oriented Development. TOD can be defined as a strategy with the main objective of integration between land-use planning and public transport that concentrates urban development (housing, employment, leisure activities, services) around existing new station areas. Another definition could be "a mixed-use community that encourages people to live near transit services and to decrease their dependence on driving." (Still, 2002). Despite becoming a solid concept in planning only after Calthorpe book, TOD is hardly a new idea, in the pre-automobile era of the late nineteenth and early twentieth centuries, most urban development concentrated along streetcar and interurban rail corridors (Cervero et al., 2017). TOD has its roots in much older concepts such as Howard's Garden city.

Moreover, as mentioned in the previous paragraphs, TOD is similar to the concept of smart growth and new urbanism. However, it can be said that TOD was first theorized by Calthorpe in the 80s' and finally published in 1993. Cervero (1998), Dittmar and Ohland (2003) and Curtis et al. (2009) are among the other important scholars that contribute to develop and theorize the TOD concept in planning literature as a sustainable alternative for contemporary unsustainable North American cities. TOD aims to build liveable, walkable and bikeable neighbourhoods with adequate mixed uses and sufficient jobs and services. These neighbourhoods are connected to public transport, either rail or bus. Typically, TOD supporters are in favour of highly dense urban areas however, recently some attention has been paid to the potential of low-density areas for TOD implementation.

2.3.1 Conceptualizing Transit-Oriented Development

2.3.1.1 History and Theoretical Evolution

Perhaps the earliest precedent of TOD is the Ebenezer Howard's *Garden Cities* as he mentions in the book "*To-Morrow: A Peaceful Path to Real Reform"* (1898) and later in "*Garden Cities of To-*

Morrow" (1902). The concept of garden city was a utopian concept in response to the urban overcrowding and social transformation of the post-industrial revolution era in the United Kingdom. During that time, especially the capital, London, has been experiencing many social, hygiene, and organizational problems as the population of London hit 2 million. As the expansion of transportation systems occurred during that time, more people preferred longer distance between workplace and home and peripheral areas emerged in the main cities of Victorian England. Howard realized the conflictual relationship between Town and Countryside living. So, he attempted to develop a concept that is neither urban nor rural but a combination of the two by taking the best features of both. The Garden city concept was a circular diagram (towns) for 32,000 inhabitants surrounded by a green belt and close to a central core (Figure 2-4). Each of these new towns was divided into six wards, each designed to accommodate up to 5000 people who were working there as well (Howard, 1869, 1902). Howard developed a *Three Magnets* diagram to illustrate his Town-Country proposal (Figure 2-4 and 2-5):

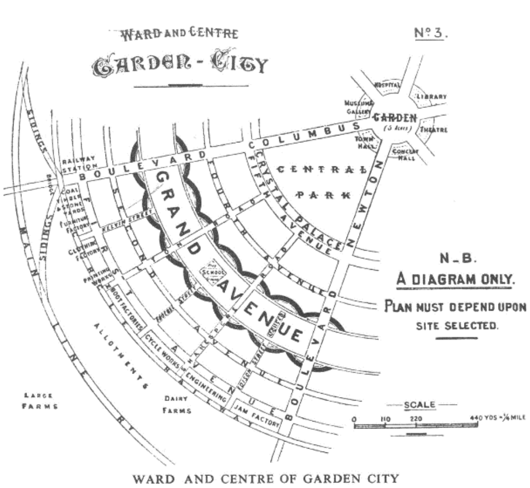

Figure 2-4 Garden City diagram (Source: Howard,1902)

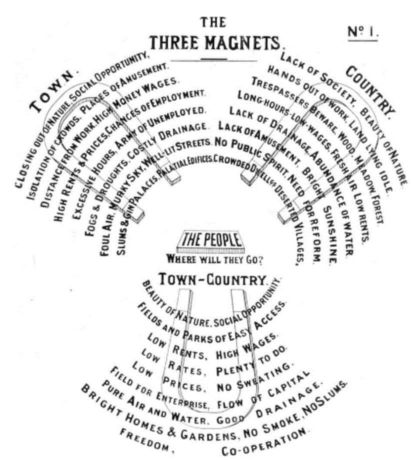

Figure 2-5 The three magnets (Source: Howard, 1902)

1. *Town Magnet:* has the opportunities for work and high wages, interactions, and leisure. Lacks nature and green areas.

2. the *Country Magnet:* on the contrary of the former, offers natural beauty, lower rents, better air quality. However, it has lower wages, leisure opportunities and less social interactions.

3. the *Town-Country Magnet:* Combination of both town and country magnets that provides benefits associated with both: Garden cities. This utopian vision is located close to a city core, provides beauty of nature, social opportunities, easy access with efficient transport, provides job opportunities, low rent, high wages.

Transportation networks in the Garden City were based on railways and winding routes with each town connected to the core with a road. A density limitation was envisioned, and land uses would be separated, residents would live in detached dwellings. Jobs and commercial activities would be located along the central avenues (Sharifi, 2016) "and ownership patterns would become essentially cooperative rather than private" (Wheeler, 2004). With the beginning of the new century, Howard's idea was put into practice as in 1903, Raymond Unwin and Barry Parker developed the first real Garden City: Letchworth. Fifty kilometres away from London, the city focused on a garden surrounded by public buildings, and off which would radiate a series of avenues leading to residential areas connected by rail. The Master Plan included a central town square with radiating axes, a main commercial corridor, clearly defined along with residential, industrial and recreation areas were planned into the design and surrounded by a minimal greenbelt representing the "country". Hampstead Garden Suburb is another interesting project inspired by Garden City with a pro-pedestrian street design that was shared by TOD guidelines set forth later by Calthorpe. Welwyn can be considered as the second garden city model in England that was constructed in the late 1920's which is again, a city surrounded by a rail network. Later models of Garden City became more adapted to automobiles, namely Wythenshawe designed by Barry Parker and developed between two world wars. The design of Princess Parkway as the main travel road proves the shift in the garden city model towards the dominant transport mode of post-World War II. Soon after, garden city models lost their roots as a rail-served community (Carlton, 2009). New Town concept, one of the Garden City successors and first introduced in England through the New Towns Act of 1946, was mostly auto focused. The concept was then repeated in other nations

Garden city concept was translated into America's *Development-Oriented Transit* era, mostly on the edge of the cities, namely Hilton Village (Newport News, VA), Chatham Village (Pittsburge, PA), Sunnyside and Jackson Heights (Queens, NY), the Woodbourne (Boston, MA), Garden City (NY), and Baldwin Hills Village (Los Angeles, CA). These designs shaped America's suburban paradigm developing in the beginning of Twentieth century, paving the path for the next phase of transit-related development (Carlton, 2009). By the half of the century, American planning scene was changed by the rise of private vehicles. Rail systems were replaced by bus transit and as private cars became more affordable; buses lost their competitive advantage. While American planning experienced a shift towards car-dominant urban areas and suburban sprawls, Jane Jackob became one of the main opponents of such designs, she believes cars should remain subservient to the pedestrian and pedestrian-scaled. In her 1961 book *"The Death and Life of Great American Cities"* she argued that the shortcomings of modern planning were attributable to the enthusiasm for Ebenezer Howard's "paternalistic, if not authoritarian" design program (Jacobs, 1961). She criticized low density and car dependent development, instead Jacobs promoted the idea of a city with high-density, mixed uses, social diversity.

By the 1970s', America's dependency on automobiles reached its highest rate, and together with the rise of environmental discussions in the 1950s and 1960s, eventually led to the establishment of Environmental Protection Agency (EPA) in 1971 and a couple of years later, with rise of the price of Gas and Petroleum imposed by OPEC, the issue America's car dependency issue became more apparent, at this point anti-low density designs and anti-sprawl movements began to rise among planners, some proposed alternatives was neo-traditional urbanism of new urbanism. Simultaneously some studies began to pay attention to the benefits of developments near transit stations. For instance, Robert Stern proposed the *Subway Suburb,* which is a low-density development with single family houses and yards (equivalent to suburban houses) adjacent to the subway station. Stern's idea is an example of Transit-Adjacent Development (TAD), described as the land adjacent to the transit stop, however, it fails to capitalize on encouraging compact mixed-use development, lacking land-use composition, in particular station access or site design (Cervero, 2002). Later studies, especially those by Robert Cervero showed that locating density around the transit system could produce positive synergies (Cervero, 1996). Regional Transportation studies like Portland, Oregon's 1988, *Making the Land Use, Transport, Air Quality Connection* were some of the first attempts to relate transportation and land-use (LUTRAQ, 1992). These major steps paved the path for more coordinated planning and transportation regulation and new legislations provided regional planning organizations with funding for such models. These models incorporated the high-density, pedestrian-friendly neo-traditional designs and thus neo-traditional neighbourhood planning was cemented as a regional solution (Carlton, 2009). Scholars like Peter Calthorpe participated in promoting this idea with the claim that it would benefit communities and at this point, transit agencies became proponents of incorporating high density neighbourhoods close to the station that encourages transit ridership.

As said earlier, Peter Calthorpe was the first individual to define TOD. Previously experienced in sustainable designs and later as a member of the Congress of New Urbanism, he finally published TOD the concept in 1993. Calthorpe co-authored the book *Sustainable Communities* (1986) with Van der Ryn in which he focused on old claims of a compact and pedestrian friendly urban design to achieve sustainability, however at this point, there is no mention of TOD or any transit consideration. Only in the history section of Calthorpe's chapter, he focused on Howard's Garden City and its attempt to reduce overcrowding industrial cities by creation of a series of small garden cities around a large core city connected by rail system (Carlton, 2009). Calthorpe's idea of sustainable communities and urbanism kept growing in joint research with UC Berkeley, University of Washington, and his long-time partner Van der Ryn. The outcome was published as a book called *The Pedestrian Pocket Book* (1989). *Pedestrian Pocket* is defined as "a simple cluster of housing, retail space, and offices within a quarter mile walking radius of a transit system" (Kelbaugh, et al. 1989) providing an ". The idea behind Pedestrian Pocket was to incorporate all the modes of transit (walking, car and public transit) environment that offers choices", but according to Calthorpe himself, it would neither offer urban growth nor reduce suburban sprawl (Carlton, 2009). Anyhow, Pedestrian pocket is not TOD, but has many characteristics of TOD just the former offers a suburban environment and latter is an alternative for sprawl. As Calthorpe claims: "The pedestrian pocket is located on a dedicated right-of-way which evolves with the development. Rather than bearing the large cost of a complete rail system as an initial expense, this right of way facilitates mass transit by providing exclusively for carpools, vanpools, bikes, and buses." Later, Calthorpe was invited to the metropolitan Portland, Oregon project of Making the Land Use, Transportation, Air Quality Connection (LUTRAQ) for which he proposed a neo-traditional Pedestrian Pocket along rail corridors. Simultaneously, Calthorpe and other experts were appointed by a local government in Sacramento, California (LGC) to propose a set of design and zoning guidelines for their transportation plan under the name: *Pedestrian/Transit Oriented Development*. This was the first time that the TOD term was used; however, Calthorpe preferred to refer to the concept as Pedestrian Pocket. Laguna West was the first project that was implemented based on Pedestrian Pocket guidelines with Calthorpe as the lead designer, the design contains mixed-use centre, pedestrian and riparian zones, narrow streets that encourage slow driving. In an article published in the New York Times, Laguna West was labelled as the first TOD project. The article described TOD as the “next evolutionary stage of American suburb” (Carlton, 2009). From that point, the use of the TOD term instead of Pedestrian Pocket became official and was used by Calthorpe himself. In 1992, Calthorpe began to collect materials for the publishing guidelines based on the TOD model and finally published it in 1993.

2.3.1.2 Main Principles

As mentioned in Chapter 1, *The Next American Metropolis* was divided into three parts. First part is dedicated to the reasons behind TOD implementation, the second part is focused on TOD definition and guidelines and the last part provides examples that show the principles and guidelines through a variety of real-life projects (Calthorpe, 1993). Calthorpe believes that the new American urban design is in favour of creating more sprawl, more segregation and isolation. He states to “Redefine the American Dream, we must make communities more accessible to our diverse population” and “diversity, community, frugality and human scale should be the foundation for the new American Dream and Metropolis” (Calthorpe, 1993). Calthorpe defines TOD as “a mixed-use community within an average 2000-foot walking distance of a transit stop and core commercial area” (Calthorpe, 1993). A Summary of Calthorpe guidelines is:

- *Organize growth on a regional level to be compact and transit-supportive*
- *Place commercial, housing, jobs parks, and civic uses within walking distance of transit stops*
- *Create pedestrian-friendly street networks that directly connect local destinations*
- *Provide a mix of housing types, densities, and costs*
- *Preserve sensitive habitat, riparian zones, and high-quality open space*

- *Make public spaces the focus of building orientation and neighborhood activity* (Calthorpe, 1993).

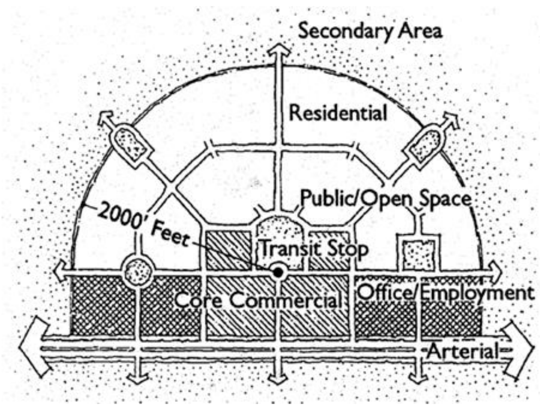

Figure 2-66 TOD diagram (Source: Calthorpe, 1993, p. 56)

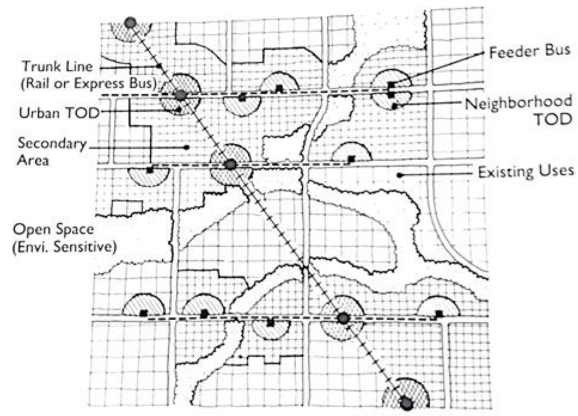

Figure 2-7 Transit circulation in TOD (Source: Calthorpe, 1993, p.

There are other guidelines based on Calthrop's book as follows:

- *Locations:* TODs should be in re-developable infills or growth areas. TODs should be in regions to maximize access to the core commercial area; TOD with competing use should be located at least one mile apart from each other; this is mostly due to commercial reasons, so TODs that do not have competing uses, can be implemented closer than one mile to each other.

- *TOD types:* Calthorpe mentions two types of TODs: Urban and Neighbourhood. The former is located just by the transit stations and have higher densities, while later are located along local or feeder bus lines within ten minutes of transit travel time to the transit station. Neighbourhood TODs are surrounded by lower density areas, mostly residential.

- *Coordinated Planning:* a "Specific Area Plan" must be provided by TOD developers that must be consistent with the design guidelines, and surrounding areas and communities. The plan should provide zoning that encourages mixed uses-ness if the standard zoning cannot be achieved.

- *Ecology and Habitat:* Open spaces environments should be preserved and incorporated into the TOD as open spaces and any change should be avoided as possible. Similarly, wild corridors should be preserved; Urban Growth Boundaries (UGB) should be established at the edges of metropolitan areas to protect existing natural resources, as well as provide a buffer between existing towns and cities; Green energies and construction techniques should be utilized whenever possible. Native plants should be used in dry climates.

- *Core Commercial Areas:* The core area should provide adequate retail and local-serving offices; It must occupy at least 10% of TOD total area and be adjacent to the transit stop with a minimum amount of commercial next to the station; The core should balance pedestrian and car access and buildings setbacks should be in a way that encourage pedestrian activity.
- *Residential Areas:* TOD must mees an average of 15 units per net acre requirement for Urban TOD. Neighbourhood TOD should have an average of 10 units per net acre. There are other guidelines about location of parking, garage doors, setbacks, front yards, and common areas in the book as well. TODs may have secondary areas which are separated from the station by a road. These areas are also subject to density measurements (6 units per net acre). Calthorpe believes that rural and low-density areas that are characterized by heavy car dependence and low job density are not suitable as a secondary area for TOD.
- *Parks, Plazas and Civic Buildings:* TOD must provide both small and big public spaces. The small ones should be located inside the TOD area while big parks should be located towards the edges or near schools. Generally, parks should take a minimum 5% of the total TOD area (a ratio of 3.5 acre per 1000 people is advisable). Plazas should be located near retail shops. Civic buildings such as libraries should be located close to transit while schools for example, should be on the edge of TOD.
- *Streets and Circulation System:* Streets should be in favour of pedestrian safety without compromising the safety and accessibility of cats. Street width should be narrower so that bike lanes can be added. Street trees should be provided in all streets. Grid street system is advisable to minimize dead ends. Arterial streets should be located on the edge and never pass through the TOD. Connector streets should connect secondary areas, schools, and commercial areas within TOD without use of arterial streets. Commercial streets, subservient to the pedestrian. should provide access to transit and should. Finally, local

streets should be narrow for slow traffic and at the same time provide accessibility for automobile and service vehicles. Local streets are the primary road of residential areas.

- *Pedestrian and Bike system:* Pedestrian and bike lanes should be present along all the streets and bike paths should be integrated in the TOD and must be separated from arterial roads.
- *Transit System:* Transit stations must be in the central area and close to commercial spaces with high accessibility, safety. Drop-off and pick-up spaces should be provided in a way that would not isolate pedestrian access to the station.
- *Parking Requirements and Configuration:* Minimizing the parking number is suggested to encourage pedestrian activities. Large surface lots are strongly discouraged, in favor of several smaller lots (Calthorpe, 1993)

It must be said that these guidelines provide a general framework for TOD, but they are not meant to be used as a universal model and should be modified based on the location and other measurements such as zonings, regional and comprehensive plans, etc.

2.3.2 TOD Measurements

2.3.2.1 The D Variables

The concept of 3D was first developed by Robert Cervero and Kockelman (1997) and emphasized in many following studies (e.g., Curtis 2009; Lund et al. 2004; Evans and Pratt 2007; Ewing and Dumbaugh 2009; Renee 2009). 3Ds: *Density, Diversity and Design* were introduced as a way that the built environment influences travel demand. The paper shows how 3Ds affect trip rate and mode of choice of residents in San Francisco Bay area and finds that density, land-use diversity, and pedestrian-oriented designs generally reduce trip rates and encourage non-auto travel in statically significant ways, though their influence appear to be marginal (Cervero and Kockelman, 1997). In this context, *Density* refers to the population of residents and job holders that use that certain area and how they access it. Density variable usually is measured through this analysis: 1. Population density per developed acre; Employment density per developed; and Accessibility which is calculated through an Index that indicates the possibility to reach to the working destination by car and all the sales and services by walking or biking. *Diversity* indicates the number of land-uses provided in the area of the study and is mostly analysed through Entropy measurements. Other elements such as: Percentage of retailing activities per acre; Percentage of activity centres per acre; Percentage of parks and recreational sites; Proportion of the commercial-retail parcels; Proportion of residential acres within the convenience distance, that can be analysed in diversity measurement. Finally, *Design* mostly refers to morphological and physical properties of the area and defined by the reachable area by 10 minutes of walking from the station. The criteria are analysed through characteristics of the streets; pedestrian and cycling provisions and site design (Cervero and Kockelman, 1997). In a later study by Cervero and Edwing (Ewing and Cervero, 2001; Ewing et al., 2009) two more Ds were added to variables. *Destination Accessibility* ease of access to trip attractions. It may be regional or local (Handy, 1993) the former can be interpreted as distance to the CBD or number of jobs or other attractions reachable within a specific travel time frame*; Distance to Transit:* measured as average of the shortest street routes from house or workplace of an area to the nearest rail station or bus stop, alternatively, it may be measured as transit route density*;* Finally, *Demand Management* which is related to the parking supply and cost in the area (Ewing and Cervero, 2010).

2.3.2.2 TOD Planning

Some of TOD measurements address not only existing TOD, but also potential future TOD implementation. Namely, the study conducted by Singh et al. (2014) that focuses on urban agglomeration as a whole and classified TOD according to the TOD index and *potential* TOD index. The former addresses existing TOD while latter identifies suitable locations for future TOD. Other than TOD indices, there are two general approaches that focus on TOD planning tools: first approach that is assessing future TODs through a *multi criteria decision analysis* (MCDA), that ranks alternative decisions, strategies, or actions according to several predefined criteria and decision-make preference (Ibraeva, et al., 2019). The approach has been used by some scholars such as Banai (1998 and 2005) and Strong et al. (2017). The former studies aimed to assess the suitability of land use around a suggested light transit station of a metropolitan area and the later investigates ways a transit agency chooses between alternative TOD sites to develop or build. Another approach is *multi-objective optimization* that determines an efficient solution (i.e., decision variable values) considering a set of objectives (Lin and Gau, 2006; Lin and Li 2008 and 2009; Sahu, 2019; Ma et al., 2018) (Ibraeva et al., 2019)

2.3.2.3 TOD Typologies

A TOD typology refers to the classification of TODs into different groups that share morphological and functional characteristics (Kumar et al., 2020) that can be utilize as a benchmark to make comparisons between different nodes. There are number of methodologies for evaluating TOD at the station area level based on station typologies (Bertolini, 2009; Balz and Schrijnen, 2009; Reusser et al., 2008; Zemp et al., 2011; CTOD, 2013; Chorus and Bertolini, 2011). Some of these typology studies are grouped and summarized by Higgins and Kanaroglou (2016) in two groups: *Normative TOD typologies* and *Positive TOD typologies.*

According to Higgins and Kanaroglou (2016), a group of typology studies are "normative in nature, cognizant of the complexities involved in TOD implementation" (Higgins, 2015). As mentioned in Chapter I, Calthorpe (1993) was the first author that attempted to classify TOD. He divided TOD typologies into two groups: *urban* and *neighbourhood* scale, recognizing that there is no 'one-size-fits-all' approach to TOD. Based on this classification, Dittmar and Ohland (2004) developed six typologies: urban downtown, urban neighbourhood, suburban center, suburban neighbourhood, neighbourhood transit zone, and commuter town centre. Higgins (2016) labeled these typologies as normative because they outline general characteristics of what different TOD contexts should look like in terms of factors such as densities, housing types, and transit services (Higgins and Kanaroglou, 2016).

Positive typology studies classify existing TOD stations based on their TOD characteristics. There are two types of positive approaches, the first one quantifies and classifies the performance of a transit station area according to nodal or place-based measures. This approach was started by Bertolini (1999) and ever since, various scholars have attempted to analyse the performance of rail stations according to the position within the node-place index according to this method (Higgins and Kanaroglou, 2016). There are five typologies to TOD in the original node-place model (see section 2.3.3). Moreover, many authors attempted to expand the node-place model (Reusser, 2008; Chorus and Bertolini, 2011; Zemp et al., 2011; Lyi et al., 2016; Vale et al., 2018). Second type of positive approaches developed transit station typologies that explicitly sought to classify existing TOD characteristics (e.g., Atkinson-Palombo, 2010; and 2011; Kamurzzaman, 2014).

Clustering is another methodology that classifies stations into similar groups in a way that stations in the same group are more similar to each other than stations in other groups. In fact, some of the aforementioned studies have utilized cluster analysis, such as Reusser et al. (2008); Zemp et al. (2011); and Kamruzzaman et. al (2014); Lyu et al. (2016). Two types of cluster analysis can be identified unsupervised (this method has been used in above examples) and latent class clustering. In the former, cluster analysis determines the stations or station area typologies using agglomerative hierarchical clustering methods. Some authors use two step clustering methods (e.g., Reusser, 2008; Kamurzzaman et al., 2014). Latent class clustering on the other hand, uses a probabilistic approach to cluster analysis that assumes that the clustering structure within the population is unobserved, but represented by other manifest variables. Estimating this latent structure involves an assumption of an underlying set of probability distributions within the population. Using maximum likelihood for parameter estimation, the model maximizes a log likelihood function and clusters cases according to posterior class membership probabilities (Higgins and Kanaroglou, 2016). This method is suitable for many studies.

2.3.3 Node- Place Model

Although the node-place model is in fact, a methodology for TOD measurements as discussed earlier, due to its importance for the present thesis, in this section, it will be discussed in more detail. The basic assumption behind Bertolini’s node place model is that enhancing the intensity and diversity of transit supplies (increased node-value) will improve accessibility, hence increasing the *potential* for more activities and interaction around the station. In return, enhancing the diversity and intensity of activities within the station's catchment area (increased place-value) will result in more demand, which eventually creates *potential* for further developments. So, as said, each station can be considered as both a *node* within a transport network and a *place* in an urban context. It is a node because people use it to physically access to transport, and it is a place because people carry out several activities in the *catchment areas* (Bertolini, 1999). The node place model is based on a simple xy diagram (see figure 2-8) in which y value corresponds to the node-content of the specific area, or accessibility node, and thus to its *potential* for physical human interaction and the x value represent place-content of an area, or the intensity and diversity of activities there.

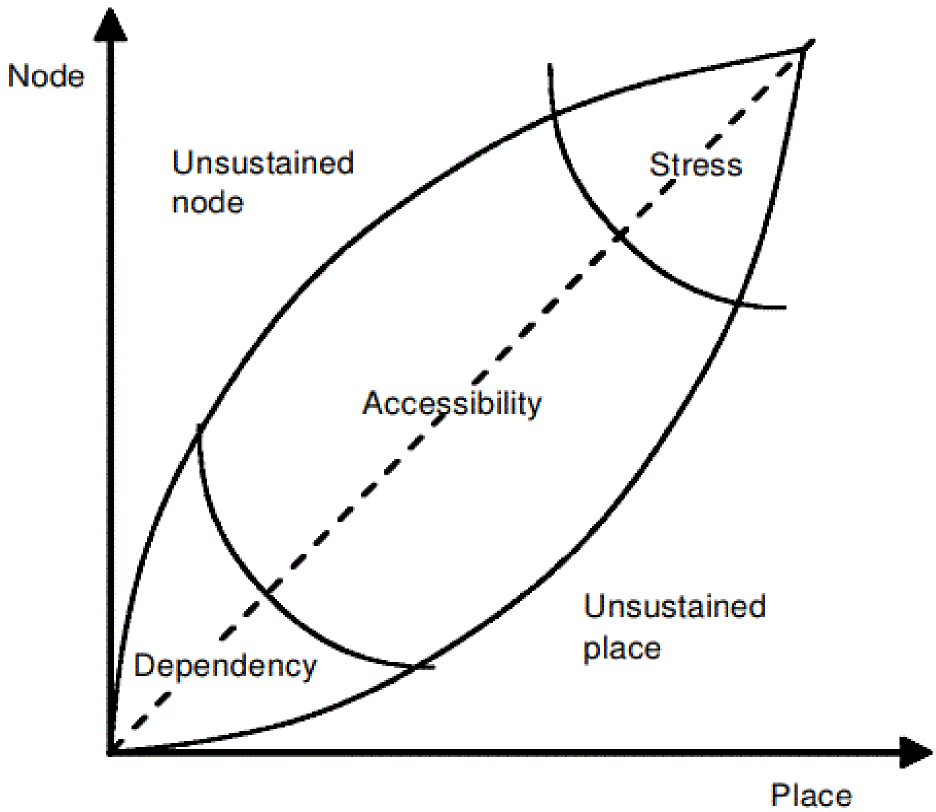

Figure 2-8 Node-Place diagram (Source: Bertolini, 1999, p.202)

There are four ideal situations in the figure. Along the middle line there are accessibility areas where node and place are in an equilibrium, meaning that both transit services (node value) and activities in and around the station (place value), are equally strong. At the top of the middle line, there are s*tress* modes where intensity and diversity of activities and density are maximum, this means the *potential* for both human interactions are and accessibility high, at the same time, the chance of conflict is higher in such a dense environment. On the bottom of the bisector line shows the *dependency* areas which means both activities and density are relatively low. This means, even though the space is not limited, the demand for transit services and activities are minimal. Two *unstained nodes/places* areas refer to disequilibrium between nodes and place. On top left, unstained nodes mean transportation services are relatively much more developed than activities in stations and its catchment areas. On the other hand, an unstained place on the bottom right indicates a situation where urban activities are more developed than transit services. These classifications can be used as a basis for evaluating stations, in order to suggest further development strategies as disequilibrium situations should move toward balanced positions. This means for example, an unbalanced node (high accessibility- low intensity and diversity of activities) can either increase its place value by providing more opportunity for physical human interactions and jobs or decrease its node value by decreasing transit services (less frequency of trains). At the same time, an unbalanced place (poor transit service, high intensity, and diversity of activities) can either increase its accessibility by, for instance, increasing the frequency of trains (node value) or decrease place value by managing the land-use. It must be noted that this evaluation should not be taken for granted, meaning that a station situation cannot be evaluated only based on its transport and land-use characteristics since there are some exceptions. For example, a railway station that serves the airport, despite low residential density of the catchment area, has a very frequent service in order to ensure adequate accessibility level (Nigro, 2017).

2.3.4 TOD Implementations

2.3.4.1 TOD in Europe

Even Though TOD was officially theorized and published by an American planner and especially came into practice with Bay Area Rapid Transit (BART), one of its earliest examples dates to the first half of 20th century in Europe. According to Cervero, TOD is most fully developed in Europe and particularly in Scandinavia through the *Finger Plan* of Copenhagen, Denmark, and *Planetary Cluster Plan* of Stockholm (Cervero, 2006). There are some characteristics that according to Cervero are present in both cases, such as:

- Corridors for channelling overspill growth from the urban centres that were defined in early planning process

- In advance implementation of rail infrastructure for demand and later growth
- Green belts wedges set aside as agricultural preserves, open space, and natural habitats
- Land-use balancing through inter-mixing land-uses along linear corridors to produce an inter-mixing of bi-directional flow
- Emphasize on regional development
- Job-housing balance along railways and axial corridors (Cervero, 2006).

In another study by Pojani and Stead (2018) examine TOD principles in three European capitals: Amsterdam, Stockholm, and Vienna. Authors divides the types of these TODs in 3 criteria:

1. Single-node TOD characterized by (A) single neighbourhood based around heavy rail station; (B) in a circular pattern around train station (C) with urban or suburban location (D) and radius range from 0.5 to 0.7 kilometres from the station. Example: Vienna
2. Multi-node TOD which is (A) based on a regional network of nodes around heavy railway stations and (B) with urban or suburban location (C)also in a circular or semi-circular nodes arrangement bounded by a (D) beads in a string pattern. (E) Nodes have complementary rather than competing use and finally (F) each node incorporates specific activity to serve the whole system. Example: Amsterdam
3. Corridor TOD that is based on (A) light rail transit or BRT, (B) has an urban location with (C) ribbon or linear shape development along transit lines. (D) this type of TOD has the potential to be integrated into existing urban areas or planned urban extension. Example: Stockholm.

2.3.4.2 TOD in Italy

There is no clear evidence of TOD strategy in Italy. In a wider perspective Italy is generally weak in terms of land-use and transport integration. This is due to the rigid nature of Italian spatial planning which heavily relied on zoning codes and regulation at municipal level. This planning model results in poor cooperation both horizontally and vertically. The weakness of horizontal, inter-sectoral coordination is particularly evident in LUT practices, also because of the strong role played in Italy by special agencies, which are in charge of a relevant part of transport and infrastructure planning (Staricco and Vitale Brovarone, 2018). However, some metropolitan areas tried to focus urban transformations on railway infrastructure, namely Rome and Naples which started in the 1990s a period of urban planning reform considering accessibility of public transport in their planning strategy with only partial achievement. Moreover, there have been some recent attempts in Milan through development of a strategy that aims to transform dismissed rail yards into parks and public spaces and in the Turin *Spina*, project was elaborated to exert urban redevelopment project linked to the transformation of a long section of railway running in the center of the city into underground by-pass, obtaining new urban spaces and reconnecting the neighborhoods once spited by railway lines (Nigro, 2017).

2.4 Mobility in Post-Pandemic Era

2.4.1 A Literature Review

It is now clear that transport is one of the most disrupted sectors by the recent pandemic. The consequences are even more severe in the case of public transport (PT) where congestion might increase the chance of infection. As the World Health Organization (WHO) statement highlights the effect of PT on the chance of COVID-19 infection: *"The real and perceived risks of exposure to the virus have transformed the greatest plus of mass transport – the ability to move large numbers of people rapidly, efficiently and affordably – into a liability".*

In fact, there is a good amount of evidence that associates public transport with transmission of COVID-19 (e.g., Carteni et. al, 2020, Du et al., 2020; Iacus et al., 2020; Kraemer et al., 2020; Wu, Leung, & Leung, 2020; Zheng et. al, 2020). So, in order to prevent the risk of human- to-human transmission, governments across the globe attempted to adopt preventive measures that decrease the chance of social contacts in daily life. Considering the policies related to transport sector which is the interest of this thesis, the measures vary among the countries from a complete closure of the public transport services and borders, to reduction of the services and capacity of the vehicles, usually combined by other safety measurements such as temperature check, ventilation of the vehicles, mandatory usage of face masks and the recommendation of maintaining the safe distance in the stations and vehicles (between 1.5 -2 meters according to WHO) (Gkiotsalitis and Cats, 2021). That said, COVID-19 also had impacts on transportation, which altered not only the timetable and frequency of transit services, but also the behavior and perception of travelers. In fact, all the global transportation data confirms the negative impact on the public transport systems (MOOVIT, 2020). A group of studies focus on the correlation between public transport ridership and COVID-19 restrictions (e.g., Ahangari et al., 2020; Barbieri et. al, 2020, Bucsky, 2020; Chivers, 2020; Chong, 2020; de Haas Faber and Hamersa, 2020; Hughes. 2020; Jenelius and Cebecauer; 2021, Rasca et. al, 2020; Teixeira and Lopes, 2020; Tiikkaja and Viri, 2021, Warren and Skillman, 2020; Zhang et al.2021). The early study about Sweden (Jenelius and Cebecauer, 2020) shows that the decrease in public transport ridership (40%–60% across regions) was severe compared with other transport modes. A study about South Korea (Park, 2020) shows the number of subway passengers in Seoul decreased markedly during late February (40.6%) but slowly increased afterward, suggesting decreasing levels of risk perception and adherence to social distancing. Similarly, a comparative study on Norway and Austria (Rasca et. al, 2021) investigates the ridership during different waves of COVID-19 pandemic, the article shows a drastic effect on PT patronage during the first wave (between 67 to 82 percent of loss) despite the low number of the cases in both countries, the consequent pandemic wave presented a reduced rate of loss in PT ridership, possibly due to the population becoming used to the situation (Rasca et. al, 2021). A comparative study (Barbieri et. al, 2020) analyses changes in mobility and transport in ten countries (Australia, Brazil, China, Ghana, India, Iran, Italy, Norway, South Africa and the United States), the paper confirms the overall loss of ridership in all the countries but the extent of it varies among countries. Another set of studies focus on the effect of COVID-19 pandemic on the perception of citizens and travel behaviour during and after COVID-19 lockdowns. One study about Italy (Campisi et. al, 2021) conducted a survey to investigate the psychological impact of COVID-10 on public transport choices in Sicily, findings showed that users' emotional perceptions led them to restrict certain travel choices. Feelings of anxiety, fear, and stress were correlated to the different periods by considering variables characterizing the users' sociodemographic aspects and parameters linked to the frequency of use of urban or regional public transport. Other studies about travel behavior after COVID-19 (Abdullah et. al, 2020; Beck and Hensher, 2020; Echaniz et. al, 2020; Shcaefer, et. al, 2020; Tarasi et. al, 2021; Thombre and Agarwal, 2021) also show negative emotions towards public transportation (train, bus, metro, and tram) and a more positive attitude towards private vehicles (car and bike) and walking. This negative perception affected modal shares as well. Zheng et. al (2021) found out Remarkable modal shifts away from public transport usage with shifts in trip demand to car, walking and cycling. Even though total modal shifts to active transport (walking and bicycle) were higher than the shift to car (especially in Europe), a greater than 60% shift from public transport to car (especially in South Korea and China) was reported. In India and other Asian countries, the shift from public transport to motorcycle was much higher than other countries/regions. In a study about Budapest, Bucsky (2020) found out that during the lockdown in Budapest, PT had the most reduction in the modal share while cycling and cars experienced an increase. In another interesting study, Hasselwander et. al (2021) analysed the change in travel behaviour in COVID-19 pandemic in the Philippines. The analysis showed that the changes are closely linked to the containment measures imposed by the governments as in the first wave, PT was completely suspended and significantly restricted as the quarantine state continued over the following months. As a result, movements at transit stations fell by as much as 95 %, and public transport trips are the slowest to recover since then. This has particularly affected lower-income groups of the population that demonstrates another dimension of social exclusion, arising from the COVID-19 crisis relates to transport and human mobility. This study finds out that walking and private cars are the two modes that are least affected by pandemics and the fastest to recover. In general, in most cases, the reduction of PT usage was due to the absence of adequate public transport. It is interesting because in a survey study about Poland (Przybyłowski, Stelmak and Suchanek, 2020), authors found out almost 75% of the participants are willing to get back to PT after stabilization of the pandemic situation. Another important factor to note is that women seem to be more reluctant to use public transport after COVID-19 pandemic (Tarasi et. al, 2020; Shcaefer, Twitter, Levin-Keitel, 2020) due to safety concerns.

In another group of studies, researchers question the future of public transport and the way it can fit into the new lifestyle. In an article about UK, the author (Vickerman, 2021) concluded that it is not possible to return to pre-COVID-19 situation for PT, and a more holistic approach is needed that addresses problems of provision such as the environmental impacts of transport, congestion, and questions of transport justice such as accessibility to transport for disadvantaged groups in society. y of the situation namely, the study about the Philippines (Hasselwander et. al, 2021).

Another interesting study about Italy, focused on the increase of so-called 'Smart Working' that is becoming the 'new normal' these days. The study investigates the correlation between physical and virtual mobility in Italy before and after COVID-19. This study concluded that although physical transportation cannot be completely replaced by virtual mobility, it could be an asset to regulate physical mobility to the externalities associated with it. Examples could be reducing peaks of physical mobility during rush hours and better distribution throughout the day. The paper emphasizes on the use of MaaS[1] (Mobility as Service). In another similar study Strenitzerova and Stalmachova (2021) investigates passengers' requirements and their satisfaction with the mobile applications used within urban public transport in Žilinam, Slovakia. The paper states that high quality mobile applications can positively asset public transport, increasing the efficiency and satisfaction of the customers. The authors concluded that stability, providing up to date information about unexpected traffic, notifications, flexibility, and security are the main concerns of the users.

2.4.2 Signs of Recovery: European Public Transport

A recent paper published by ING[2] shows a clear recovery of public transport now that the restrictions are loosened with France and Germany already close to pre-COVID levels and Netherlands and UK still much behind it. The paper states that although the PT recovery will continue to happen in this autumn, it will take more time to fully return while passengers will be still conscious about new pandemic waves and social distancing measures. Figure 2-9 shows the recovery rate of Western European countries and the United States based on Google Mobility Data.

[1] **Mobility-as-a-Service** (**MaaS**) is an emerging type of service that, through a joint digital channel, enables users to plan, book, and pay for multiple types of mobility services.

[2] https://think.ing.com/articles/european-public-transport-shows-signs-of-sustained-recovery/

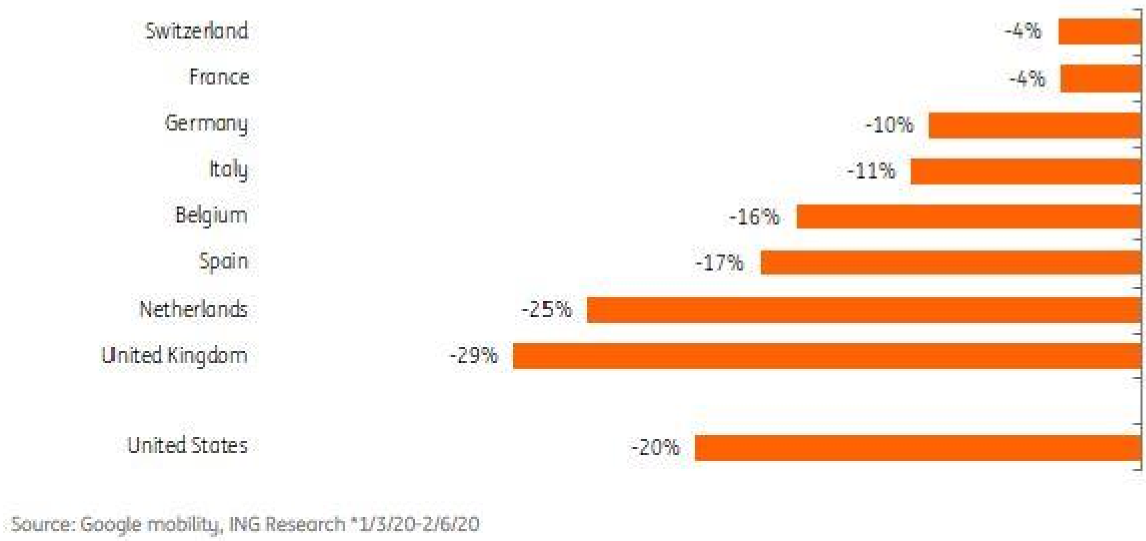

Figure 2-9 Public Transport volume compared to pre-COVID baseline (Source: https://think.ing.com)

2.4.3 TOD After COVID-19: Unclear future

Even though the literature still lacks a new framework for Transit Oriented Development post COVID-19 era, there is a rising question about the very nature of TOD, as it promotes high density and accessibility while COVID-19 clearly exposed the weaknesses of such planning approaches as high density is associated with high-risk of infection. Among the small number of research dedicated to this topic, in an interesting study about Milan, Italy (Fossa, Deponte and Gorrini, 2020) authors raised attention on the establishment new kind of TOD approach, focusing not only on the nodes and the networks, but on the spaces 'in between'. The authors emphasize the 'resiliency' approach, which in this case, means the regeneration of not only dismissed sites around major nodes and networks but also the whole mesh of network, public open spaces and exploring specifically a new resilient role for streets for both mobility and urban space. According to the authors, in this context attention can be paid to so called "slow" territories: low-medium density areas bypassed by railway often with great historic and natural landscapes, that could offer alternative healthy lifestyles, supported by broadband connections, smart working opportunities, home care and e-commerce services, enjoying outdoor private spaces and larger indoor spaces, thanks to a low-budget real estate market. The paper gives examples on Milan, in the way of developing 'intermediate hotspot' for smart working in between wide-spread remote working and the company headquarters. For instance, banks such as Intesa Sanpaolo, which located company co-working spaces in the major district poles of Lombardy, such as Gallarate or Saronno, intermediate cities of the polycentric Milano region structure (Fossa, Deponte and Gorrini, 2020). In another article [3] *"Towards a new society brought about by the COVID-19 pandemic; Transit Oriented Development (TOD) as a Network Hub"* the authors emphasize on shifting towards a 'Decentralized Mobility' where people work from home one day, at workspaces near the home, at offices in city centres or nearby workplaces after meetings. The author provides some interesting ideas for the future of mobility giving examples about Tokyo Metro including walkable hubs around stations, connecting stations with buses and personal transport options, multi-functional open spaces, introduction of Maas (Mobility as a Service), automatic disinfecting machines, open stations with more entrance and exits (Figure 2-10).

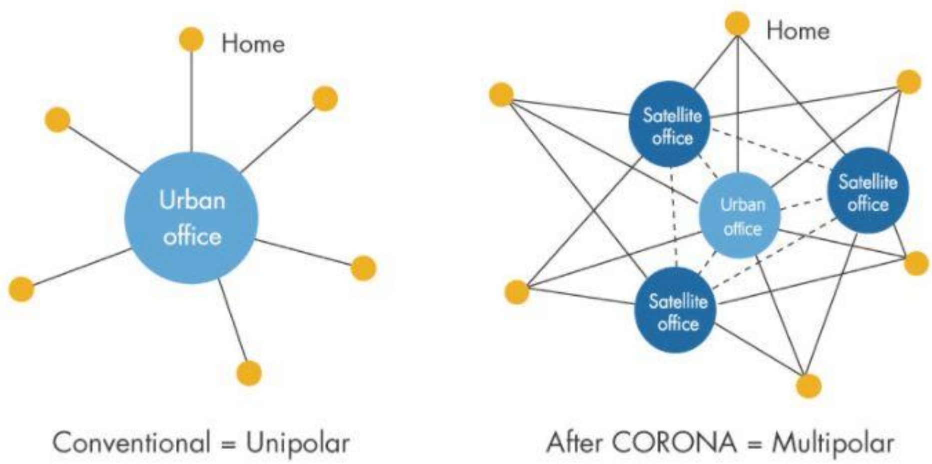

Figure 2-10 Schematic diagram of centralized and decentralized models (Source: https://www.nikken.co.jp/en/insights/beyond_covid_19_07.html)

In another article on the web, *"Will Coronavirus Kill Transit Oriented Development"* the author argues that re-evaluation of TOD must incorporate both outdoor and indoor spaces, allowing the expansion that ensures preparedness for emergency of events like future pandemic. Measures include relocating the escalators, adding new openings, and expanding the floor plates which can accommodate new physical distance. Extra platform for the time of pandemic is another solution proposed by the author (Figure 2.9).

---

[3] https://www.nikken.co.jp/en/insights/beyond_covid_19_07.html

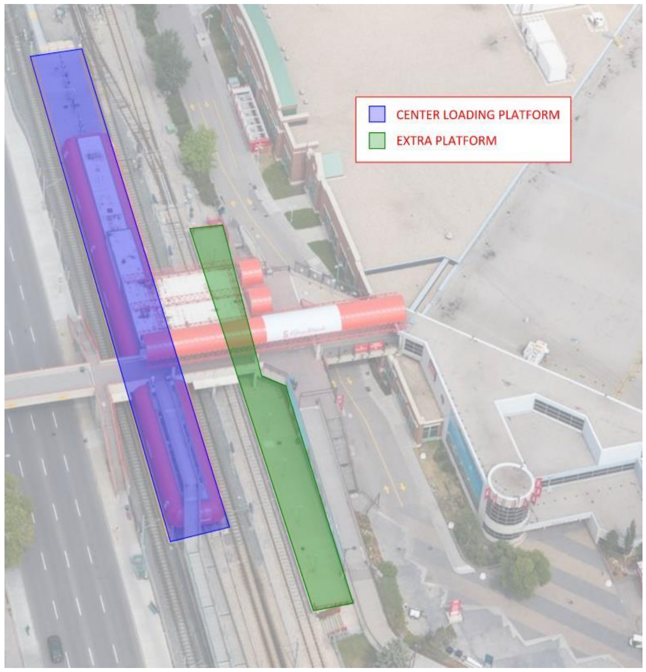

Figure 2-11 Victoria Park Station in Calgary with extra platform (Source: https://www.entuitive.com/ensight-trend-home/will-coronavirus-kill-transit-oriented-development/)

All in all, it seems hard to predict the future of public transport. However, based on the findings of current literature, focusing on active mobility (e.g., biking and cycling), paying more attention to the transit nodes 'in between' spaces, integrating new technological tools such as MaaS to public transport and considering expansion of nodes could be considered as a recovery plan to get people back to the public transit. In the next chapter, a revised methodology for Node-Place is proposed.

3 METHODOLOGY

3.1 CONTEXT DEFINITION: LOW DENSITY STATION AREAS

As discussed earlier, the stations located in "low density" areas are the main interest of this thesis. However, the definitions of these terms vary among different European countries. For this reason, a wider scale definition has been adopted in order to clarify the concepts. This section briefly discusses the international definition of rural and suburban areas with the latest tool proposed by the European Commission as well as national Italian definitions.

3.1.1 Intranational Definitions: European Classifications

3.1.1.1 NUTS- Nomenclature of Territorial Units for Statistics[4]

From the early 1970s, Eurostat set up the NUTS classification as a standard geocoding system for dividing up the EU's territory in order to produce regional statistics for the Community. For each EU member country, there are three subdivisions in NUTS as well as two level of Local Administrative Units (LAU[5]). It must be noted that the subdivisions in some levels do not correspond to the administrative division within the country. At the local level, two levels of Local Administrative Units (LAU) have been recognized, which were previously referred to as NUTS levels 4 and 5.

[4] Data retrieved from: https://ec.europa.eu/eurostat/web/nuts/

[5] Local administrative units (LAUs) are building blocks of the NUTS, comprising the municipalities and communes of the EU. LAU is used to divide up the EU territory for the purpose of providing statistics at a local level.

3.1.1.2 At Local Level: Degree of Urbanization

"Degree of Urbanization" is a classification at a local level introduced by Eurostat in the early 1990s. The concept indicates the character of an area based on the population size, density, and contiguity of local administrative units (LUA2 level 2), dividing them into three types, densely populated; intermediate; and thinly populated areas. The original degree of urbanization method suffers from international compatibility issues because different countries use different sizes of local administrative units. A more recent paper by Dijkstra and Poelman (2014) and published by Eurostat, provided a tool called "New Degree of Urbanization" (DEGURBA), classifying the areas based on the population grid. This method gives more accurate information about the population distribution classifying LUA2s as follows:

1. *Densely populated area* (cities, urban center): at least 50% of the population living in high-density clusters[6] ;
2. *Intermediate density area* (towns and suburbs/ small urban areas): (a) less than 50% of the population living in rural grid cells[7] (b) less than 50% living in a high-density cluster.
3. *Thinly populated area* (rural area): more than 50% of the population living in rural grid cells (Dijkstra and Poelman, 2014).

In the list above, following definitions are used:

- *Rural grid cells*: Grid cells outside urban clusters.
- *Urban clusters*: Clusters of contiguous grid cells of 1 km^2 with a density of at least 300 inhabitants per km2 and a minimum population of 5000.
- *High-density cluster:* Contiguous grid cells of 1 km^2 with a density of at least 1500 inhabitants per km2 and a minimum population of 50000; alternative names: urban center or city center (Dijkstra and Poelman, 2014).

---

[6] Each high-density cluster should have at least 75% of its population in densely populated LAU2s. This also ensures that all high-density clusters are part of at least one densely populated LAU2, even when this cluster represents less than 50% of the population of the LAU2

[7] In 2010, the European commission published a new definition of urban and rural areas, rural cell grids define rural regions and rural LAU2s. This ensures that rural areas and rural regions are defined based on the same concept (rural grid cells)

Figure 3-1 and 3-2 [8] shows the degree of urbanization in European countries and Italy respectively based on Eurostat data. This research takes this measure as a basis to identify low density stations in the case study area. All the stations located in municipalities that fall within intermediate density and thinly populated areas are considered as low-density station areas.

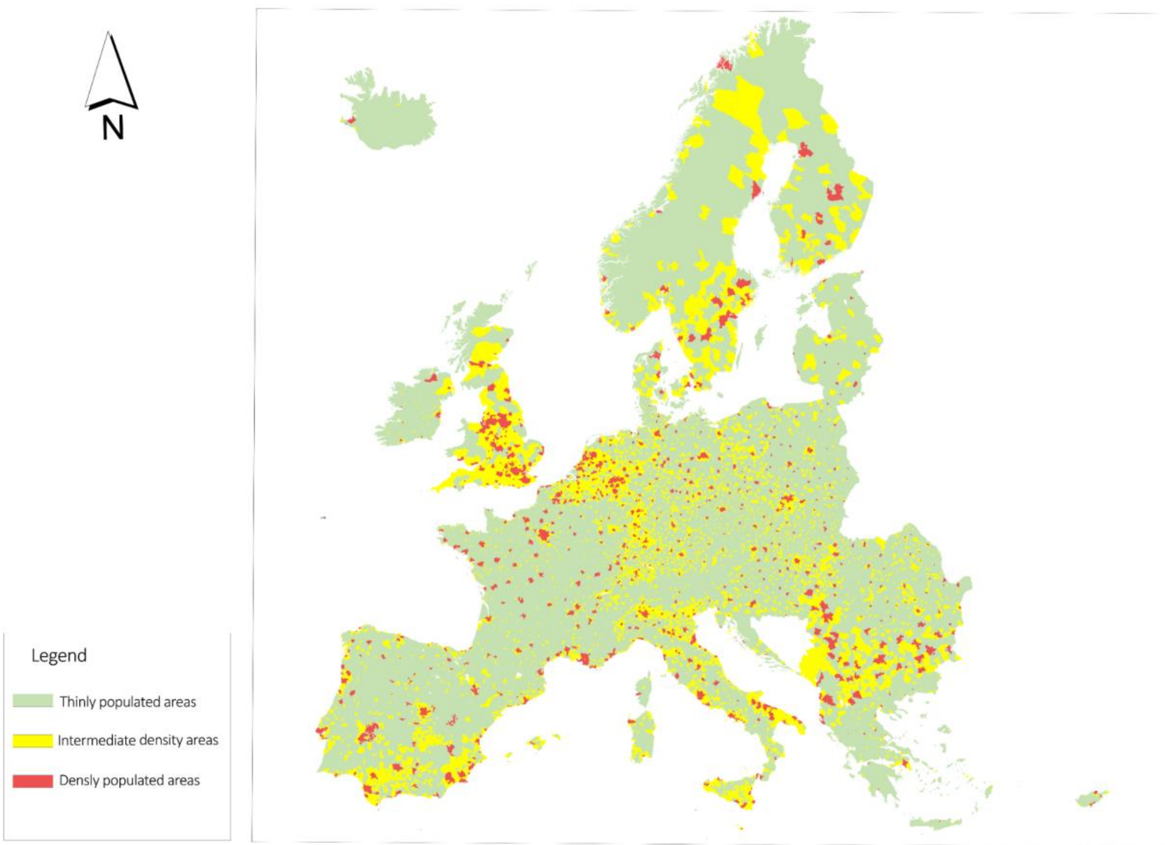

Figure 3-1 Degree of urbanization in Europe based on Eurostat data (elaborated by author)

[8] Data retrieved from: https://ec.europa.eu/eurostat/web/gisco/geodata/reference-data/population-distribution-demography/degurba

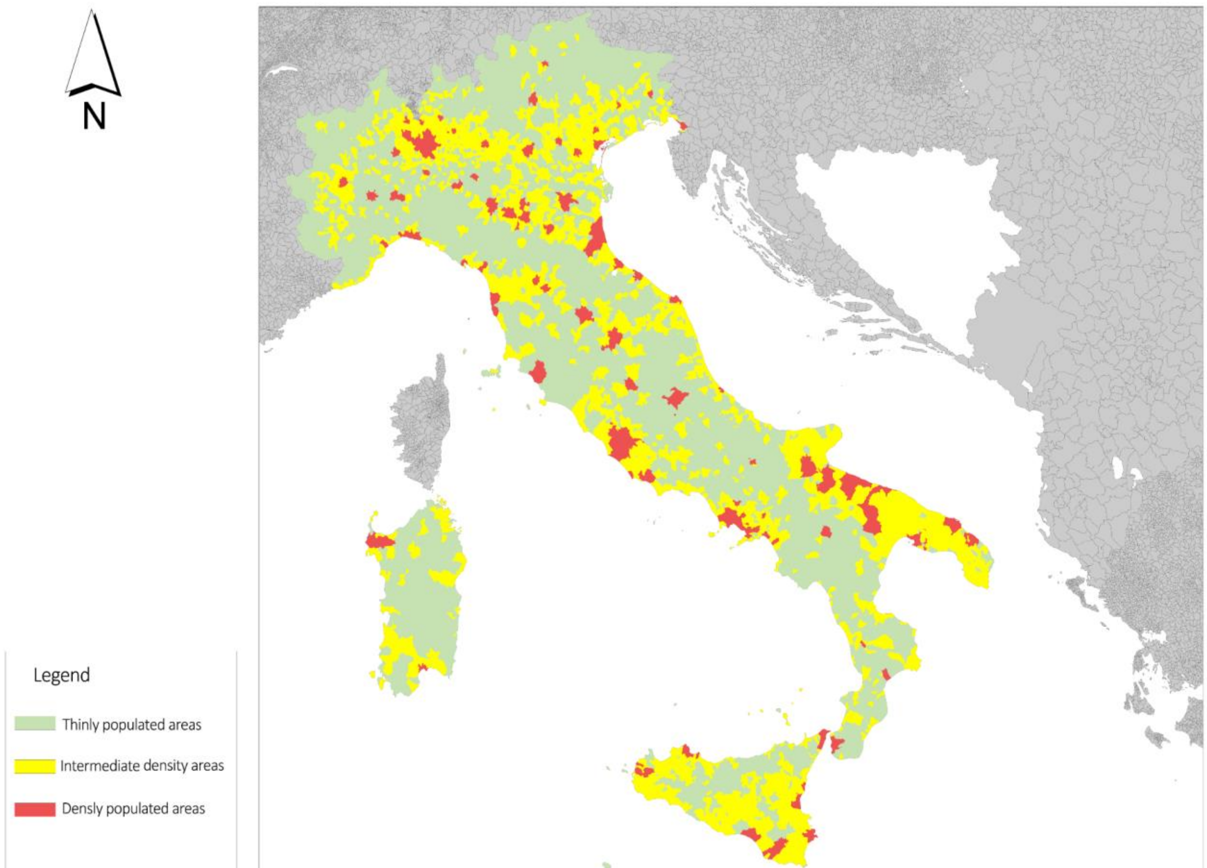

Figure 3-2 Degree of urbanization in Italy based on Eurostat data (elaborated by author)

3.1.2 Italian Definition

3.1.2.1 Urban/Rural Classification

In Italy, ISTAT[9] provided a document "Forme, Livelli e Dinamiche Dell'urbanizzazione in Italia" [10] (2017) that analyses urban-rural definitions in an Italian context. The paper consists of two parts, the first part addresses the problems connected to the conceptual definition of urban area and city and focuses more on the related theoretical-methodological aspects. The second part explores the main characteristics of urban areas, offering original contributions on relevant topics such as land consumption, the dynamic relationship between urban and rural, the study of the spatial concentration of the population, the flows of mobility within cities, environmental pressures,

[9] The Italian National Institute of Statistics is the main producer of official statistics in Italy.
[10] The document is retrieved from: https://www.istat.it/it/archivio/199520

comparison with other European realities. Aside from Degree of Urbanisation adopted at European level, this document addressed two Italian tools:

'Inner (Internal) Areas' Definition

This methodology is part of a national strategy to delimit marginalized areas with low accessibility to services (such as health, education, and public transport). Almost 4,200 municipalities (or more than half of the total) fall within the internal areas. These territories cover 61% of the national surface and are inhabited by about 13 million people (22.3% of the resident population as of 1 January 2018). Most of the inhabitants of inland areas (8.8 million people) live in the intermediate municipalities, 20 to 40 minutes away from the nearest pole. 3.7 million live in peripheral municipalities, while another 670 thousand people live in outermost areas[11]. The methodology consists of two parts. Firstly, identification of the poles, according to a criterion of the ability to offer some essential services; Secondly, classification of the remaining municipalities in four bands: peri-urban areas; intermediate areas; peripheral areas and areas ultra-peripheral, based on the distances from the poles measured in terms of travel times road as shown in table 3-1 (see also figure 3-3).

Table 3-1 Definition of Inner Areas by travel time distance to an urban pole

Classification of the Municipality	**Category**	**Distance from Pole (min)**
Cintura	Pre-Urban Area	0
Intermedio	Inner Area	20
Periferico	Inner Area	40
Ultra Periferico	Inner Area	75

National Rural Development Program Method

[11]Data retrieved from: https://www.openpolis.it/parole/che-cosa-sono-le-aree-interne/ and https://www.agenziacoesione.gov.it/strategia-nazionale-aree-interne/?lang=en

Aside from inner areas, Italy adopted its own method of classification under the *Programma di sviluppo rurale nazionale 2014-20*[12] (PSRN) that recognize four typologies:

A) Urban and peri-urban areas.

B) Rural areas with agriculture intensive.

C) Intermediate rural areas, which include diversified areas.

D) Rural areas with development problems (see figure 3-4).

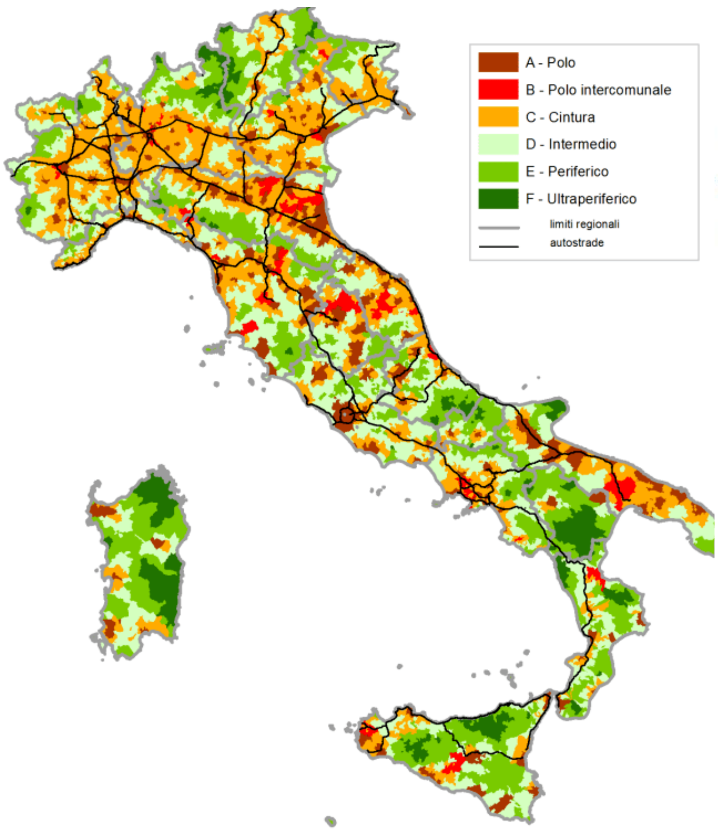

Figure 3-3 Inner areas (Source: Ministero della Salute, Ministero dell'Istruzione)

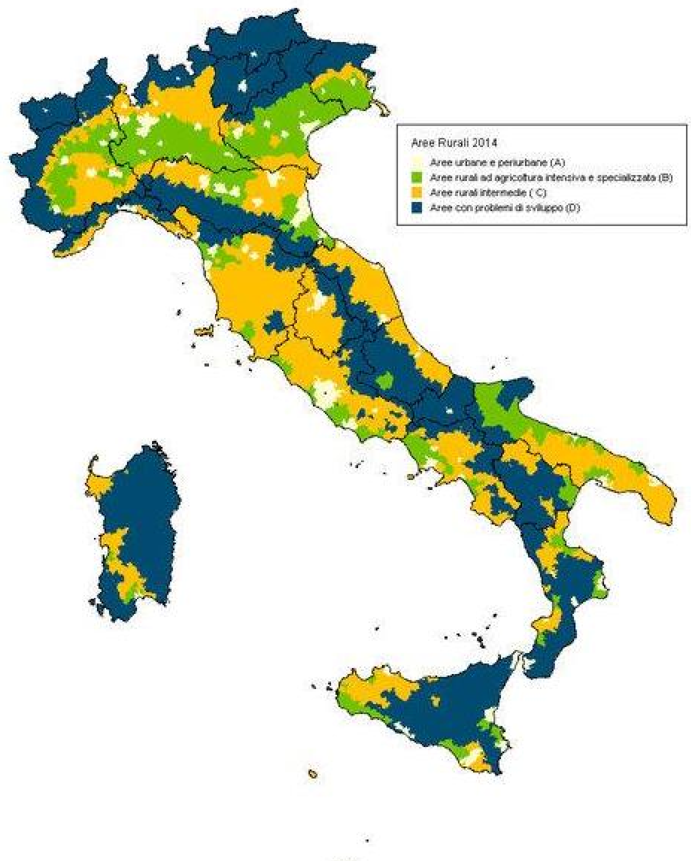

Figure 3-4 PSR classification (source: https://www.reterurale.it/areerurali)

[12] For more details on the methodology, see: https://www.reterurale.it/areerurali

Figure 3.5 shows the PSRN classification for the Piemonte region. It is interesting because based on the Italian classifications, each station falls into a different category. The first station, Lingotto, is categorized as urban and pre urban, while next four stations, Moncalieri, Nichelino, Candiolo, None and Airasca belong to the rural areas with agriculture intensive this followed by intermediate rural areas municipalities which are Piscina, Pinerolo stations, Bricherasio, Bibiana and Luserna. Finally, Torre Pellice station that falls within the rural areas with development problem category.

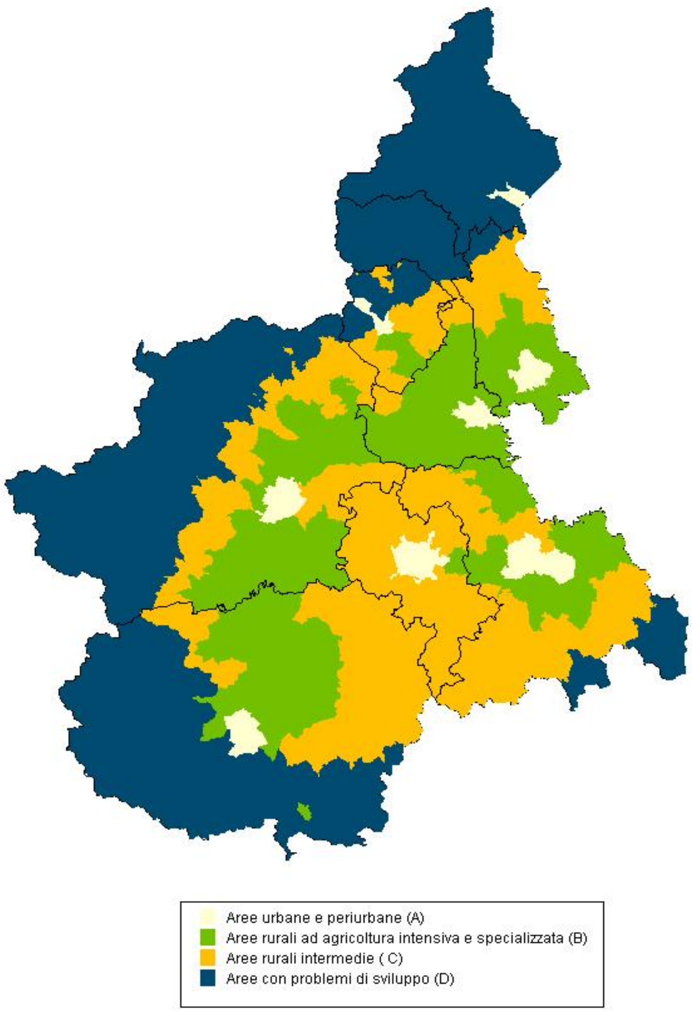

Figure 3-5 PSR classification for Piemonte Region

3.2 METHODOLOGY: NODE-PLACE ANALYSIS

The methodology is originally based on the article "Land use and public transport integration in small cities and towns: Assessment methodology and application" by Nigro et. al (2019). However, as the COVID-19 pandemic has changed the perspectives to PT, a new set of indicators are needed to be introduced to the evaluation. For instance, the role of active mobility (walking and cycling) is now more important than ever so attention must be paid to the accessibility of such modes. To begin with, the original methodology and the key elements are explained in the next step and in section 3.2.2, the additional indicators are explained. Unlike common TOD studies that solely focus on walking as the way to reach the station, the Node-Place model proposed by Nigro et. al (2019) focuses on other feeder transport because walking is not the only mode that people in low-medium density areas choose to get to the stations, and the accessibility through other modes (bikes, public transportation, and private cars) should be also realized. Second issue about the catchment areas. The authors introduce the concept *"extended catchment area"*; they argue that the common catchment area (usually circular buffer) is not sufficient in analysis of low-density stations. First because the job people living in these areas have, or the services they use usually commute further than the station buffer zone. Secondly, the destinations and origins of the trip takes place in a wider geographical context due to the irregularity of road networks compared to high-density urban areas (Nigro et. al, 2019). In this regard, there are two important elements to be taken into consideration for (1). The amount of time people is willing to spend to reach the train station rather than defining a distance (Access/Egress trips). This is possible with calculating the average travel time. (2). 'Network distance' catchment areas instead of 'Euclidean distance' catchment areas commonly used in transportation studies. Both elements are discussed in the following paragraphs.

3.2.1 Catchment Areas

Catchment area is defined by the distance people are willing to travel in order to reach a transport node. It is one of the most important concepts in transportation and planning studies, and strongly influences whether people use the service or not. Recently, the concept has been used for designing TOD as well (Guerra and Cervero, 2012). According to Calthorpe, it is an 800 meters walking radius to the station node and if the person uses the bus line, the value decreases to around 400 meters. These values correspond to the distance a person can walk with the speed of 1-1.5 meter per second. So, 400 meters walk takes between 7 to 4.5 minutes and 800 meters walk falls between 9 to 13 minutes. It is important to note that the size of the catchment area could differ across countries. For example, in the Netherlands TOD catchment area tends to be larger than in other regions since a high number of access and egress trips to the main transit hub are made by bicycle (Balz and Schrijnen 2009). Generally, a circular area of 400 to 800 meters is usually recognized as the catchment area, with the transit node in the centre of the circle or by a 10-minute walk (or, half-mile catchment). Some authors believe this circular assumption of the catchment area may marginalize other important elements such as the design of the roads, bike lanes, and pedestrian paths and the Isochrone approach is suggested by some scholars.

3.2.1.1 Extended Catchment Areas

As said, in low density areas, walking is not the main access egress transport mode, but the accessibility of all the modes of transportation must be taken into consideration. So instead of the usual 'walking- main mode- walking', the access/egress trips should be considered as 'mixed modes-main mode- mixed modes' (Nigro et. al, 2019). Here, access egress trips consist of other sub-trips by other modes with the main transport usually referring to high-capacity transport modes such as train or metro stations. With this in mind the catchment area analysis goes further than only 'walkable area' and includes an 'Extended catchment area' consisting of the catchment areas belonging to all possible transport modes (Figure 3-6).

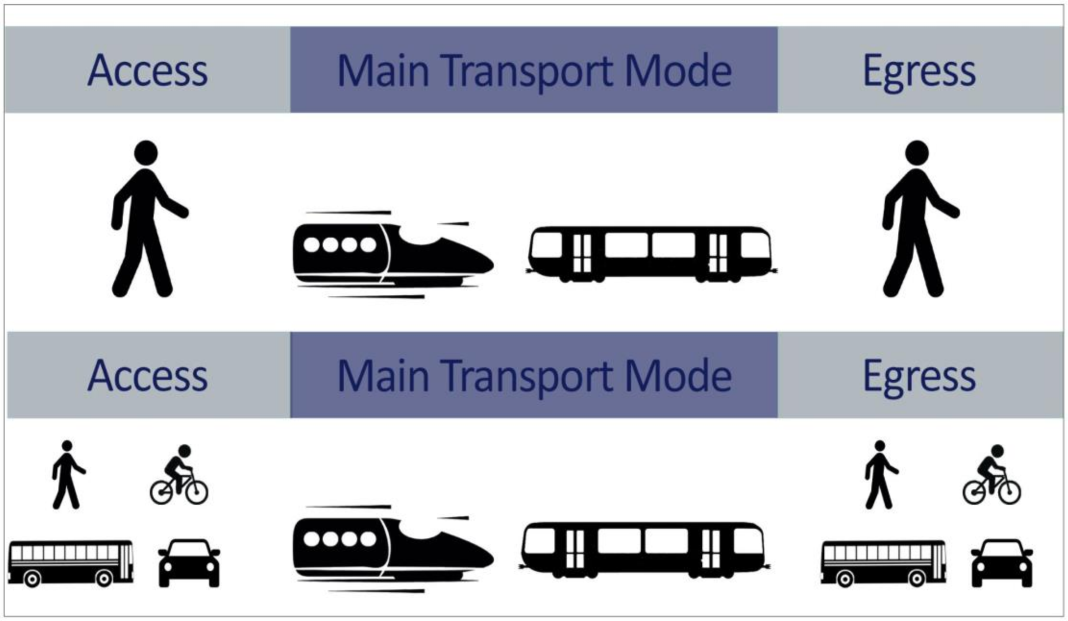

Figure 3-6 Access/Egress trips in low density stations (elaborated by author)

Moreover, as said circular catchment areas (buffers) are more suitable in compact cities with dense and well-connected road networks, where the result of approximation is close to the actual situation. On the other hand, in low density areas, road patterns follow a more irregular pattern and Euclidean distance approach results in overestimation of transit services (Gutiérrez and García-Palomares, 2008). So, this study follows the Isochrone catchment area based on the existing road networks and for each of the feeder transports, a different catchment area is identified. This calculation is performed through a tool in GIS software.

3.2.1.2 TravelTime Esri ArcGIS pro add-in

In this thesis, the calculation of catchment areas (isochrone maps) is performed through the "Travel Time" tool, a relatively new add-in for ArcGIS pro software. The biggest advantage of this method compared to Network Analyst tools such as "Service Area Layer" is that it provides the same result with a much shorter procedure. In general, this tool is useful for:

1. Isochrones - create reachable areas by travel time

2. Travel time matrices - calculate travel times between 1000s of locations in one go

3. Routes - generate A to B routes, with turn-by-turn directions

For Generating isochrone maps, TravelTime calculates all the routes within the time limit that is set by users (in minutes) differentiated by transport modes. The result is different travel time polygons that can be overlapped with each other. Another important factor is the travel speed. For walking/biking isochrones, this tool uses the average walking/cycling speed taking into account delays on routes including traffic lights, roundabouts, and crossings. Considering public transport (bus, tram, train and metro) it uses real routes and timetables and allows for the time it takes to enter the station or switch platforms. Finally, driving time is calculated by applying specific driving speeds to each individual road. It allows time for parking the car, using roundabouts and traffic lights. At this moment, TravelTime tool has full coverage of all transport modes in all EU countries except for Bulgaria and Slovenia. So, the calculation of walk, bike and car catchment areas are calculated with this tool. For public transportation however, this method is not useful since it includes all types of public transportation while in this study public transportation feeder is bus and train are considered as the main transportation mode. So, the calculation of public transport feeders will be based on open data website[13].

3.2.2 Indicators and Selection

The choice of indicators followed these steps: first the indicators from TOD literature review are extracted in Table 3-3. In the next step, a series of indicators are selected based on the priorities of the thesis. Then, an additional set of indicators are introduced by the author based on the emerging challenges of mobility in the post -COVID-19 era.

3.2.2.1 Indicator from Literature Review

[13] For generating the public transport isochrone https://openrouteservice.org/ is used. Same as travel tool this website generates the same result as Network Analyst toolbox, but the advantage compared to TravelTime add-in is the possibility to choose type of public transport which in the case of this analysis, only bus is taken into consideration

After reviewing the literature in Chapter 1, a list of articles is chosen to select a new set of Node and Place indicators. The choice was based on the frequency of the article's citation in the literature related to Transit Oriented Development. To keep the confusions minimum, in table 3.2 each paper is assigned with number[14] and table 3.3 shows the set of indicators used in each article. Final selection of indicators for this analysis are explained in the methodology section of Chapter 3.

Table 3-2 Selected articles from literature review

No.	Title	Author and Date
1	Spatial Development Patterns and Public Transport: The Application of an Analytical Model in Netherlands	Bertolini (1999)
2	Advance Transit Oriented Development Typology: Case study in Brisbane, Australia	M.Kamruzzaman et al. (2014)
3	Classifying Railway Stations for Sustainable Transitions	Reusser et al. (2008)
4	Land Use and Public Transport Integration in Small Cities and Towns: Assessment Methodology and Application	Nigro et al. (2019)
5	Classifying railway stations for strategic transport and land use planning	Zemp et al. (2011)
6	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	Vale (2015)
7	Measuring TOD Around Transit Nodes- Towards TOD Policy	Singh et al. (2017)
8	Developing a TOD typology for Beijing Metro Station Area	Lyu et al. (2016)

Table 3-3 Set of indicators extracted from selected articles

	Dimension	Indicators	1	2	3	4	5	6	7	8
Node	*Transport Services*	Accessibility by train								
		Number of directions served	*		*	*		*		*
		Number of stations within 45 min travel	*							

[14] The number assigned to each paper is solely based on the citation date and has no other reason

	No. stations within 20 min travel		*			*		*
	No. arrivals/departure per day (workday/holiday)			*				
	Span (workday/holiday)			*				
	Ticketing service			*				
	Daily frequency of the services	*		*	*	*	*	*
	Accessibility by bus							
	Number of directions served	*	*	*		*		
	Daily frequency of the services	*	*	*	*	*		
	Presence of at least one line			*				
	Number of of likens			*				
	Numbers of. departure/arrivals per day (workday/holiday)			*				
	Span (workday/holiday)			*				
	Degree of Integration			*				
	Passenger Services[15]			*				
	Accessibility by car							
	Distance from the closest motorway	*						*
	Car- Based facilities			*				
	Parking capacity	*		*		*	*	*

[15] Passenger services, like good-quality waiting places and kiosks/restaurants.

Accessibility by bike							
. Number of bike paths						*	
Parking capacity	*					*	
Length of paths			*			*	
Presence of quality bike lanes				*			
Presence of bike facilities				*			
Accessibility by walk							
Pedestrian connectivity					*	*	
Total length of walkable length of path						*	*
Impedance pedestrian catchment area (IPCA)						*	
Public transport accessibility level		*					
Walk Scores							*
Quality of sidewalks				*			
Presence and quality of pedestrian streets				*			
Passenger services				*			
Other indicators							
Interchange to different routes of transit						*	
Passenger load in peak						*	

		Passenger load off-peak							*	
		Accessibility level of PT		*						
		Access to walkable opportunities within walkable distance from train station							*	
Place	Activities	*Residents*								
		Number of residents	*		*			*		*
		Net residential density		*		*	*			
		Employments								
		Number of retails; hotel and catering workers	*					*		*
		Number of educations; health; cultural workers	*					*		*
		Number of. administration and services workers	*					*		*
		Number of industry and distribution workers	*					*		
		Number of secondary sector workers			*					
		Number of. tertiary sector workers			*					
		Employment density		*		*	*		*	
		Other indicators								
		Number of students				*				*
		Number of jobs								*
	Land-use	Functional mix	*	*	*			*	*	*

Node and Place	User friendliness	Average distance from station to jobs				*
		Average distance from station to residents				*
		Intersection Density	*		*	*
		Cul-de-sac density	*			
		Land-use diversity		*	*	
		Average block size				*
		Travel times to major employment and activity centers by Metro				
		Street Connectivity		*		
		Density of business establishments			*	
		Safety of commuters at transit stop			*	
		Basic amenities at stations			*	
		Presences of information display systems			*	

3.2.2.2 Selection of Node Indicators

This family of indicators assesses the accessibility of a transit station (node) therefore, its *potential* for human interactions (Bertolini, 1999). Based on the original model, node contents are located on the *y* axis of the node-place diagram. In this research main transport indicators are shown in the table 3.4:

Table 3-4 Node indicators

no.	Indicator	Measure
1	Number of directions served by train	n
2	Number of arrivals/departures per day both for holidays and workdays;	n
3	Ticketing service	Y/N
4	Safety Amenities at the transit stops	Y/N
5	Availability of Hygiene measures at the transit stop	Y/N
6	Number of entrances and exits	n
7	Availability of night train (Y/N)	Y/N

Number of directions and frequency (number of arrivals/departures) of stations are two important factors in assessing the accessibility of a transit node and are most commonly used in Node-Place analysis and other TOD studies[16]. Ticketing service is the availability of a ticket machine within the station. This indicator was originally introduced by Nigro et. al (2019) and is chosen in this analysis because it shows the convenience of public transportation as passengers can easily obtain the ticket inside the station. First three indicators are originally recognized in Nigro et. al (2019). Aside from those, the indicator 'Safety Amenities' of the node is extracted from the article by Singh et. al (2017) as it can be relevant to the purpose of this study because if the residents of small cities and towns feel safe in a station area, they would be more incentivized to use trains instead of private cars. According to the authors, safety in the station can be indicated based on the presence of other people in the stations, the layout and design provide good visibility and good lighting during the day and at night. However, it is a hard indicator to quantify, since the data about the number of people in the station is usually unavailable, Singh et. al (2017) considers the number of shops and bars within the station area as they attract people. In this study, the same measure is taken. It must be noted that only shops and bars within the station areas are considered and the ones inside catchment areas are excluded. Last four indicators are added by the author based on the current pandemic situation and literature reviews in section 2.4. As the studies demonstrate, the first post-pandemic issue of public transport is that people generally exhibit anxiety about hygiene in trains. The availability of hand sanitizer, temperature checks at the entrance and social

[16] In the original methodology 'Span' of the services is also considered but the indicator is omitted here because the span of every station within the case study is the same which makes the comparison impossible.

distancing measures like putting marks on the seats can help passengers feel safer. Similarly, the number of openings allows the ventilation of the air. Finally, the availability of night trains is recognized as an indicator because according to the studies it can be effective in managing the crowd especially in peak hours of stations.

3.2.2.3 Selection of Place Indicators

As Bertolini (1999) notes, the intensity and diversity of activities falls within in place content. Meaning, the more activities available, the more interaction is happening (Bertolini, 1999). The choice of place indicators was based on the availability of the data. It is also important to note that the residential and job density is calculated separately for each four catchment areas of stations (Table 3-5). There is one additional indicator 'The availability of open spaces' in the walking catchment area. As discussed in the section 2.4.3 about TOD in post COVID-19 time and the emergence of smart working, one idea is to provide intermediate spaces where workers can go instead of offices for work meetings etc. Availability of open spaces around transit nodes can evaluate the potential of developing such spaces for the future.

Table 3-5 Place indicators

no.	Place indicators	Measure
1	Residential density	number of people/km2
2	Employee density	number of jobs/km2
3	Availability of open space within station walk catchment area	Y/N

3.2.2.4 Selection of Feeder Transportation

This family of indicators aim to assess the accessibility of each isochrone catchment area. For each isochrone, a separate assessment is performed. Considering walking feeder transport indicators, Nigro et al. (2019) consider only qualitative indicators as 'quality of sidewalks. So, in order to add the quantitative value, the length of sidewalks (Singh et. al, 2017). Within the catchment areas is also added. Walk Score[17] is another additional indicator that is extracted from the article Lyu et al. (2016). Table 3.6 shows the walk feeder transport indicators.

Table 3-6 Walking feeder transport indicators

no.	Indicators	Measure
1	Quality of sidewalks	0: Sidewalks are not present 0.33: Sidewalks are partially present with poor quality 0.66: Sidewalks are partially present with acceptable quality 1: Sidewalks are present in all roads with a high quality
2	Length of the sidewalks	Meter
3	Walk score	Calculating the walk score based on the https://www.walkscore.com/ website

Similarly, for bike feeder transport indicators the original methodology considered only qualitative indicators as 'quality of the bike lanes. Again, an additional quantitative measure is added. It is not possible to calculate the length of the bike lane due to the unavailability of bike lanes in most of the catchment areas. Instead, the percentage of road network that is served by bike lanes is considered. Another criterion in the availability, is binary indicators referring to the presence of bike facilities at the transport node, like bike parking, bike lockers, bike repair. Table 3.7 shows the bike feeder transport indicators.

Table 3-7 Bike feeder transport indicators

no.	Indicators	Measure
1	Bike lanes ratio	Length of bike lanes/ length of all roads
2	Bike-share facility	Y/N
3	Bike parking	Y/N

Public feeder transport indicators are the same as main transport indicators with the addition of indicator, the degree of fare integration[18]. It must be noted that this indicator is different from

[17] Download the walk score of each station area from the website https://www.walkscore.com/

[18] This indicator measures the possibility of buying integrated tickets, and how many, among the transport companies operating in these transport nodes, issue integrated tickets? E.g., in a transport node served by one train company and two bus companies, can occur that every company participates to fare integration – i.e., is possible to buy tickets valid for train and bus – or can happen that only two of them issue integrated tickets; in the worst case, there is no fare integration. The indicator will assume value 1 – maximum – in the first case and 0 – minimum – in the last.

others because in some stations where the bus stations are not available within the station catchment area, the result of other values would be invalidated.

Table 3-8 Public transport feeder (bus) indicators

no.	Indicators	Measure
1	Presence of at least one line (if the answer is no, all the next indicators will be equal to zero)	Y/N
2	Number of lines	n
3	Number of arrivals/ departures (workday and holiday)	n
5	Integration Service	Y/N
6	Passenger services, like good-quality waiting places and kiosks/restaurants	Y/N

Car-based indicators are exclusively important for low density areas where car transport mode is a common access/egress mode and can be considered complementary to train transportation. This family of indicators refers to all car related activities such as car renting, car-sharing, carpooling, taxi services, and park-and-ride. Here, the availability of specific infrastructures is a crucial factor (for instance, car parking for park-and-ride). For this reason, the indicators are as follows.

Table 3-9 Car feeder transport indicators

no.	Indicators	Measure	
1	Car-Based Facility	Kiss and ride	0/1
		Taxi area	0/1
2	Area of parking	Sq. meter	
3	Parking accessibility	Distance between station the closest parking	

3.2.2.5 Transforming Indicators to Index

Node indicators are translated into Node indices through three steps, first the value of each indicator is separately calculated, then each value is divided by the maximum value of the same category. The result of this division will be a number between 0 and 1. In the last step, the Node Index of each station is obtained simply by calculation of the average value. For the indicator number 3,4,5,7 the value will be either 0 (in the case that there is no service) and 1 (in the case of availability of the service). Considering Place indicators; however, a more complex approach is taken. First, place and feeder transport indicators are separately transformed into average values then, the values are multiplied in their relative pairs (according to the transport mode considered, in order to obtain Place Indexes referred to each catchment area. Due to the great number of indicators involved, indexes are shown in the tables with the specific code assigned to them (see table 3.2). Figure 3.5 shows how the place index has been obtained:

Table 3-10 Translation of the indicators to indices

Original Indicators		**Index**	**Area of the analysis**	**Code**
Main Transport Indicators	Accessibility of the transit services	Node Index	Stations	N
Place Indicators	Intensity and diversity of activities (land-uses)	Place Average Values	Walk catchment area average values	Pw
			Bike catchment area average values	Pb
			Public transport catchment area average values	Pp
			Car-based catchment area average values	Pc
Feeder Transport Indicators	Quality of feeder transports	Feeder transport Average Values	Walk transport average values	Tw
			Bike transport average values	Tb
			Public transport average values	Tp
			Car-based transport average values	Tc

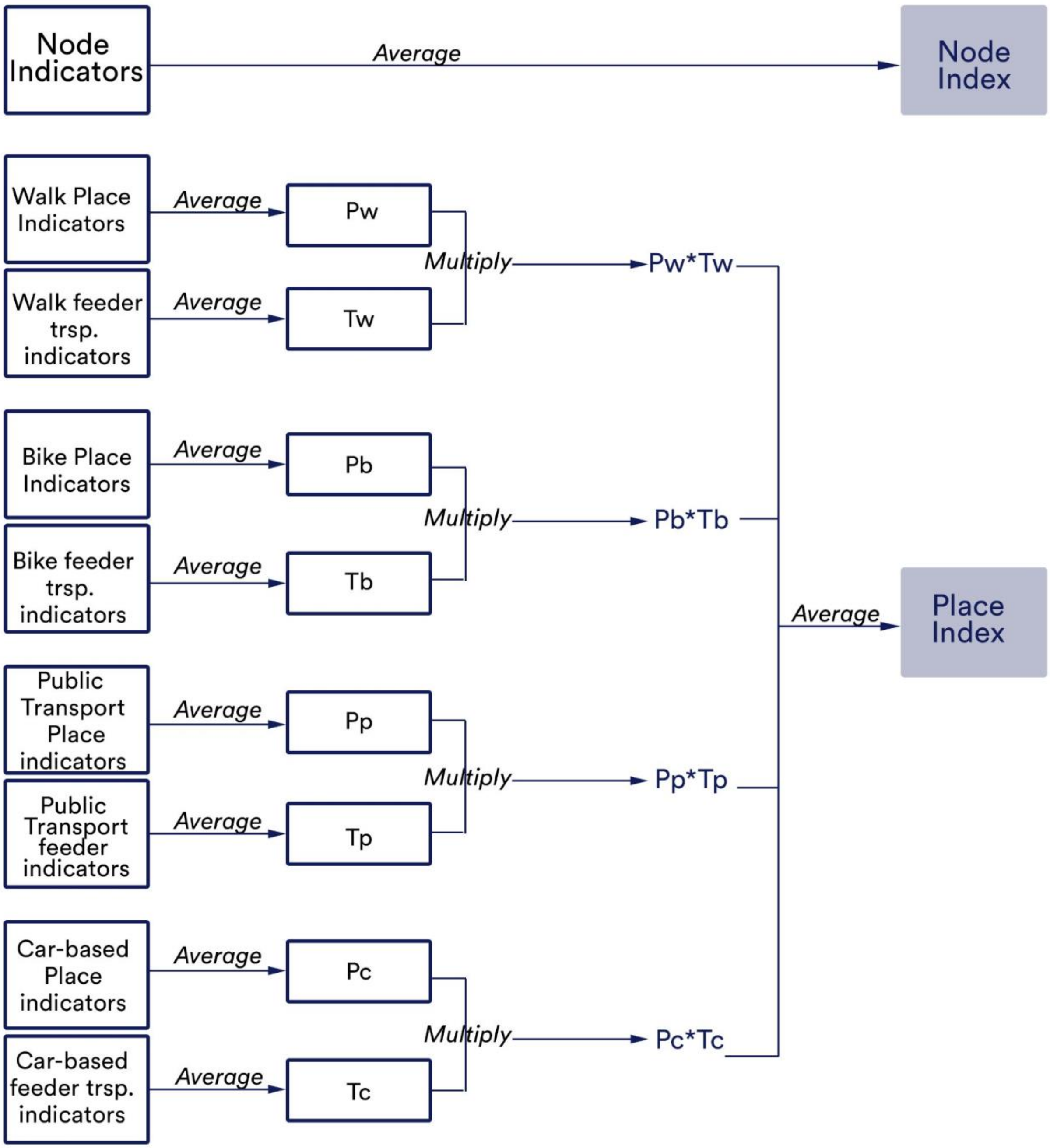

Figure 3-7 Node and Place Index. Elaborated by the author based on the article Land use and public transport integration in small cities and towns (based on Nigro et. al, 2019).

3.2.3 'Three-step' Node-Place Analysis

This Node-Place approach follows three steps as shown below:

1. A ‘general’ node-place analysis: like the original model, includes general description of the accessibility of transport nodes in case study area, compared to intensity of the land uses.
2. A ‘detailed’ node-place analysis, differentiated by feeder transport mode catchment area.
3. A ‘radar diagram’ analysis, able to display which catchment area could host urban development, and whether an improvement of main or feeder transport is needed.

3.2.3.1 General Node-Place Analysis

General Node-Place analysis is performed based on Node Index (N) and General Place Index (P) which is the combination of place and feeder transport indicators as discussed. Like the original model by Bertolini (1999), Node content is placed on the vertical y axis while Place content is set on the horizontal *x* axis of the diagram. So, each transport node (station) is positioned as a point on the *xy* diagram, indicating the accessibility level of that node area, and the potential for human interaction at and around the station. Here, the attention must be paid to the General Place index since it is not only influenced by residential and job density, but also by the quality of feeder transports. However, this analysis is not able to give us a deep insight into the accessibility of different feeder transport and intensity of the land-use. Another deficiency of this method is the overlap between density of jobs and residential areas of the walking catchment areas, with densities belonging to bike and car-based transport areas, giving job and residential density of walk catchment area, a higher weight compared to bike and car-based areas. For public transport catchment areas, this is not always true but generally, the overlap can occur. For these two reasons ‘detailed’ Node-Place analysis is set to give more insight to the accessibility of transport nodes.

3.2.3.2 Detailed Node-Place Analysis

This analysis consists of four Node-Place diagrams that are differentiated by feeder transport and the relative catchment area. Similarly, the Node index is placed on the *y* axis while Place indexes of each catchment area are positioned on the *x* axis. Each Place index is obtained by multiplying place average values (Pw, Pb, Pp, and Pc) into the average value of the feeder transport of relative catchment area (Tw, Tb, Tp, and Tc). This analysis gives more insight into the differences of the Place value for each catchment area.

3.2.3.3 Radar Diagram

Even though Detailed Node-Place analysis gives a good view on the performance of General Place content in relation to a transport node, 'Radar diagram' illustrates the quality of Place and Feeder transport values separately. Radar diagram, or spider chart, is a triangular diagram that shows multivariate data in the form of a two-dimensional chart of three or more quantitative variables. In this step of the methodology, 4 radar diagrams, representing each of the four catchment areas are developed. Node index (N), Place average values (Pw, Pb, Pp, Pc) and Feeder transport average values (Tw, Tb, Tp, Tc) are placed on each axis as Figure 3.6. shows.

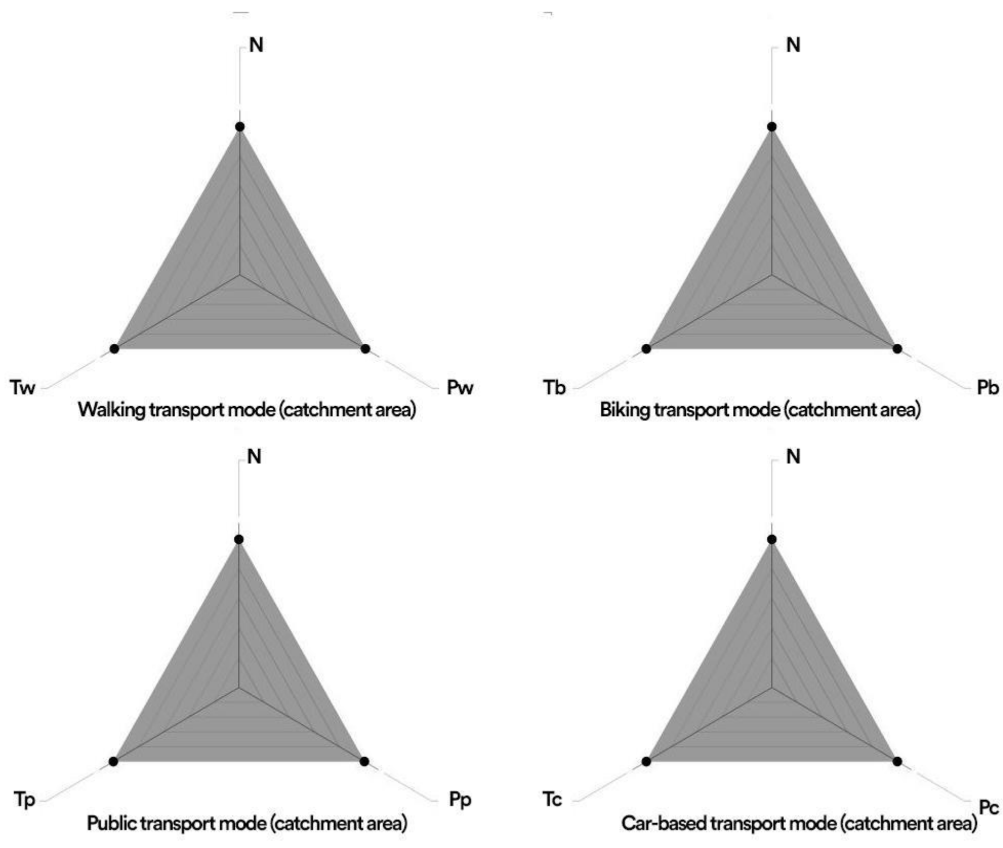

Figure 3-8 Radar chart for four catchment areas, elaborated by the author based on Nigro et. al (2019).

According to the author, the radar diagram is set to highlight the potentials of ‘unbalanced’ nodes to suggest policies while considering land-use, accessibility of main transport and quality of feeder transport at the same time. Also, the diagram can be ‘translated’ into four maps, showing one transport node and relative catchment areas to each feeder transport (figure 3.6). Moreover, each axis can be linked to a group of stakeholders and public decision-makers. For instance, ‘Node index’ is decided by main transport companies, ‘Place average value’ is influenced by planning strategies of Municipal and Provincial planning offices, and feeder transport is controlled by the decision of transport providers (Nigro, et al, 2019)

4 APPLICATION OF NODE-PLACE MODEL

4.1 CASE STUDY AREA

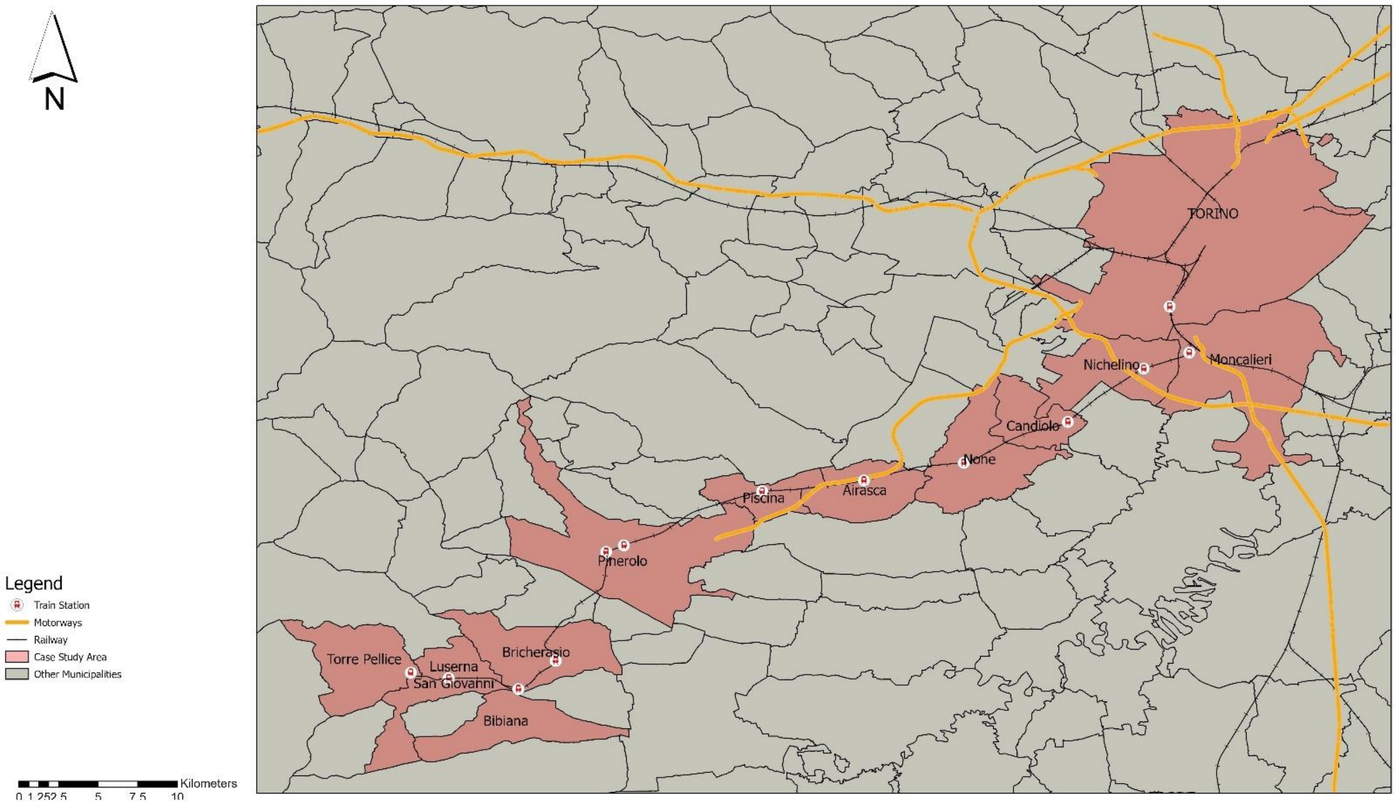

Figure 4-1 Case Study Area (Elaborated by author)

The selected case study is a part of *Torino-Torre Pellice* regional railway line (Figure 4-1). It is one of the radial lines of the metropolitan railway system of Turin in Piemonte region, located in North-Western Italy. The Turin-Torre Pellice line was originally opened in 1854 from Turin to Pinerolo, and then extended up to Torre Pellice in 1882. It is about 55 km long and has 14 stations (Staricco and Vitale Brovarone, 2018). At the moment, the line is only active from Turin to Pinerolo. Bricherasio, Bibiana, Luserna and Torre Pellice stations have been out of the service since 2012.

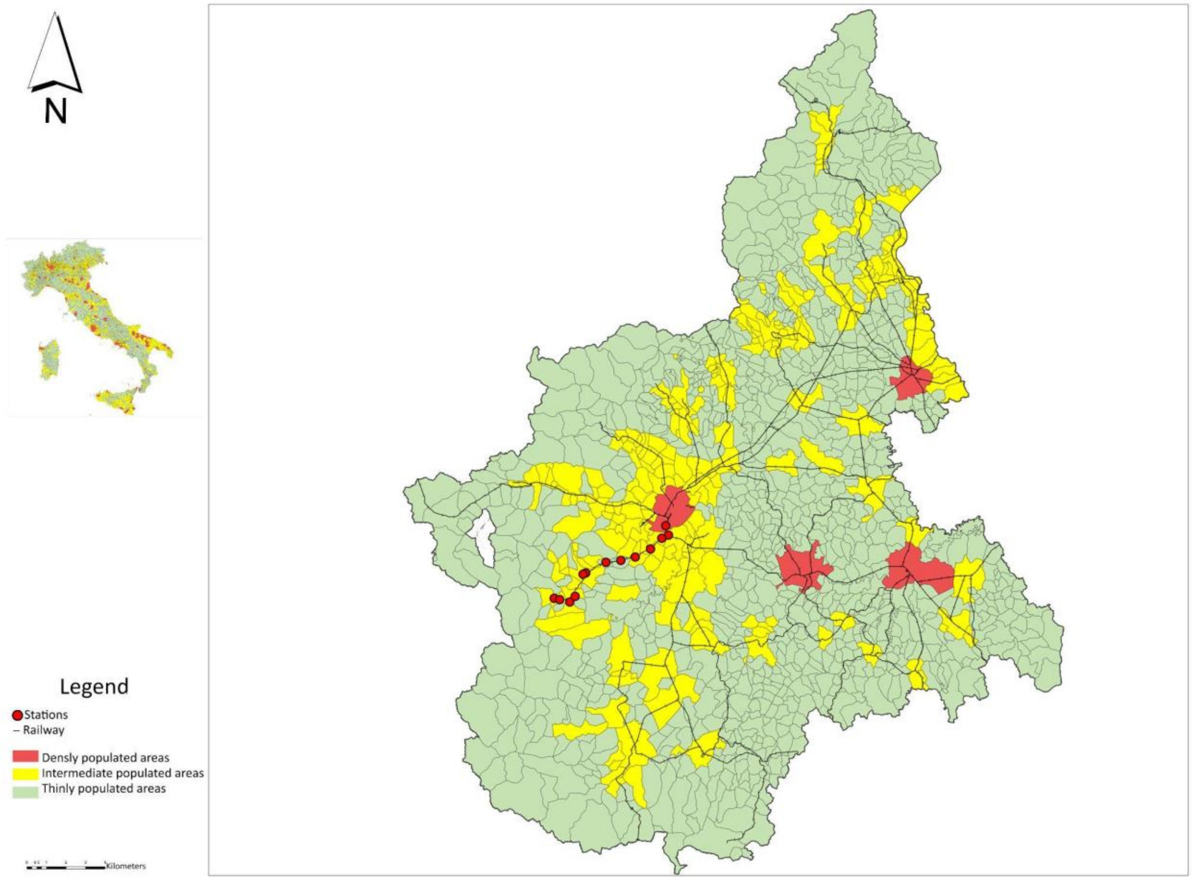

Figure 4-2 Degree of urbanisation in Piemonte region (elaborated by author based on Eurostat data)

As figure 4-2 shows, the settlement pattern in Piemonte region exhibits a slight polarization around the Turin urban area with several towns and suburbs around it. Population density drops as the distance from Turin increases. Three other densely populated areas (red zones) can be spotted in the region, belonging to *Ast*i, *Alessandria*, and *Novara* cities while other intermediate populated towns (yellow) are scarcely located throughout the region. And mountainous areas have the least population density (green zones). Infrastructure pattern complies with urban pattern (figure 4-3) stations are mostly in the most populous areas. Figure 4-4 shows the degree of urbanization in the case study area. Except for one station in the densely populated area of Turin and two stations in the thinly populated mountainous area, all stations belong to intermediate populated zones. The reason for adding high and medium density station to the analysis is to compare the result of the model between stations with different densities.

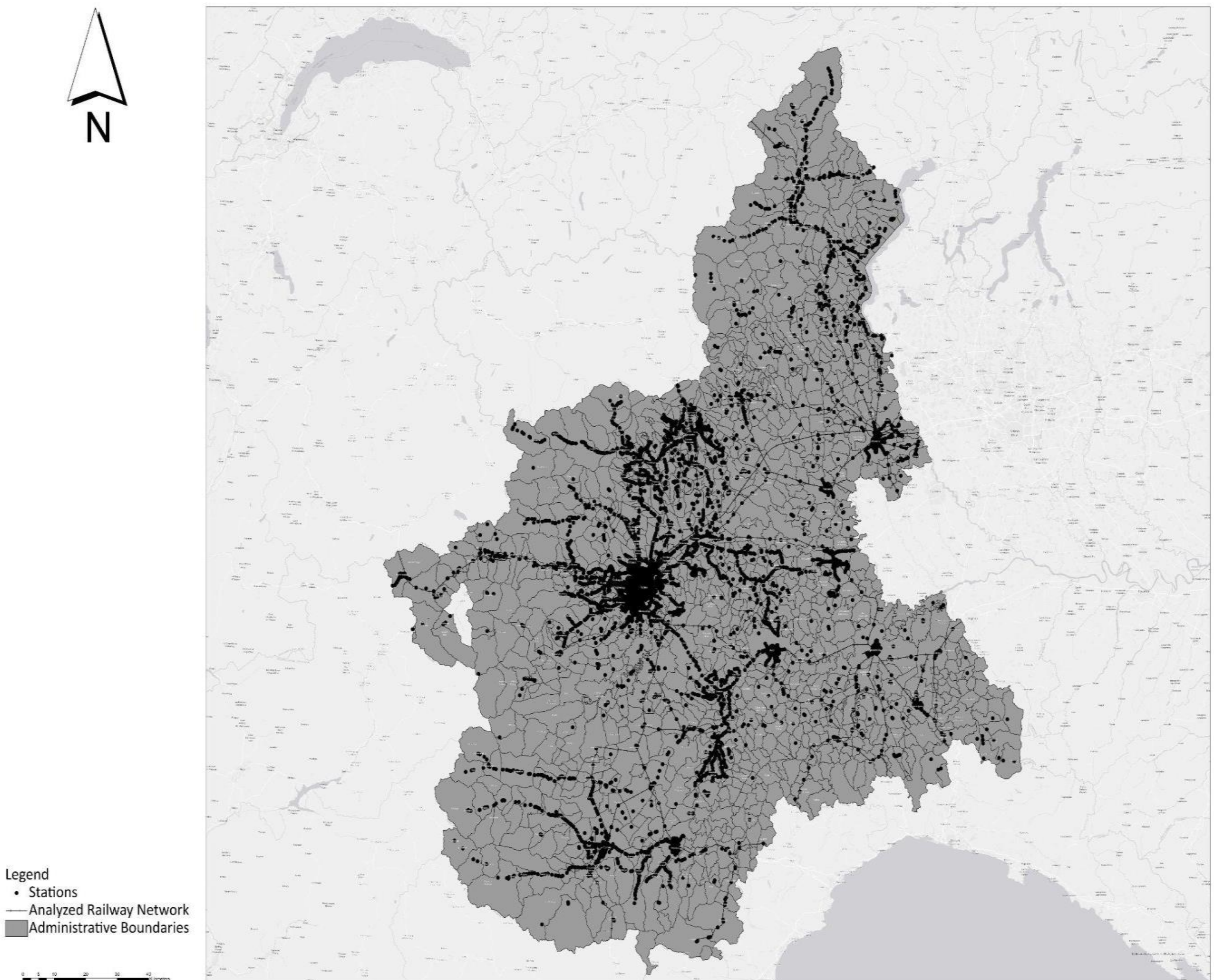

Figure 4-3 Infrastructure pattern in Piemonte region (elaborated by author)

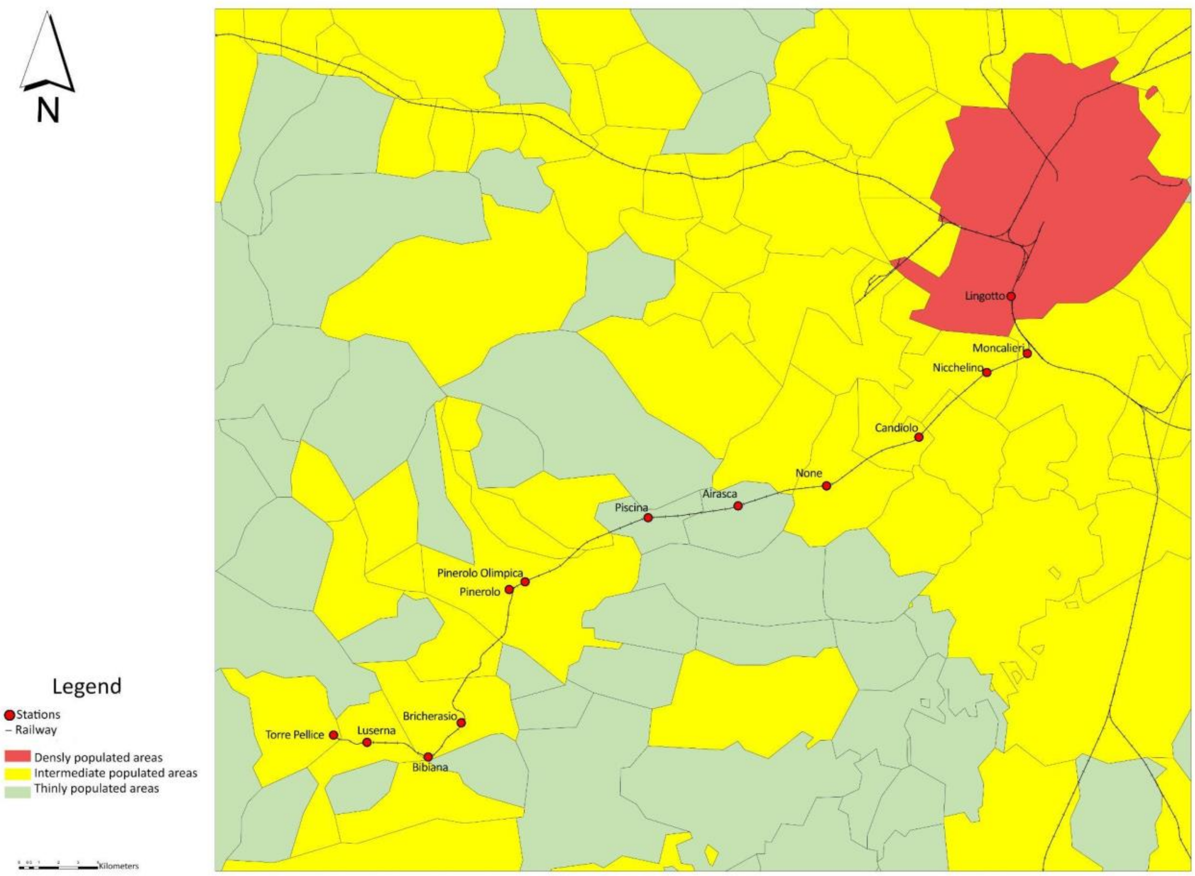

Figure 4-4 Degree of Urbanization in case study area (elaborated by author based on Eurostat data)

The analysed railway consists of 13 stations. The first station, Turin *Lingotto* is characterized by high connectivity due to its location within the urban area, next two stations: *Moncalieri* and *Nichelino* are located in the neighbouring towns with around 50,000 inhabitants (marked as intermediate populated area). Next four stations: *Candiolo, None, Airasca and Piscina* are small towns with less than 10,000 inhabitants. It is interesting that as of figure 4.4, only Piscina and Airasca are considered as thinly populated areas while Candiolo and None are intermediate populated areas according to degree of urbanization. The next two stations are located in *Pinerolo* town with slightly more than 35,000 inhabitants. Last four stations: *Bricherasio, Bibiana, Luserna San Giovanni* and *Torre Pellice* are small towns in mountainous areas of the Piemonte region.

4.2 DATA COLLECTION

4.2.1 Access/Egress Duration

To calculate the extended catchment area of each station, two elements are needed: First is the duration of each access and trip to the transport node, meaning the time people are willing to travel to from the origin point to the departure station, and from arrival station to the destination. Second is the travel speed based on each transport mode. To obtain the duration of the access/egress trip, it is necessary to first calculate the average commuting time by train. In the reference article, the travel time is calculated based on ISTAT data on commuting travel[19]. It is a text file containing information relating to travel for work or study purposes of the population residing in the family or in cohabitation, measured at the 15th General Census of the population (9 October 2011) containing the data relating to 28,871,447 individuals (28,852,721 resident in the family and 18,726 residents in cohabitation) who declared that they go daily to their usual place of study or work starting from their residence and return daily to the same. It is the latest data publicly available and is used in the article Nigro et. al (2019). So, to avoid repetitive calculation, the obtained value from the reference article is used. The value obtained is 54.2 minutes as the average travel time with train as the main mode, for home-to-work and home-to-school travels. Second step is to calculate access/egress time based on average travel time. This calculation is based on findings of Krygsman et al. (2004) 'interconnectivity ratio' which is the proportion of access and egress time to total trip time (Krygsman et al., 2004). Figure 4-5 shows Interconnectivity ratio for different multimodal chains.

[19] https://www.istat.it/it/archivio/139381

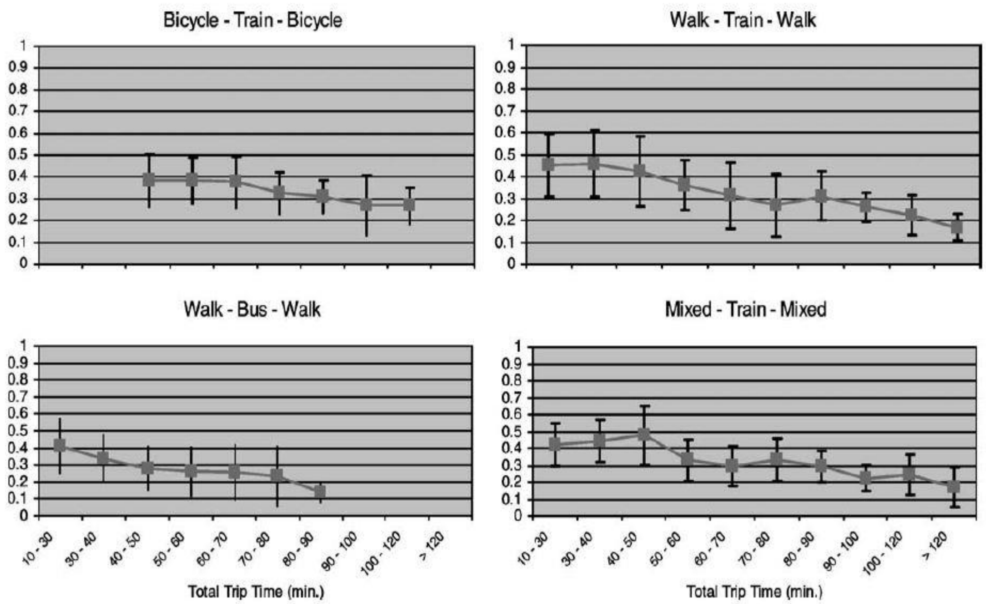

Figure 4-5 Interconnectivity ratio for different multimodal chains (Source: Krygsman et al., 2004)

According to this paper, the interconnectivity ratio reflects the proportion of time spent on access and egress as a share of total trip time. Although individual access and egress times show significant individual variability, the interconnectivity ratio shows less variation falling mainly in the range of 0.2–0.5 for most multimodal public transport chains. With increasing trip time, the ratio shows a continuously decreasing trend. This decreasing trend is very much a function of the multimodal mode chain (e.g., access–main–egress) and the overall trip time. With 54.2 minutes as the value of travel time, the interconnectivity ratio is 0.45 (See the mixed-train-mixed diagram in figure 4.5). So, the access plus egress time is 24.4 minutes and 12.2 minutes for each access egress trip. This value is rounded to 12 minutes. It must be noted that the author is aware of the caution regarding the adoption of interconnectivity ratio since in most of the transportation studies in Italy, a common 10-minute time threshold is considered as the travel time. However, the main reason for this choice was to test the methodology introduced by Nigro et. al (2019).

4.2.2 Travel Speed

Travel speed of cycling, walking, and driving have been built within Esri ArcGIS pro plug-in (TravelTime) using a combination of open data sources and their own proprietary algorithms to imitate how real people travel. Considering public transportation, the plug-in uses the timetable of public transport for 40 countries. So, the only input needed is the travel time.

4.2.3 Extended Catchment Area

Once the travel time is clear, it is possible to generate Isochoric maps with the TravelTime plug-in. For all transportation modes, the arrival time to the station is set at 8:30 in the morning on a working day. Figure 4-6 shows the catchment areas for walking, bike, and car transportation[20] modes. As it shows, the first issue that emerges is the conflict between polygons for the station with small distances, especially in the case of bike and car catchment areas. This creates a problem because in counting the services within the buffers, some areas would be counted two (figure 4-7) or even more than two times (figure 4-9).

[20] Public transport catchment areas are presented separately in the following section.

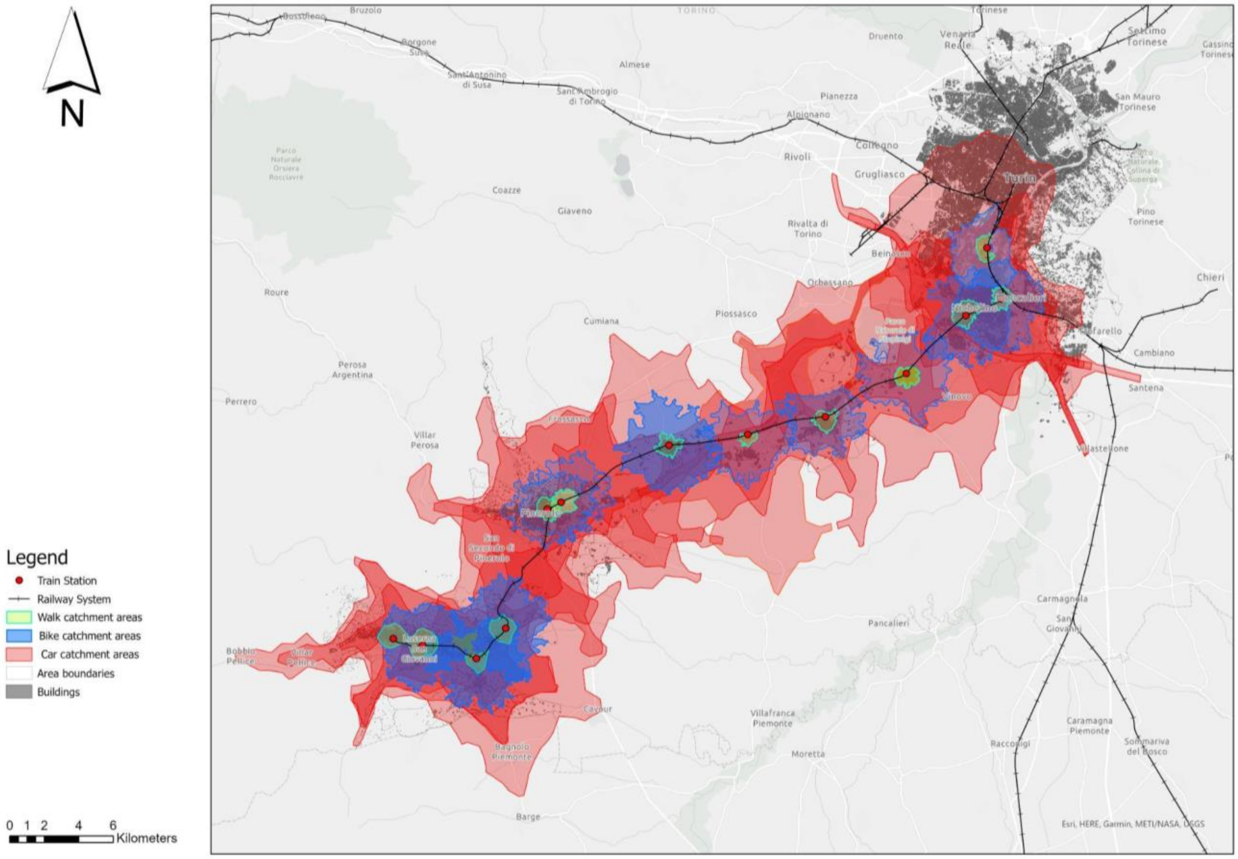

Figure 4-6 Catchment areas for walking, biking and car transportation modes (elaborated by authors).

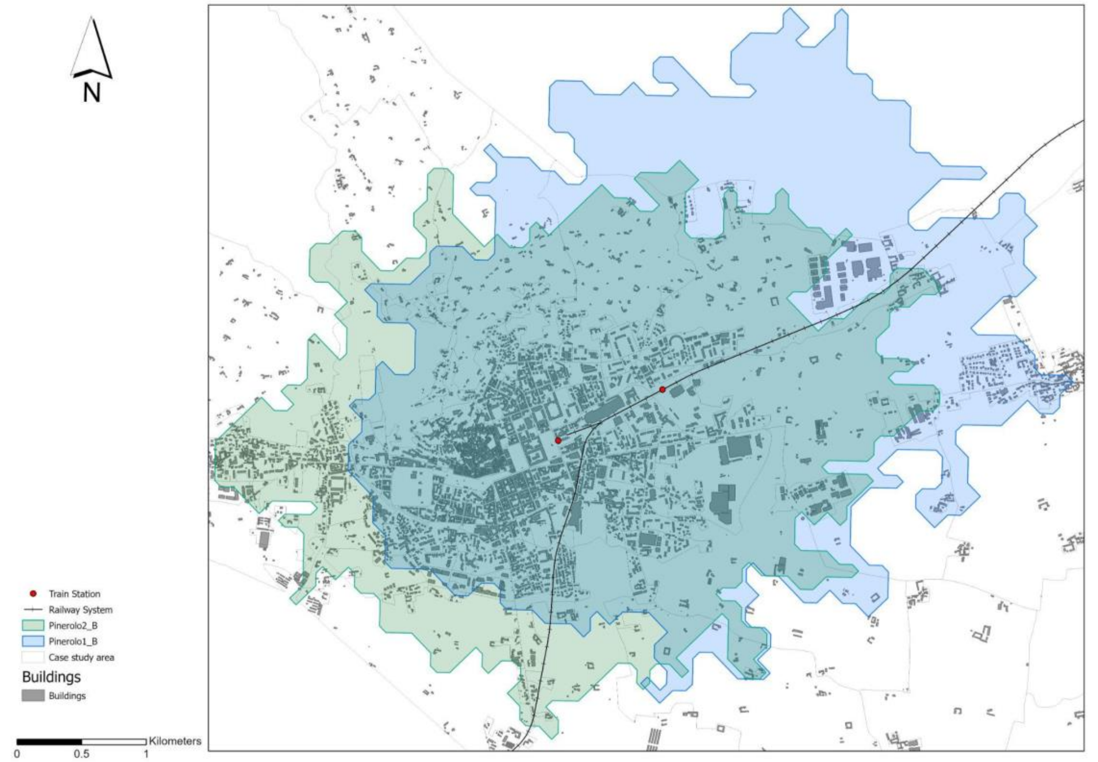

Figure 4-7 Catchment areas are overlapping in short-distanced stations (elaborated by author)

To address this issue, the overlapping areas are counted using the GIS tools (figure 4-8). Then the calculation of services and population within the overlapping areas are divided between relative stations.

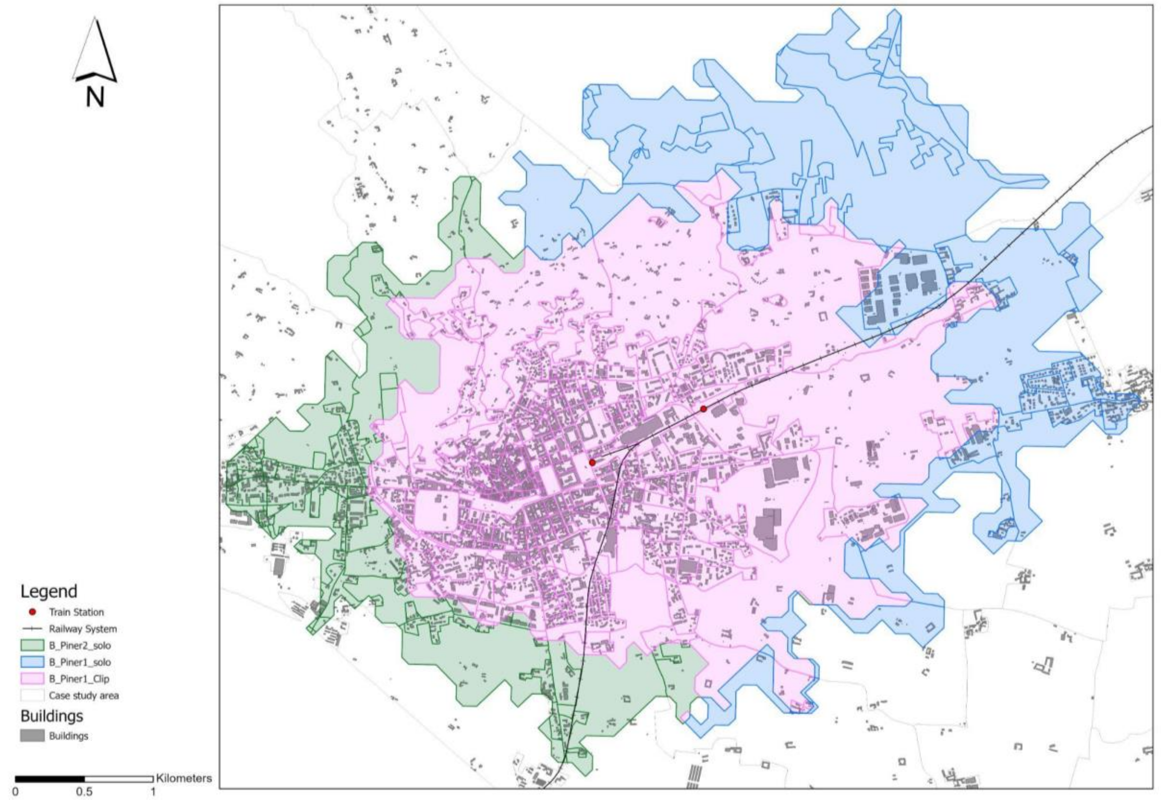

Figure 4-8 Counting the overlapping areas in bike catchment areas in Pinerolo Olimpica and Pinerolo F.S (elaborated by author)

The conflicting catchment areas can be considered as one of the shortcomings of this methodology that does not occur in usual TOD studies because only walking catchment areas are recognized and of course, in same amount of travel time, the distance travelled by car and bicycle will be much longer than a person on foot hence the catchment areas would be bigger. This overlapping can occur between three or even four and five isochrone buffers in the case of car catchment areas which makes the approximation even more complex (see figure 4-9).

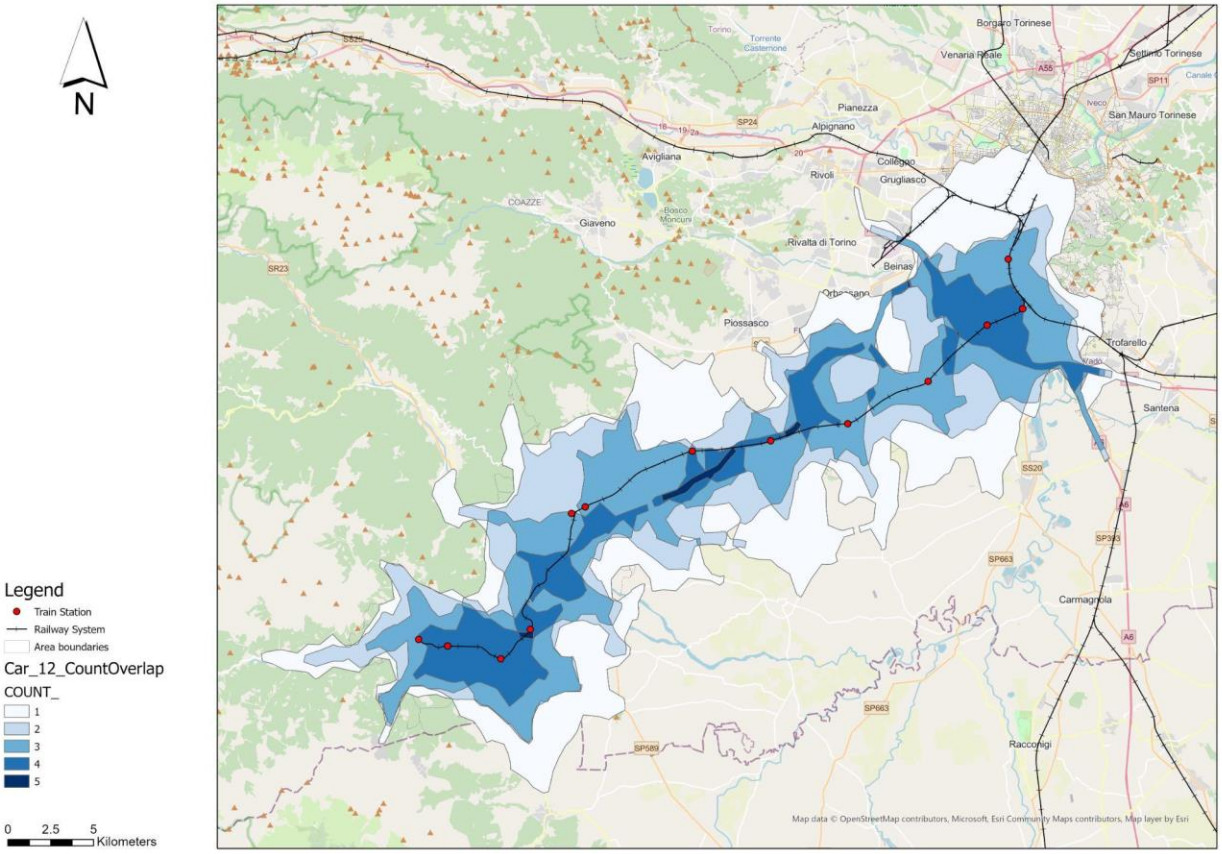

Figure 4-9 Overlaps can occur between up to five catchment areas in the case of car transportation mode (elaborated by author)

In the case of public transport catchment areas, some differences can be observed compared to other transport modes. First, the isochrone buffers do not follow the road network, but the network of public transport (in this case, only trams and buses). As shown in figures 4-10, 4-11 and 4-12 the polygons stretch along the location of bus stops. It must be noted that except for Lingotto station, none of the other stations can be considered as an integrated node with the bus network. However, for the Moncalieri, Nichelino, Pinerolo, bus stations are placed within a short distance from the train station, enabling passengers to move between two transport modes by the 12 minutes travel time threshold. For the stations Bricherasio, Luserna and Torre Pellice, the only reachable line is the one connecting Pinerolo to Torre Pellice. On the contrary in the case of the stations Candiolo, None, Airasca and Piscina passengers are not able to move between the two modes within the travel time limit. So, these stations are excluded from the public transportation analysis.[21] [22] Aforementioned stations are also excluded from the public transport feeder transport analysis (section 4.3.3). Another important factor is the shape of public transport catchment areas. Some catchment areas show gaps between two or more polygons for a single station. These gaps can be shortly distanced like in the case of Moncalieri and Nichelino station catchment area, or rather far away from each other like in the case of Bricherasio station. In both cases the gaps in the polygons simply occur since the areas between two shapes are out of the reach with respect to travel time limit since the area close to bus stops is reachable by walk within the travel time limitation whereas the areas between are not accessible. Finally, like in the case of bike and car catchment areas, overlaps can be observed in the catchment areas of stations within a short distance (Figure 4-11 and 4-12).

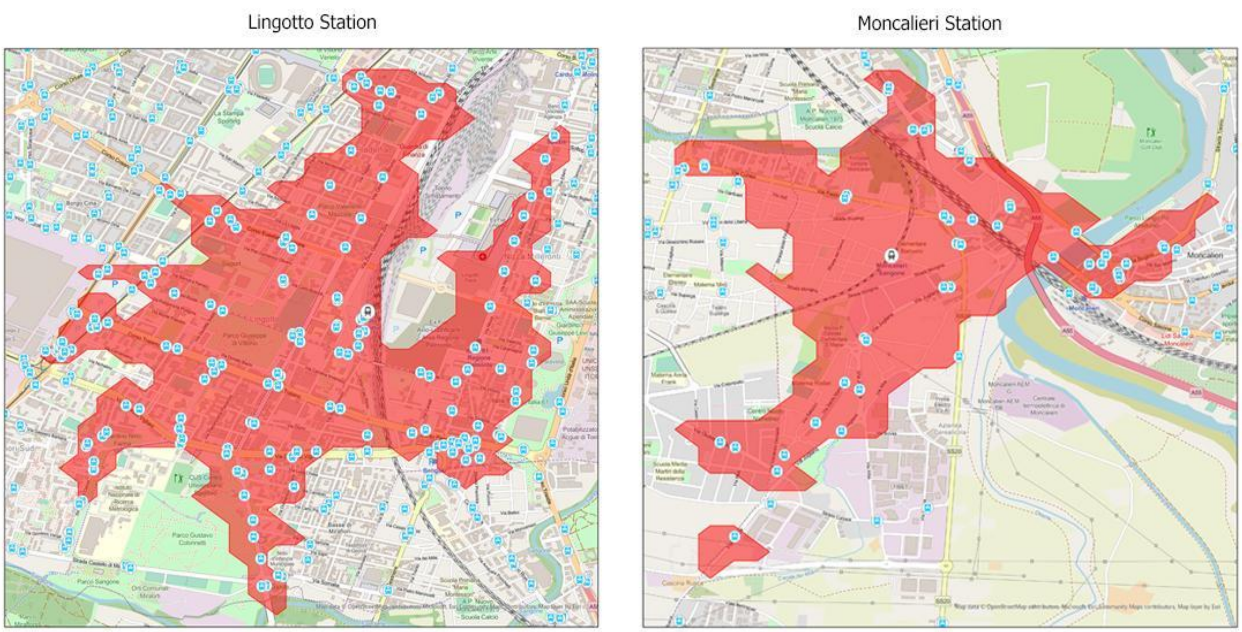

Figure 4-10 Public Transport catchment areas Lingotto and Moncalieri Stations (elaborated by author)

[21] In the case of unavailability of the public transportation network, the plug-in generates an 'imaginary' network not based on the bus routes, but on the normal network routes.

[22] In order to confirm the result of public transport catchment area, all the bus routes are controlled through this website with respect to 12 minutes travel time https://www.muoversinpiemonte.it/

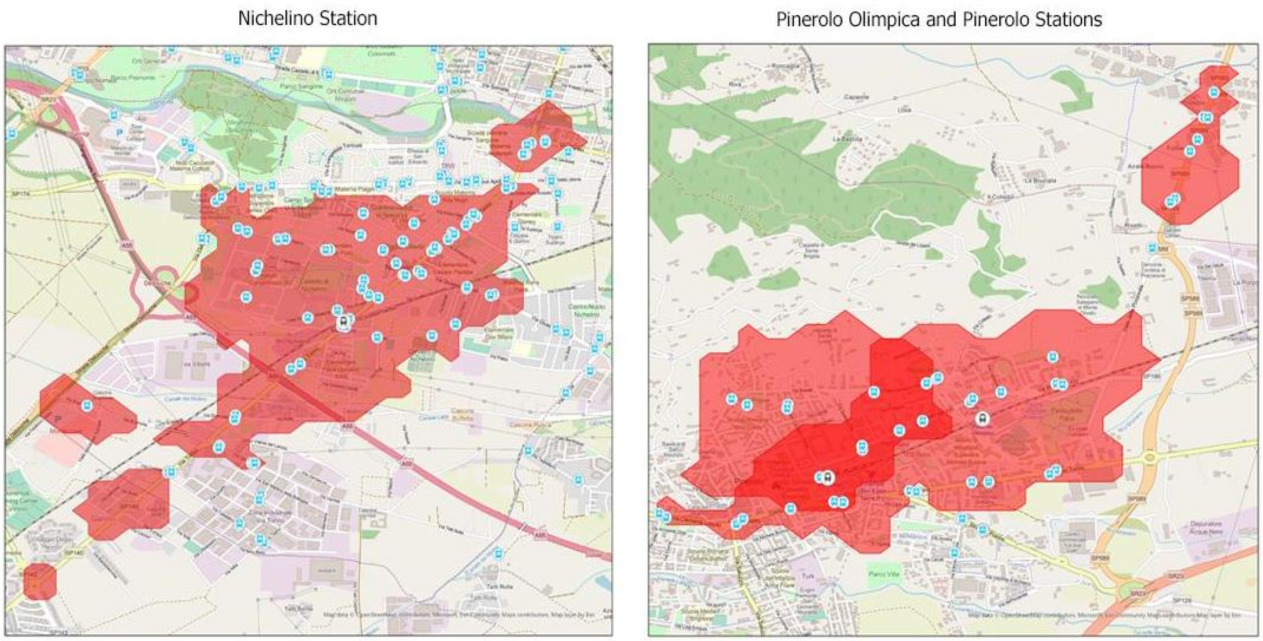

Figure 4-11 Public Transport catchment areas Nichelino, Pinerolo Olimpica and Pinerolo Stations (elaborated by author)

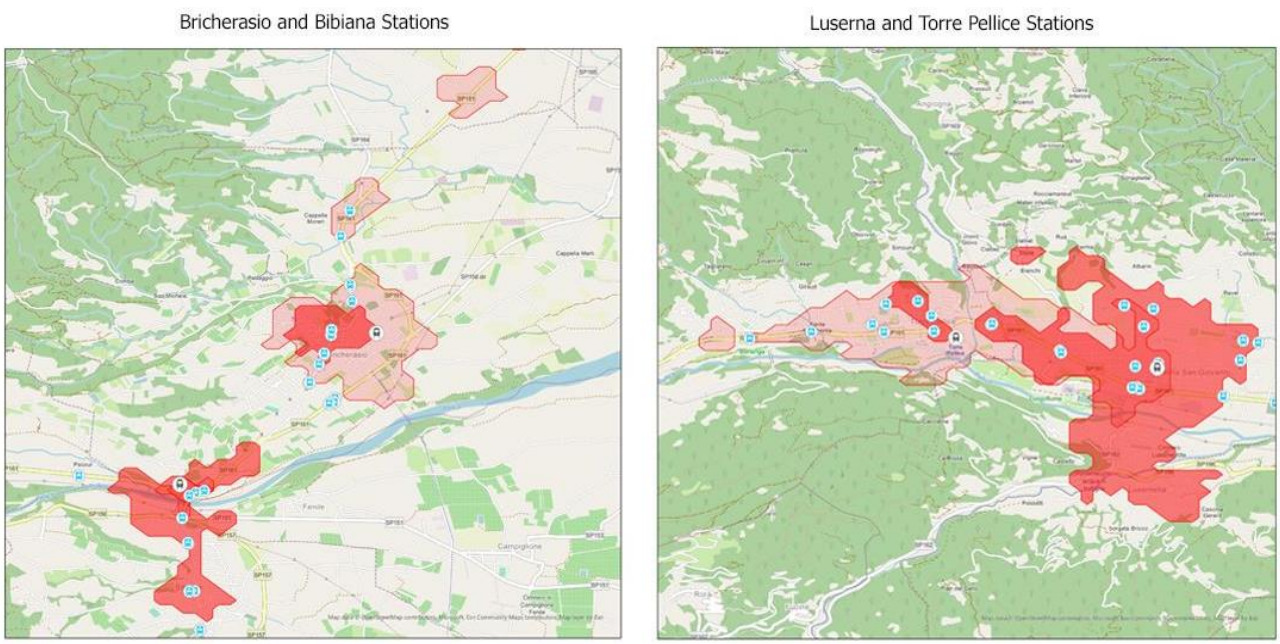

Figure 4-12 Public Transport catchment areas Bricherasio, Bibiana, Luserna and Torre Pellice Stations (elaborated by author)

4.2.3 Population Data

ISTAT provides data about population and jobs related to the last census dated back in 2011[23]. The data provided by ISTAT are associated with census tract and are in the format of xlsx and txt. In order to use them, the data is joined to the census tract. Here the issue is about compatibility of the catchment areas with census tract as figure 4-13 shows, some of the census tracts are partially within the catchment areas, this generates the problem because ISTAT data is related to the whole tract and the data about a part of it is unknown. To tackle this issue following measure has been taken:

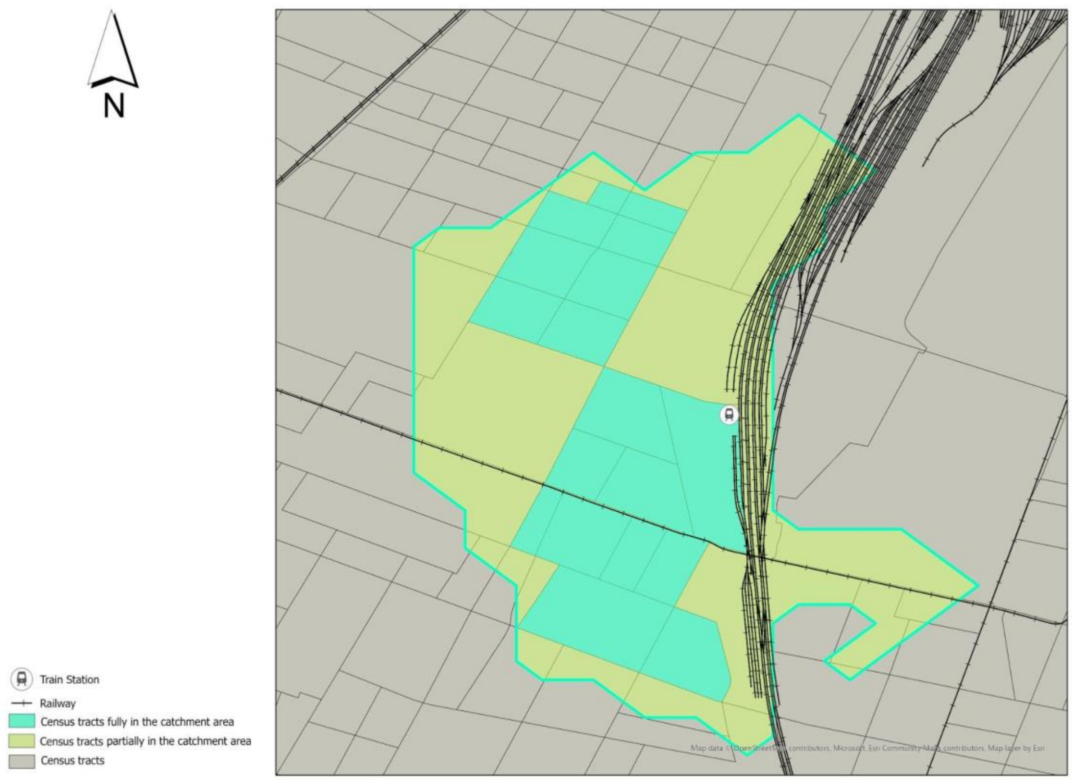

Figure 4-13 Catchment areas completely and partially in the catchment areas (elaborated by author)

First, the density of population and jobs in each census tract is calculated. Once the density of each tract is known it is possible to overlay the polygon of the catchment with the census tract through

[23] Data is publicly available in: https://www.istat.it/it/archivio/104317

GIS software. In the last step, it is possible to estimate the population and job density based on the values of density obtained in the first step and the area of the tract within the catchment area[24].

4.3 METHODOLOGY IMPLEMENTATION

4.3.1 Node Indicators

This section shows the result of the calculation of the indicators. Table 4-1 shows all the stations are assigned with a number. The same number will be used for further calculations. Among the indicators, *safety amenities at the transit stop* are more of a qualitative indicator. According to Singh et al. (2017) is ideally measured by presence of other people in the stations, the layout and design provide good visibility and good lighting during the day and at night. This indicator is selected because safety is one of the most important factors that encourage people to use transit services. Here however, due to the unavailability of the data about the number of the people in the station area, Singh et al. (2017) measures this indicator by counting 'number of shops and eating joints' at the station since they attract people and influence the number of people at the station. Another issue is about the last four stations: Bricherasio, Bibiana, Luserna and Torre Pellice. Since 2012, train services from Pinerolo to Torre Pellice have been discontinued so in reality, the values of frequency and direction for these stations is equal to zero, however, it is a possibility that this service will open in the next few years. So, the same value for Pinerolo station is considered for these stations as well.

Table 4-1 Analysed stations with associated numbers

No	Stations
1	Lingotto
2	Moncalieri
3	Nichelino
4	Candiolo
5	None
6	Airasca
7	Piscina
8	Pinerolo Olimpica
9	Pinerolo F.S.
10	Bricherasio
11	Bibiana

[24] Population/Jobs estimation= density * area

12	Luserna
13	Torre Pellice

Another important issue is the calculation of the number of arrivals and departures for the stations that are located at the end of the line. In this case, the stations Pinerolo and Torre Pellice are placed at the end of the lines Chivasso-Pinerolo and Pinerolo-Torre Pellice, respectively. And while all the nodes have the same accessibility level, the count of arrivals/departure for the stations located between the last stations would be twice more as in the case stations at the beginning and the end of the line. To tackle this issue, for the stations that are in the middle of the lines, each arrival/departure is counted only once, while in the case of the stations at the end of the line, each arrival and departure is counted separately. Table 4-2 shows the result of the calculation.

Table 4-2 Node Indicators (elaborated by author)

Node Indicators	**Description**	**Unit**	**Score**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Direction Served	number of directions served[25]	n	n/n max	15	2	2	2	2	2	2	2	2	2	2	2	2
Frequency (Working days)	arrivals or departure per day	n per day	n/n max	253	44	44	44	44	44	44	44	44	44	44	44	44
Frequency (Holidays)	arrivals or departure per day	n per day	n/n max	117	15	15	15	15	15	15	15	15	15	15	15	15
Ticketing Service	Ticket Machine/ Desk	Y/N	0/1	Y	N	Y	Y	Y	Y	Y	N	Y	N	N	N	N
Safety amenities at the stops	number of shops and eating places	n	n/n max	3	0	0	0	0	0	0	0	2	0	0	1	2
Hygiene measures	Availability of hand sanitizer, temperature measurement , distant management measures within the station	Y/N	0/1	0	0	0	0	0	0	0	0	0	0	0	0	0
Number of entrance and exits	Count the number of entrance and	n	n/n max	1	1	1	1	1	1	1	0	2	1	1	1	1

[25] Data about train timetables is publicly available in: https://prm.rfi.it/qo_prm/

	exit to evaluate															
Night train (Y/N)	Availability of night train as a crowd management measure	Y/N	0/1	N	N	N	N	N	N	N	N	N	N	N	N	N

Table 4-3 shows the final Node Index for each criterion. The final score is the average of all the scores obtained in each indicator. The values are extremely low in the case of Moncalieri and Pinerolo Olimpica station. In the former, the station building is abandoned and in the later, there is no station building. It is also important to mention that for the Bricherasio, Bibiana, Luserna and Torre Pellice, it is assumed that the stations are in the service.

Table 4-3 Node Index values for each station (elaborated by author)

Node Index	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Direction Served	1	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
Frequency (Working days)	1	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
Frequency (Holidays)	1	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
Ticketing Service	1	0	1	1	1	1	1	0	1	0	0	0	0
Safety amenities at the stops	1	0	0	0	0	0	0	0	0.67	0	0	0.33	0.67
Hygiene measures	0	0	0	0	0	0	0	0	0	0	0	0	0
Number of entrance and exits	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0	1	0.5	0.5	1	0.5
Night train (Y/N)	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Score	**0.69**	**0.12**	**0.24**	**0.24**	**0.24**	**0.24**	**0.24**	**0.05**	**0.39**	**0.12**	**0.12**	**0.18**	**0.20**

4.3.2 Place Indicators

This section shows the result of the Place indicators calculations. Population and jobs are calculated four times for each station, with respect to the catchment area of different transport modes. There is an additional indicator for the availability of an open space within the walking catchment area. This indicator is added by the author with respect to the post Covid situation of smart working that has been discussed in the literature review (see section 2.4.3) The availability of the open space is controlled through physical development plan of each municipality[26]. As explained in section 2.4.3 an open space close to the station has the potential to be utilized as a 'satellite office' in the future. Table 4-4 to 4-6 shows the result of the Place indicators.

Table 4-4 Place Indicators: stations Lingotto, Moncalieri, Nichelino and Candiolo (elaborated by author)

isochrone areas	Indicator	Measure Unit	Score	1	2	3	4
Walk area	Job density	Job/km2	Density/Max Density	1178.54	1103.99	971.80	324.736
	Population density	People/km2	Density/Max Density	8074.87	5132.76	7843.51	3285.014
	Availability of open space	Y/N	0/1	Y	Y	Y	Y
Bike area	Job density	Job/km2	Density/Max Density	2749.81	663.34	586.43	105.79
	Population density	People/km2	Density/Max Density	10052.27	3125.90	2589.49	623.93
Public transport area	Job density	Job/km2	Density/Max Density	4283.95	1274.71	829.55	-
	Population density	People/km2	Density/Max Density	12714.58	5655.88	6904.04	-
Car area	Job density	Job/km2	Density/Max Density	4304.314	3384.354	1765.226	772.076
	Population density	People/km2	Density/Max Density	12219.5	16112.15	8374.54	4047.98

Table 4-5 Place Indicators: stations None, Airasca, Piscina, Pinerolo Olimpica (elaborated by author)

isochrone areas	Indicator	Measure Unit	Score	5	6	7	8
Walk area	Job density	Job/km2	Density/Max Density	607.60	114.86	240.49	1095.77
	Population density	People/km2	Density/Max Density	3654.80	136.65	1590.72	3105.82
	Availability of open space	Yes/No	0/1	N	N	Y	Y
Bike area	Job density	Job/km2	Density/Max Density	254.98	182.657	53.537	433.26
	Population density	People/km2	Density/Max Density	623.37	247.740	218.609	1300.99
Public transport	Job density	Job/km2	Density/Max Density	-	-	-	1429.63

[26] PRG or *Piano Regolatore Generale* is an Italian urban planning tools that regulates the activities of the buildings within municipalities. Data retrieved online from https://geoportale.sportellounicodigitale.it/

area	Population density	People/km2	Density/Max Density	-	-	-	3369.21
Car area	Job density	Job/km2	Density/Max Density	83.64	71.15	58.32	160.46
	Population density	People/km2	Density/Max Density	254.56	212.36	162.83	598.68

Table 4-6 Place Indicators: stations Pinerolo F.S, Bricherasio, Bibiana, Luserna, and Torre Pellice (elaborated by author)

isochrone areas	Indicator	Measure Unit	Score	9	10	11	12	13
Walk area	Job density	Job/km2	Density/Max Density	3057.82	212.65	61.50	527.16	300.49
	Population density	People/km2	Density/Max Density	8112.75	986.58	416.64	1847.94	2059.54
	Availability of open space	Y/N	0/1	Y	N	N	Y	Y
Bike area	Job density	Job/km2	Density/Max Density	531.68	74.83	96.49	54.40	88.46
	Population density	People/km2	Density/Max Density	1907.55	227.84	398.78	507.39	513.69
Public transport area	Job density	Job/km2	Density/Max Density	920.14	300.12	105.72	333.99	363.94
	Population density	People/km2	Density/Max Density	6216.36	947.349	779.412	1665.78	1889.71
Car area	Job density	Job/km2	Density/Max Density	110.4	150.52	68.756	57.32	48.89
	Population density	People/km2	Density/Max Density	440.10	493.44	267.92	277.16	259.73

Table 4-7 shows the final score of each station for the place values. For each catchment area, the average values are calculated separately to later be multiplied by the feeder transportation counterparts (section 4.3.3). A quick glance at the results shows a huge difference between the density of Lingotto in all the catchment areas than the rest of the stations. Interestingly, both scores of densities in station Pinerolo F.S. are maximum considering walk catchment area but as the catchment area grows in other modes of the transport, the score significantly drop this is directly related to the location of the station within the city centre of the municipality. Similar issue happens in rest of the stations (with the exceptions of Airasca, Bricherasio and Bibiana) located in rural and mountainous area as most of the residents and activities are concentrated within the station walking catchment area. This resulted in very low scores for the densities in the category of bike, public transport, and car. Moreover, the result shows some irregularities as well. In the case of Moncalieri Sangone car catchment area, both density values are close to the biggest station (Lingotto) and even exceeded the score of Lingotto station in terms of population density, while it clearly belongs to the category of medium density station area. This happens because the car catchment area of this station overlaps with the boundaries of Turin and Nichelino municipality.

Table 4-7 Place Indices (elaborated by author)

Place Index	1	2	3	4	5	6	7	8	9	10	11	12	13
Walk - Job Density	0.58	0.36	0.32	0.11	0.20	0.04	0.08	0.36	1	0.07	0.02	0.17	0.10
Walk - Pop. Density	0.99	0.63	0.97	0.40	0.45	0.02	0.19	0.38	1	0.12	0.05	0.23	0.25
Walk - Open Space	1	1	1	1	0	0	1	1	0	0	0	1	1
Walk-Final Score	**0.86**	**0.66**	**0.76**	**0.50**	**0.21**	**0.02**	**0.42**	**0.58**	**0.67**	**0.06**	**0.02**	**0.47**	**0.45**
Bike- Job Density	1	0.24	0.21	0.04	0.09	0.07	0.02	0.16	0.19	0.03	0.04	0.02	0.03
Bike - Pop. Density	1	0.31	0.26	0.05	0.06	0.03	0.02	0.13	0.19	0.02	0.04	0.02	0.03
Bike-Final Score	**1**	**0.28**	**0.24**	**0.05**	**0.08**	**0.05**	**0.02**	**0.14**	**0.19**	**0.02**	**0.04**	**0.04**	**0.03**
PT - Job Density	1	0.30	0.19	0	0	0	0	0.33	0.21	0.07	0.02	0.08	0.08
PT- Pop. Density	1	0.44	0.54	0	0	0	0	0.26	0.49	0.07	0.06	0.13	0.08
PT-Final Score	**1**	**0.37**	**0.37**	**0**	**0**	**0**	**0**	**0.30**	**0.35**	**0.07**	**0.04**	**0.10**	**0.12**
Car - Job Density	1	0.79	0.41	0.18	0.02	0.02	0.01	0.04	0.03	0.03	0.06	0.13	0.01
Car - Pop. Density	0.76	1	0.52	0.25	0.02	0.01	0.01	0.03	0.04	0.03	0.02	0.01	0.02
Car-Final Score	**0.88**	**0.89**	**0.46**	**0.22**	**0.02**	**0.01**	**0.01**	**0.04**	**0.04**	**0.03**	**0.02**	**0.02**	**0.01**

4.3.3 Feeder Transport Indicators (TW, TB, TP, TC)

4.3.3.1 Walk Feeder Transport Indicators (TW)

This section illustrates the result of the calculation for the walk feeder transport (table 4-8, and 4-9). In the calculation of the length of sidewalks, both sides are considered and, in some cases, where there is a walkable path in the middle of a boulevard, it also has been taken into consideration. For the qualitative indicators, four options are added, value zero in the cases where there are no sidewalks, value 0.33 where sidewalks are partially available but with a very low quality, value 0.66 in the cases where sidewalks are partially available with good condition and finally value 1 for the cases where sidewalks are available in all the areas with a good quality. The indicator 'walk score' which is added based on the literature review is obtained through a website that assesses the walkability of any address using a patented system giving a score between 0 to 100[27]. For each address, Walk Score analyses hundreds of walking routes to nearby amenities. Points are awarded based on the distance to amenities in each category. Amenities within a 5-minute walk are given maximum points. A decay function is used to give points to more distant amenities, with no points given after a 30-minute walk[28]. So even though the obtained number is not based on the catchment area presented in section 4.2.3, since this score gives a general idea about pedestrian friendliness of the station area, the indicator is added to the final selection. Walk score collects data from Google, Factual, Open Street Map, Walk score community and in the case of location in USA from U.S. Census, Localeze.

Table 4-8 Walk Feeder Transport Indicators: stations Lingotto, Moncalieri, Nichelino, Candiolo, None, and Airasca (elaborated by author)

TW Indicators	Measure	1	2	3	4	5	6
Quality of sidewalks	0: Sidewalks are not present						0[29]
	0.33: Sidewalks are partially present with poor quality		0.33		0.33	0.33	
	0.66: Sidewalks are partially present with acceptable quality	0.66		0.66			
	1: Sidewalks are present in all roads with a high quality						
Length of the sidewalks	Meter	21618	12168	28800	8801	6346	623
Walk score	Calculating the walk score based on the https://www.walkscore.com/ website	90	74	78	67	63	11

[27] The website categorizes the places as follows: Score 90-100: walking paradise; Score 70-89 very walkable; Score 50-69 somewhat walkable; Score 25-49 car dependent; Score 24- 0 car dependent

[28] https://www.walkscore.com/methodology.shtml

[29] In the case of Airasca station, the length of the sidewalk the quality is considerably lower in comparison to other station so the value is zero is chosen,

Table 4-9 Walk Feeder transport Indicators: stations Piscina, Pinerolo Oimpica, Pinerolo F.S, Bricherasio, Bibiana, Luserna, and Torre Pellice(elaborated by author)

TW Indicators	Measure	7	8	9	10	11	12	13
Quality of sidewalks	0: Sidewalks are not present					0		
	0.33: Sidewalks are partially present with poor quality	0.33			0.33		0.33	0.33
	0.66: Sidewalks are partially present with acceptable quality		0.66	0.66				
	1: Sidewalks are present in all roads with a high quality							
Length of the sidewalks	Meter	4093	15488	27507	3726	1135	7323	5966
Walk score	Calculating the walk score based on the https://www.walkscore.com/ website	36	62	98	53	31	58	54

Table 4-10 shows the final score of each station in walk feeder transport criteria:

Table 4-10 Walk feeder transportation indices (elaborated by author)

TW Index	1	2	3	4	5	6	7	8	9	10	11	12	13
Quality of sidewalks	0.66	0.33	0.66	0.33	0.33	0	0.33	0.66	0.66	0.33	0	0.33	0.33
Length of the sidewalks	0.75	0.42	1	0.31	0.22	0.02	0.14	0.54	0.96	0.13	0.04	0.25	0.21
Walk score	0.92	0.76	0.80	0.68	0.64	0.11	0.37	0.63	1	0.54	0.32	0.59	0.55
Final Score	**0.78**	**0.5**	**0.82**	**0.44**	**0.40**	**0.04**	**0.28**	**0.61**	**0.87**	**0.33**	**0.12**	**0.39**	**0.36**

4.3.3.2 Bike Feeder Transport Indicators (TB)

This part addresses bike accessibility as a feeder transportation. The road data is obtained from OpenStreetMap (https://download.geofabrik.de/europe/italy.html). The reason for the choice of bike roads ratio instead of length is the general poor condition of the bike network in the analysis area as most of the bike lanes are not connected to each other. As the numbers show, the length of the bike lanes are not more than 15 percent of the total roads. Table 4-11 and 4-12 show the result of the calculations and table 4-13 illustrates the final score (index) for each criterion.

Table 4-11 Bike feeder transport indicators: stations Lingotto, Moncalieri, Nichelino, Candiolo, None, Airasca (elaborated by author)

TB Indicators	**Measure**	**1**	**2**	**3**	**4**	**5**	**6**
Bike network and road network ratio	Length of bike lanes/ length of all roads	0.12	0.10	0.05	0.06	0.05	0.04
Bike-share facility	Y/N	Y	N	N	N	N	N
Bike parking	Y/N	Y	N	N	N	N	Y

Table 4-12 Bike feeder transport indicators (stations Piscina, Pinerolo Olimpica, Pinerolo F.S, Bricherasio, Bibiana, Torre Pellice (elaborated by author)

TB Indicators	**Measure**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Bike network and road network ratio	Length of road network/ length of bike lanes	0	0.08	0.09	0.03	0	0	0
Bike-share facility	Y/N	N	N	N	0	0	0	0
Bike parking	Y/N	N	Y	Y	0	0	0	0

Table 4-13. Bike feeder transport indices:

Table 4-13 Bike feeder transport indices (elaborated by author)

TB Index	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Bike network and road network ratio	1	0.83	0.42	0.5	0.42	0.33	0	0.66	0.75	0.25	0	0	0
Bike-share facility	1	0	0	0	0	0	0	0	0	0	0	0	0
Bike parking	1	0	0	0	1	0	0	1	1	0	0	0	0
Final Score	**1**	**0.28**	**0.14**	**0.17**	**0.47**	**0.11**	**0**	**0.55**	**0.58**	**0.08**	**0**	**0**	**0**

4.3.3.3 Public Transport Feeder Transport Indicators (TP)

To calculate the public transport feeder transport indicator, the first step is to define the number of bus lines within the station area and their services[30]. Ideally, the feeder bus service stations should be located within the node area. However, except for the stations Lingotto and Pinerolo, none of

[30] All the data about timetable retrieved from https://www.gtt.to.it/ ; https://moovitapp.com/; https://www.google.com/maps; https://arriva.it/ . Different sources are used in order to control the accuracy of the data. In some stations the datas are not matched between different websites, especially between data in Google Maps and Company websites. In these cases, the most updated data is considered.

the analysed stations have an actual bus-train interchange service. So, the closest bus stop is taken into consideration, and to have a more realistic analysis, an additional indicator as ‘Bus Stop Accessibility” is considered to evaluate the distance between train station and bus stop (Nigro, 2017). In the cases where there is more than one line in the area, the maximum value of frequency is considered. Table 4-14 shows the final indicators.

Table 4-14 Public transport (bus) feeder transport indicators(elaborated by author)

TP Indicator	Description	Measure	Score
Feeder transport availability	Presence of at least one line	Y/N	If the answer is no, all indicators are equal to zero
Feeder lines	Number of lines	n	n/ max value
Bus stop accessibility	Distance between train station and bus stop	meter	1- (n/max value)
Frequency (workdays)	Number of Departure per working days	n	n/ Max value
Degree of Fare Integration	The possibility to use the same ticket for train and bus	Y/N	0/1
Quality of services	Availability of waiting room, bar or kiosk in the bus stop	Y/N	0/1

Table 4-15 shows the bus lines for each station. From the table a huge gap between the number of the services can be observed. Table 4-16 shows the calculation result of the public transportation feeder transport and table 4-17 shows the score for each of the indices.

Table 4-15 Bus services connected to the analyzed stations (elaborated by author)

Station	Line N.	Transportation Service	Frequency workday	Frequency holiday	Span workday hh:mm	Span holiday hh:mm	Fare integration	Quality of service
	14	GTT Urban service[32]	75	32	19:00	17:00	Y[33]	Y
	63	GTT Urban service	76	29	19:00	17:00	Y	Y
	63/	GTT Urban service	136	49	20:00	18:00	Y	Y
	41	GTT Urban service	65	32	18:30	17:00	Y	Y

[32] GTT Servizio Urbano

[33] Data retrieved from: https://www.gtt.to.it/cms/biglietti-abbonamenti/775-biglietti-integrati#rivendite. With the GTT integrated ticket it is possible to travel with SFMlines (only once), or metro (only once) and use public transport within the Turin urban area. Information is available on the website.

Lingotto[31]	74[34]	GTT Urban service	-	-	-	-	-	-
	95	GTT Urban service	5	-	13:00	-	N	Y
	3902	GTT Urban service	2	-	5:00	-	N	Y
Moncalieri	39	GTT Urban service	52	12	16:00	13:00	Y	N
	82	GTT Urban service	14	-	10:30	-	Y	N
	84	GTT Urban service	21	-	15:30	-	Y	N
Nichelino	35N	GTT Urban service	60	26	17:00	14:15	Y	N
	267	Arriva Italia[35][36]	24	6	17:20	13:20	N	N
Pinerolo Olimpica	214	Cavourese S.p.a.	1	-	-	-	N	N
	708	Cavourese S.p.a.	1	-	-	-	N	N
	278	Arriva Italia	1	1	-	-	N	N
	281	Arriva Italia	1	-	-	-	N	N
	283	Arriva Italia	1	-	-	-	N	N
	298	Cavourese S.p.a.	5	-	7:00	-	N	N
	386	Cavourese S.p.a.	7	-	8:00	-	N	N
Pinerolo F. S	214	Arriva Italia	1	-	-	-	N	Y
	220	Cavourese S.p.a.	25	2	16:00	11:20	N	Y
	275[37]	Arriva Italia	11	11	21:00	21:00	N	Y
	278	Arriva Italia.	11	-	14:00	-	N	Y
	279 (901)	Arriva Italia	28	3	15:00	10:00	N	Y
	280	Arriva Italia	7	-	18:00	-	N	Y
	281[38]	Arriva Italia	9	-	10:20	-	N	Y

[31] Line 901 is also present in the timetables but it is omitted from the analysis since it is a substitution for trainline from Porta Nuova to Pinerolo

[34] This line operates only Wednesday and Thursday so it is omitted from the calculation (https://moovitapp.com/index/en/public_transit-line-74-Torino-222-2226-517082-1)

[35] Ex-SADEM TURIN. From January 2021 Arriva Italia has incorporated SAVDA Aosta, SADEM Turin, SAB Bergamo, SIA Brescia and KM Cremona, thus becoming the public transport operator instead of local companies (https://torino.arriva.it/en/arriva-torino/) .

[36] Data about timetables of the buses own by private and semi-private companies are retrieved from https://torino.arriva.it/

[37] Also line 282

[38] Line 281 covers four different routes, so the frequency is the sum of all the departures.

	283	Arriva Italia	28	3	13:30		N	Y
	296	Cavourese S.p.a.	2	-	7:00	-	N	Y
	298	Cavourese S.p.a.	15	3	11:00	7:00	N	Y
	386	Cavourese S.p.a.	5	-	6:00	-	N	Y
	703	Arriva Italia	11	6	10:45	9:00	N	Y
	705	Cavourese S.p.a.	19	4	11:00	6:00	N	Y
Bricherasio	296	Cavourese S.p.a.	1	-	-	-	N	N
	298	Cavourese S.p.a.	19	-	11:00	-	N	N
	279 (901)	Arriva Italia	40	4	16:40	12:00	N	N
Bibiana	279[39] (901)	Arriva Italia	40	4	16:40	12:00	N	N
Luserna	279 (901)	Arriva Italia	40	3	16:40	12:00	N	N
Torre Pellice	279[40] (901)	Arriva Italia	65	7	16:40	12:00	N	N

Table 4-16 Public transport (bus) feeder transport indicators (elaborated by author)

TP Indicators	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Feeder transport availability	Y	Y	Y	N	N	N	N	Y	Y	N	N	Y	Y
Feeder lines	7	3	2	-	-	-	-	7	13	3	1	1	1
Bus stop accessibility	0	350	76	-	-	-	-	400	0	500	210	350	43
Frequency (workdays)	136	52	60	-	-	-	-	7	28	40	40	40	65
Frequency (holidays)	49	12	24	-	-	-	-	-	3	4	4	4	7
Degree of Fare Integration	Y	Y	Y	-	-	-	-	N	N	N	N	N	N

[39] Lines 279 and 901 have the same direction but the timetables are different

[40] In the case of Torre Pellice, Line 279 has two service routes the first one comes from Pinerolo and ends the service in Torre Pellice and the second one continues from Torre Pellice to Bobbio Pellice

Quality of services	Y	N	N	-	-	-	-	N	Y	N	N	N	N

Table 4-17 Public transport feeder transport indices

TP Index	1	2	3	4	5	6	7	8	9	10	11	12	13
Feeder transport availability	Y	Y	Y	N	N	N	N	Y	Y	N	N	Y	Y
Feeder lines	0.54	0.23	0.15	0	0	0	0	0.54	1	0.23	0.08	0.08	0.08
Bus stop accessibility	1	0.3	0.85	0	0	0	0	0.2	1	0	0.58	0.3	0.9
Frequency (workdays)	1	0.38	0.44	0	0	0	0	0.05	0.21	0.29	0.29	0.29	0.47
Frequency (holidays)	1	0.24	0.49	0	0	0	0	0.06	0.08	0.08	0.08	0.08	0.14
Degree of Fare Integration	1	1	1	0	0	0	0	0	0	0	0	0	0
Quality of services	1	0	0	0	0	0	0	0	0	0	0	0	0
Final Score	**0.92**	**0.36**	**0.49**	**0**	**0**	**0**	**0**	**0.13**	**0.38**	**0.10**	**0.17**	**0.13**	**0.27**

4.3.3.4 Car-Based Feeder Transport Indicators (TC)

This paragraph shows the calculation of cars as feeder transport. Like the bus stations for public transportation feeder transport indicators, in the cases which car parking is not available within the station area, the closest parking is considered. Again, compensate for it, the accessibility of the parking space is added to the set of indicators. The value of accessibility of parking area is measured by the distance of the station from the parking. First, the distance is calculated (table 4-18). To normalize the value, it is divided by the greatest distance calculated (in this case Moncalieri station has the greatest distance to the closes parking area). The obtain value is a number between 0 to 1 which is subtracted from 1 and the obtain number is inserted as the accessibility index. Data about the parking are retrieved from OpenStreetMap (https://download.geofabrik.de/europe/italy.html). Table 4-18 and 4-19 shows the result of the calculations and table 4-20 shows the final score (index) for each indicator.

Table 4-18 Car feeder transport indicators: stations Lingotto, Moncalieri, Nichelino, Candiolo, None, Airasca (elaborated by author)

TC Indicators	Measure		1	2	3	4	5	6
Car-Based Facility	Drop off/ Pick up	Y/N	Y	N	N	N	N	N
	Taxi area	Y/N	Y	N	N	N	N	N
Area of parking[41]	Sq. meter		8700	7600	1600	1084	950	100
Parking accessibility	1- (n/MAX n)		0	500	200	250	350	0

Table 4-19 Car feeder transport indicators (stations Piscina, Pinerolo Olimpica, Pinerolo F.S, Bricherasion, Bibiana, Luserna, and Torre Pellice (elaborated by author)

TC Indicators	Measure		7	8	9	10	11	12	13
Car-Based Facility	Kiss and ride	Y/N	N	N	Y	N	N	N	N
	Taxi area	Y/N	N	N	N	N	N	N	N
Area of parking	Sq. meter		600	13160	3800	100	0[42]	4100	1700
Parking accessibility	1- (n/MAX n)		0	0	0	0	0	0	0

Table 4-20 Car feeder transport indices (elaborated by author)

TC Index	1	2	3	4	5	6	7	8	9	10	11	12	13
Car-Based Facility	1	0	0	0	0	0	0	0.5	0.5	0	0	0	0
Area of parking	0.66	0.57	0.12	0.08	0.07	0.007	0.04	1	0.28	0.007	0	0.31	0.13
Parking accessibility	1	0	0.6	0.5	0.3	1	1	1	1	1	1	1	1
Score	**0.89**	**0.19**	**0.24**	**0.19**	**0.12**	**0.34**	**0.35**	**0.83**	**0.59**	**0.33**	**0.33**	**0.44**	**0.38**

---

[41] Free parking is considered only

[42] Only paid parking are available in the Bibiana station area

4.4 Results

This part shows the result of applying the calculation in section 4.1 to the Node-Place model. The part consists of three sections, 'General Node-Place' analysis, fourfold 'Detailed Node-Place' analysis, and radar diagrams.

4.4.1 Application of General Node-Place Model

As explained in section 3.3.4, the general Node-Place model is a *xy* diagram that visualizes the average value of Node indices on y axis and Place indices on the horizontal axis. Place index is the average of Place average values (PW, PB, PP, PC) multiplied by their counterparts as feeder transport indices (TW, TB, TP, TC). Table 4-21 and 4-22 shows the general node-place model values.

Table 4-21 Values of node and place indices: stations Lingotto, Moncalieri, Nichelino, Candiolo, None, Airasca, and Piscina (elaborated by author)

	Lingotto	Moncalieri	Nichelino	Candiolo	None	Airasca	Piscina
Node Index	0.69	0.12	0.24	0.24	0.24	0.24	0.24
Place Index	0.84	0.18	0.24	0.070	0.032	0.003	0.03

Table 4-22 Values of node and place indices: stations Pinerolo Olimpica, Pinerolo F.S, Bricherasio, Luserna, and Torre Pellice (elaborated by author)

	Pinerolo Olimpica	Pinerolo	Bricherasio	Bibiana	Luserna	Torre Pellice
Node Index	0.05	0.39	0.12	0.12	0.18	0.20
Place Index	0.13	0.29	0.01	0.003	0.051	0.020

Figure 4-14 shows the application of the values in the Node Place model. First glance at the diagram shows that most of the stations are placed in the 'Dependence' zone, indicating the low levels of both accessibility and intensity of activities (land use) within the catchment areas. At the same time stations Lingotto, Nichelino, and Pinerolo F.S are closer to the diagonal line as they have equal node and place values.

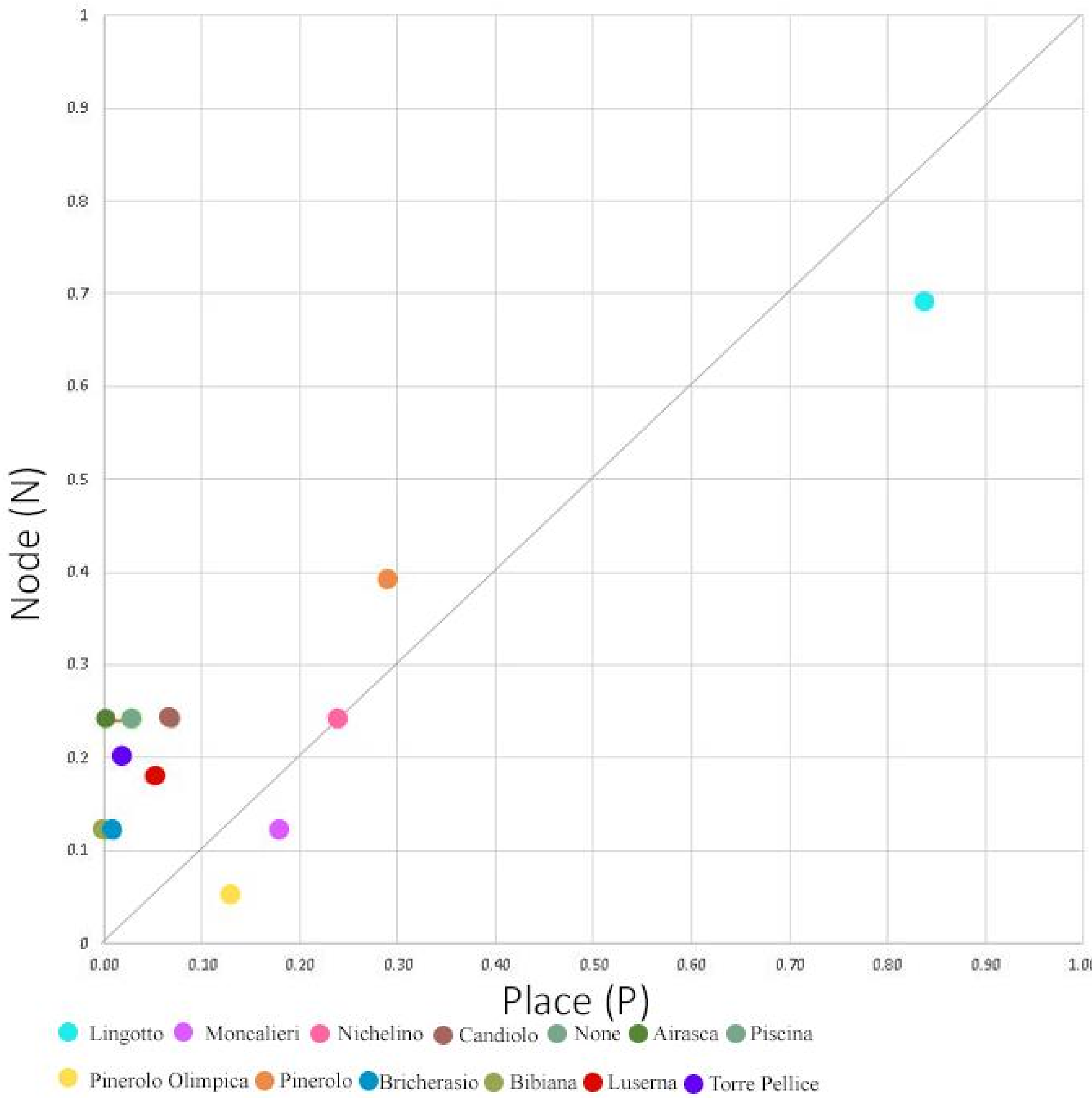

Figure 4-14 General Node-Place model (elaborated by author)

Among all stations, Lingotto has the highest values in both node and place indices, which indicates the huge differences in the node place model results between a station located in a high-density context and others that located in low or medium urban areas. Moreover, Lingotto node benefits from a high connectivity with the surrounding areas and the fact that it scores more in place values seems to be related to the deficiency of additional node indices such as unavailability of night train and hygiene measurements. Following Lingotto station, Pinerolo F.S station has the second highest node and place values, and seems to have higher potential for TOD implementation, probably because the station area has a generally good quality of a node (two bars within the station area, acceptable numbers of entrance) and benefits from place indicators, such as bike parking, good connection to bus lines and higher intensity of the land use around the station compared to other stations. Nichelino station has an acceptable score, locating exactly on the diagonal line showing a balance between accessibility and the land use within the area. The stations Candiolo, None-Piscina[43], Airasca, and then Bricherasio, Bibiana, Luserna and Torre Pellice have similar values due to the homogeneous transit service (SFM2 Chivasso-Pinerolo) along this line and similar density of urban areas. The stations Pinerolo Olimpica scores the least on node values because of the poor condition of the station node. The unavailability of ticketing service and an actual building structure as a station seems to be the reasons for such low place score. Finally, Bibiana, Airasca, and Piscina stations score the lowest on the place value because of the poor connectivity to the urban area. General evaluation of the first analysis shows that the stations Lingotto, Nichelino, Pinerolo F.S and to a lesser extent Moncalieri, have more potentials to perform as TOD. While remaining station needs significant enhancement in terms of urban density or the accessibility of other transportation modes. However, a deeper analysis is needed to understand the position of each station.

4.4.2 Detailed Node-Place Analysis

Tables 4-23 and 4-24 shows the values for the detailed node place analysis. Some values are extremely small, e Figure 4.16 shows the fourfold detailed node-place analysis.

Table 4-23 Values of detailed node place indices: stations Lingotto, Moncalieri, Nichelino, Candiolo, Airasca and Piscina (elaborated by author)

Index	Lingotto	Moncalieri	Nichelino	Candiolo	None	Airasca	Piscina
Node	0.69	0.12	0.24	0.24	0.24	0.24	0.24
Place (walk)	0.67	0.33	0.62	0.22	0.08	0.0008	0.12
Place (bike)	1	0.08	0.03	0.008	0.03	0.005	0
Place (PT)	0.92	0.13	0.18	0	0	0	0
Place (car)	0.78	0.17	0.11	0.04	0.002	0.007	0.003

[43] None and Piscina stations scores exact same amount on the general node-place model

Table 4-24 Values of detailed node place indices: stations, Pinerolo Olimpica, Pinerolo F.S, Bricherasio, Bibiana, Luserna, and Torre Pellice (elaborated by author)

	Pinerolo Olimpica	Pinerolo	Bricherasio	Bibiana	Luserna	Torre Pellice
Node Index	0.05	0.39	0.12	0.12	0.18	0.20
Place (walk)	0.13	0.29	0.01	0.003	0.051	0.162
Place (bike)	0.08	0.11	0.002	0	0	0
Place (PT)	0.04	0.13	0.007	0.003	0.01	0.03
Place (car)	0.03	0.02	0.01	0.007	0.009	0.004

First observation of figure 4-15 shows noticeable difference in the positions of some stations in different catchment areas, generally the stations have better place value considering walk catchment areas which means either the density of land-use or the accessibility of pedestrian has a better score in the stations. The most obvious one is Pinerolo F.S station that shifts dramatically from an 'unbalanced place' in the model for the walk catchment area, to an 'unbalanced node' when considering car catchment area which makes sense because the density of land use within the walkable area of the station (centre of Pinerolo municipality) is considerably higher than further areas that are reachable only by car with respect to the travel time threshold. Nichelino station has the same situation as Pinerolo F.S albeit to a lower extent, in this case, the place value for the bike catchment area is considerably lower than the rest of catchment areas[44], that is a result of poor connection between station node and bike network. In fact, except for Lingotto all the stations score lowest in the case of bike catchment area, this analysis confirms the poor quality of the bike network in the region. Here, the Lingotto station is an exception because the area benefits from relatively good connection between the node bike networks. That said, it is important to note that even though the Lingotto place value for bike catchment area is equal to one (maximum value) due to the normalizing method adopted by the methodology, in reality, the ratio of the bike network to all the roads is relatively low (12% of the roads). This can be considered as a shortcoming of this analysis especially when there is a huge gap between the stations in terms of urban density surrounding area or the quality of feeder transport services. Another interesting observation about

Lingotto station is that it scores the maximum in all the place values except for the walk feeder transport catchment area. This is probably related to the land use pattern around the station that affects the density. Presence of *Grattacielo della Regione Piemonte* on the east side of the station and the huge construction site around it seems to be the reason for the score. In all the models, a homogeneity can be observed between the results of two groups of stations first, Candiolo, None, Airasca, Piscina and, then between the stations Bricherasio, Bibiana, Luserna and Torre Pellice. As said in the previous part, these lines are characterized by the similar railway services and at the same time, the quality of feeder transport services, for instance the very same bus line (901) passes from Pinerolo to Torre Pellice with the almost same number of stops in the analysed municipalities. Moreover, the density of the catchment areas in these stations are somehow similar (except for Luserna in the walk catchment area). Another issue is about the same group of stations that score zero in place values of public transport and bike catchment areas. Generally, the analysis shows a very poor connection between the bus network and railway services in all the stations located in the medium and low-density urban areas. However, in the case of stations Candiolo, None, Airasca, Piscina, there is no bus line that connects the station to the bus network. In the case of Bricherasio, Bibiana, Luserna and Torre Pellice stations, the only present line is simply the substitution for the railway service. This lack of service obviously encourages residents to use private vehicles, and while the bike network and facilities are also poor, using a private car seems to be the most preferred option for the residents of these areas. Moreover, Luserna place value in the walking catchment area, this is probably related to the position of the station being adjacent to the city centre, which is the most urbanized area of the Luserna town with good accessibility within the catchment area however, in the other catchment areas that obviously cover greater area, the value is low.

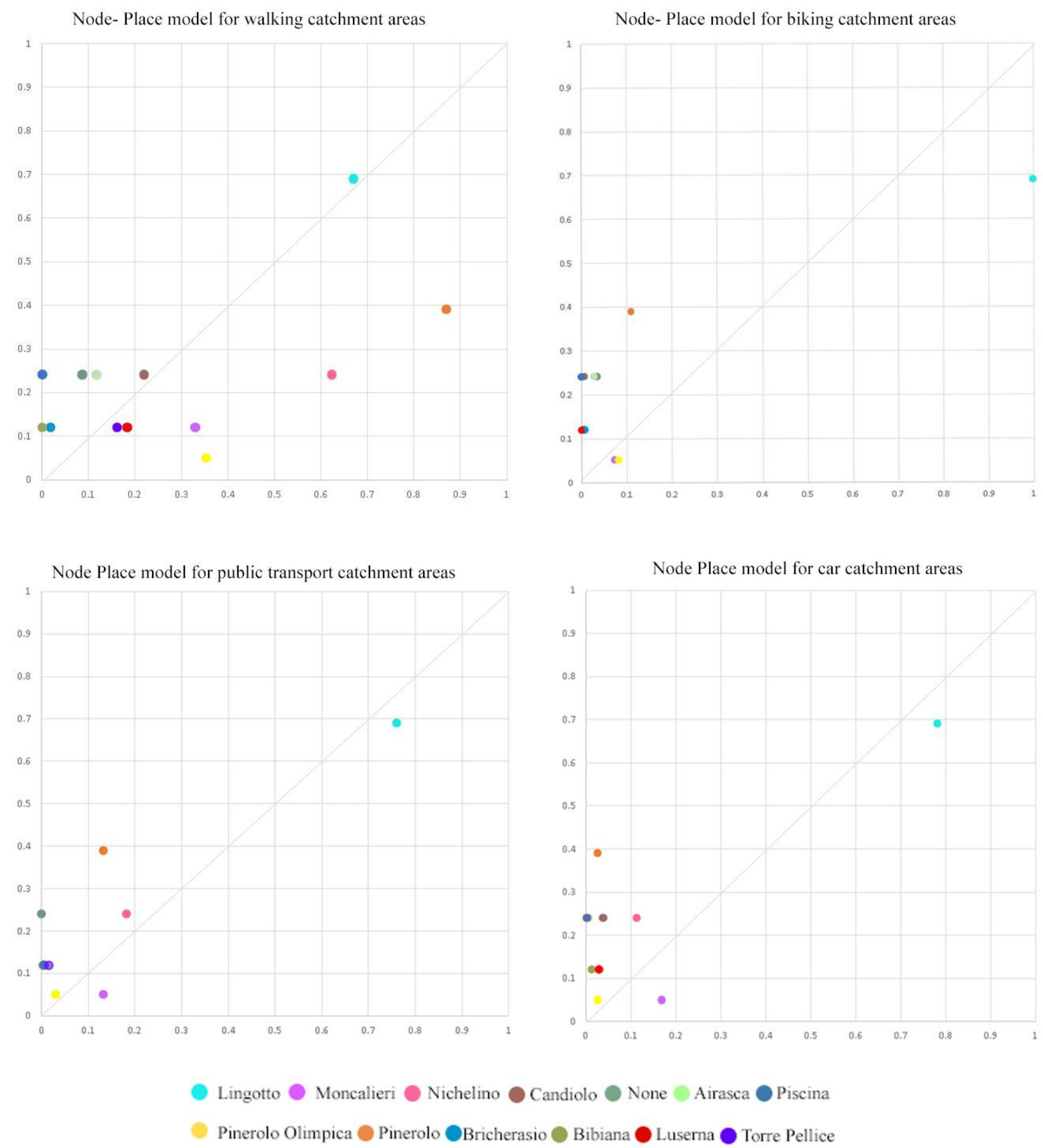

Figure 4-15 Detailed Node-Place model (elaborated by author)

4.4.3 Radar Diagram

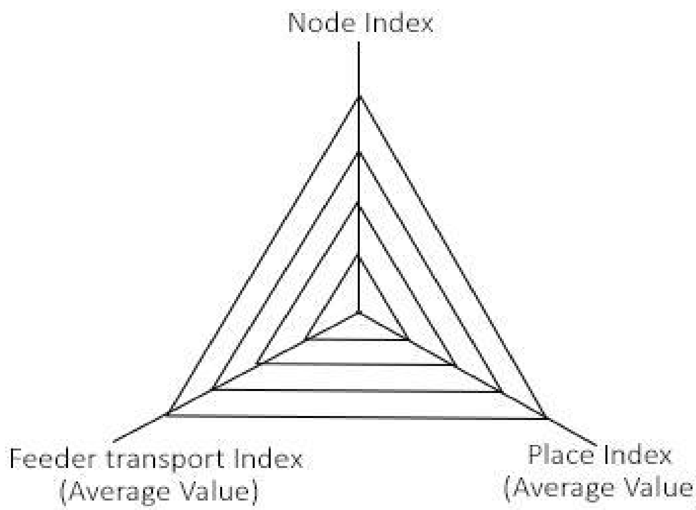

Figure 4-16 Detailed Radar Diagram (elaborated by author based on Nigro et. al, 2019)

Third part of the results section shows the average value of Node, Place and Feeder transport indices on a radar diagram for a deeper understanding of the reasons behind each unbalanced station. Figure 4-16 shows the general structure of the radar diagram. For each station, four radar diagrams are presented.

4.4.3.1 Lingotto Station

Figure 4-17 Detailed Radar Diagram- Lingotto Station (elaborated by author)

Figure 4-17 shows generally good place and feeder transportation values in all the catchment areas. However, a tendency towards place value in the walk and public transport catchment areas can be observed. This means first, the urban density should not be increased within these catchment areas, and secondly, actions towards enhancement of accessibility of feeder transportation can boost the performance of the station as a TOD node. Another issue is about the railway services (node index value) that scores less than two other indices, so based on the model, there is potential to increase main transport mode (train accessibility) through introducing more lines or introducing night trains for long distance trips to manage the daily traffics. However, any suggestion on the increasing of the transport services should be accompanied by a careful attention to governance processes, especially at regional where in the case of transportation planning, has the highest competence through "Regional Mobility and Transport Plan" (*Piano Regionale della Mobilità e dei Transporti* or PRMT). Another set of suggestions can be related to the amenities within the station areas, such as enhancement of hygiene measurements, as at the moment are absent.

4.4.3.2 Moncalieri Station

Figure 4-18 Detailed Radar Diagram- Moncalieri Station (elaborated by author)

As figure 4-18 illustrates, Moncalieri station scores very low in the node value compared to place and feeder transport indices, indicating the poor accessibility level of the railway station with respect to the density of land use and the accessibility of feeder transports. This probably related to the fact that this station is placed on the secondary rail line of Moncalieri municipal boundaries. Main Moncalieri station is located only one kilometre away. It is bigger, and has more lines and frequency, whereas in Moncalieri (Sangone) station, only line 2 passes. Another reason for this low score is the unavailability of ticketing desk/machine despite the availability of such service even in the stations with lowest urban density, such as Airasca and Piscina. Currently, the station building is also out of service, and passengers are directed to the platform through the back garden. So, the first and foremost solution to improve this station could be rethinking the quality of the station node. Another point is about place and feeder transport values. The station performs moderately in the case of walk feeder transport and place value but does not have a good quality in the case of bike, public transport, and car feeder transportation. So, the enhancement of the accessibility for bikes, bus networks and cars are suggested. However, if we compare these three figures, a balance can be observed in the case of bike and public transport and feeder transport, indicating that the quality of feeder transport services is aligned with the density of the areas and of course, the character of this station as a secondary transit node. So, the improvement in accessibility, should be accompanied by enhancing the density of each catchment areas. In addition, for the car feeder transport, the value is considerably lower than urban density within the relative catchment area. As figure 4-19 shows, this station does not have an adequate parking area around it despite being in an intermediately dense area that affects the score in the car feeder transport index[45]. All in all, it seems that an intensification in the railway accessibility should be the top priority in the case of Moncalieri station. This, followed by a moderate enhancement in land-use intensity and the quality of feeder transport services, can improve the position of Moncalieri station as a TOD.

[45] The closest free parking area is located 500 meters away from the station but the distance between station and the parking affects the accessibility of the facility.

Figure 4-19 Unavailability of parking space in Moncalieri Station (taken by author)

4.4.3.3 Nichelino Station

Figure 4-20 Detailed Radar Diagram- Nichelino Station (elaborated by author)

Figure 4-20 shows a variety of results in the case of Nichelino station. First glance shows a relatively low performance regarding network accessibility (node value) in all the figures. So, similar to the Moncalieri case, the station can benefit from enhancement of railway services that matches the urban density in case of walk catchment area, probably by introducing more lines[46] on increasing the frequency of the service (for instance, two trains per hour instead of one) and also enhancing the physical situation of the station. Moreover, while the values of place and feeder transport on the radar diagram related to walk catchment areas are very high, the station scores low and medium in the place indicators regarding the bike and public transport catchment areas, meaning that hosting more residents and employees within these catchment areas can improve the TOD-ness of this station of Nichelino municipality, as some of the developments have been already recognized by the municipal regulatory plan (*Piano regolatore generale comunale* or PRGc[47]). Considering bike catchment area, the value of bike feeder transport is extremely low compared to two other values that highlights the necessity of improvement in bike accessibility maybe through introducing more lanes. Looking at the score of place value in bike catchment area, further developments can be suggested as well. Interestingly, in the case of public transport, the accessibility of bus exceeds the value of the density so the development in this catchment area can boost the situation. Regarding the car catchment area, the feeder transport value is almost half of the place value, which is probably the result of unavailability of car-facilities in the station area despite medium density of population and employment. In general, improvement in all the three aspects seems to be necessary for the Nichelino station with the priority of railway services and bike accessibility.

---

[46] As discussed in section 4.4.3.1, any suggestion should consider the vertical hierarchy of transportation and land use planning.

[47] To see the regulatory plan of Nichelino municipality online, visit https://geoportale.sportellounicodigitale.it/GisMaster/Default.aspx?IdCliente=001164&IdSer=1

4.4.3.4 Candiolo, None, Airasca, Piscina Stations

Due to the high similarity between these stations, the analysis is done altogether.

Figure 4-21 Detailed Radar Diagram- Candiolo, None, Airasca and Piscina Stations (elaborated by author)

As figure 4-21 shows, all these stations share the same node value due to the homogeneous railway service, for all the stations, the value is equal to 0.24 which is relatively low, meaning the accessibility of main transport in all the cases is low. So, an enhancement in the frequency of the line is suggested for better node performance. Moreover, from the figure it is obvious that the value of public transport feeder transportation for all the stations is equal to zero. This issue has been discussed in section 4.2.2 in detailed node-place models, but it seems to be the most critical challenge in the accessibility of rural stations on the railway line. Considering the bike feeder transport, all the stations score low. No station seems to have a better score due to the availability of bike parking facilities in the station area. On the other hand, the worst case happens in Piscina station where not even a single bike lane is identified. Candiolo and Piscina stations score very close, but generally, all the stations can benefit from enhancement of bike accessibility. The greatest variety can be observed in the case of walk catchment area place values, these differences stem from the position of the station within the urban area. For instance, Candiolo and No stations are placed on the edge of their municipalities, whereas the Airasca station is rather far from urban core, and closer to the motorway resulting in the lower place score in walking catchment compared to Candiolo and None. In the case of Piscina, the place value is medium in walking catchment area since both residential and industrial activities are present in the buffer. It is important to note that although further development seem to be relevant in all the stations, they would require re-thinking the quality of feeder transports, especially in terms of bus and bike modes. Another noticeable issue about further urban development is related to the land coverage of each catchment area, especially when considering the low place value (low land use density) in bike and car catchment areas. All these catchment areas exceed the municipal boundaries. So, the analysis cannot be limited to the municipality where the station is located and a deeper investigation regarding the neighbouring municipalities is necessary before giving any suggestions about the land developments.

4.4.3.5 . Pinerolo Olimpica and Pinerolo Station

These two stations are also analysed together because they are both located within the same municipality. Figure 4-22 and Figure 4-23 show the radar diagrams for Pinerolo Olimpica and Pinerolo stations respectively. Considering Pinerolo Olimpica station, the first observation shows a very low score in node values. While the railway service is the same as other stations, this low score is the result of the lack of the services within the node, as discussed in section 4.2.2, this station lacks a physical building and ticket machine. In addition, feeder transport value is medium-high for pedestrians, bike riders and car drivers, indicating a general good accessibility. The score of feeder transport value is extremely high in the case of car- based transport that is the result of huge parking capacity within the station areas followed by a medium quality accessibility of bike and pedestrians. On the other hand, the station is not well connected with the bus network as the low score of PT feeder transport illustrates. So, only an enhancement to the bus accessibility can be suggested. Finally, the place values are generally low compared to the accessibility. Urban development can be encouraged as it is already considered in the municipal physical development plan. It is important to note that if we look at the Pinerolo Olimpica station alone, it does not seem to be qualified for TOD implementation without major enhancement in urban developments and feeder transportation accessibility. However, if we consider this station as a complimentary to Pinerolo main train station, the interpretation can be different.

Figure 4-22 Detailed Radar Diagram-Pinerolo Olimpica station (elaborated by author)

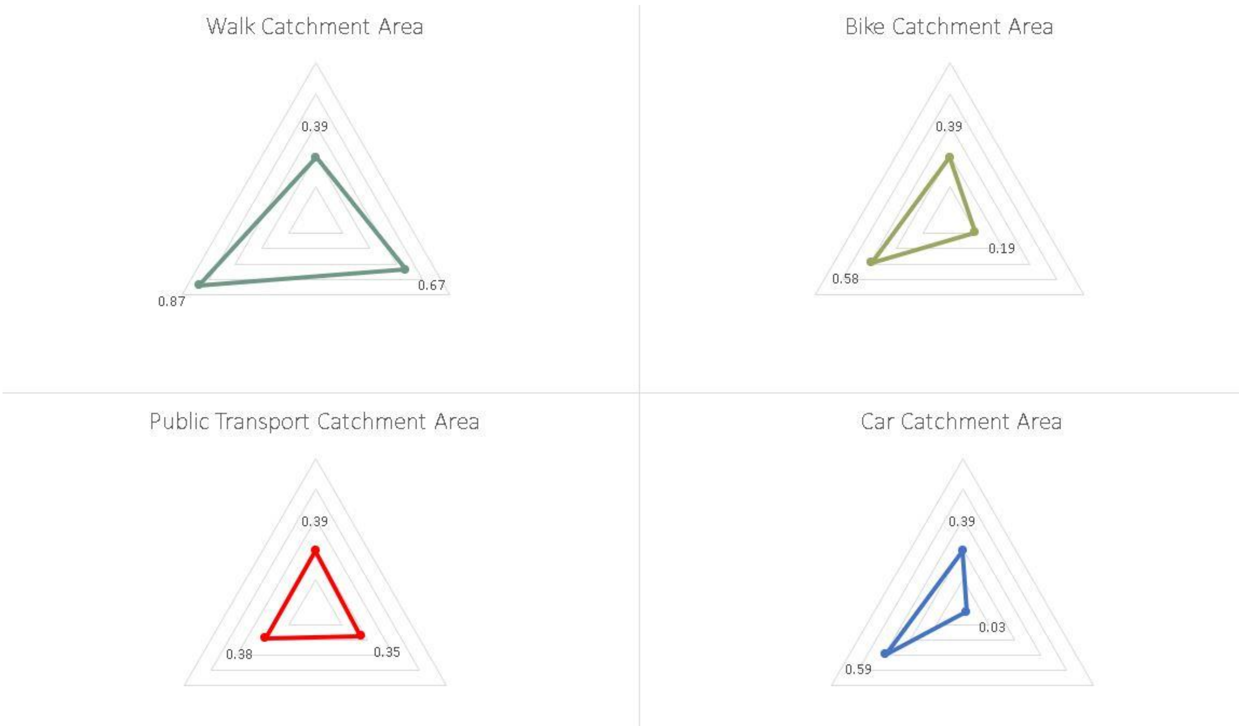

Figure 4-23 Detailed Radar Diagram-Pinerolo F.S. Station (elaborated by author)

Pinerolo Olimpica station has been built in 2006 for the winter Olympic games, and later introduced to the SFM2 since 2012[48]. With this in mind, the low score in the node value can be compensated with a medium to high score in the feeder transport value. The station shows a good potential for urban development within the bike and car catchment area. The huge capacity of the parking area (both for cars and bikes) within the station area can attract drivers and cyclists from Pinerolo and neighbouring municipalities. On the other hand, Pinerolo main station can be enhanced in terms of railway services with more frequency. The station has a very good walk accessibility and relatively good connection to the land-use in the walk catchment area. Moreover, the quality of the bike network is high thanks to the projects such as *La bicipolitana a Pinerolo* and presence of bike facilities within the station and the catchment area. New urban developments within the bike catchment area can enhance the position of the station as a cyclist attractor. Public transport accessibility is moderate but can be enhanced in terms of both accessibility and land development. Finally, Pinerolo station has good quality of car-based services as well, considering the low place value in both stations, the enhancement in urban development of one of the stations would affect the score of the other one as well, since the catchment areas cover almost the same territory.

4.4.3.6 Bricherasio, Bibiana, Luserna and Torre Pellice Stations

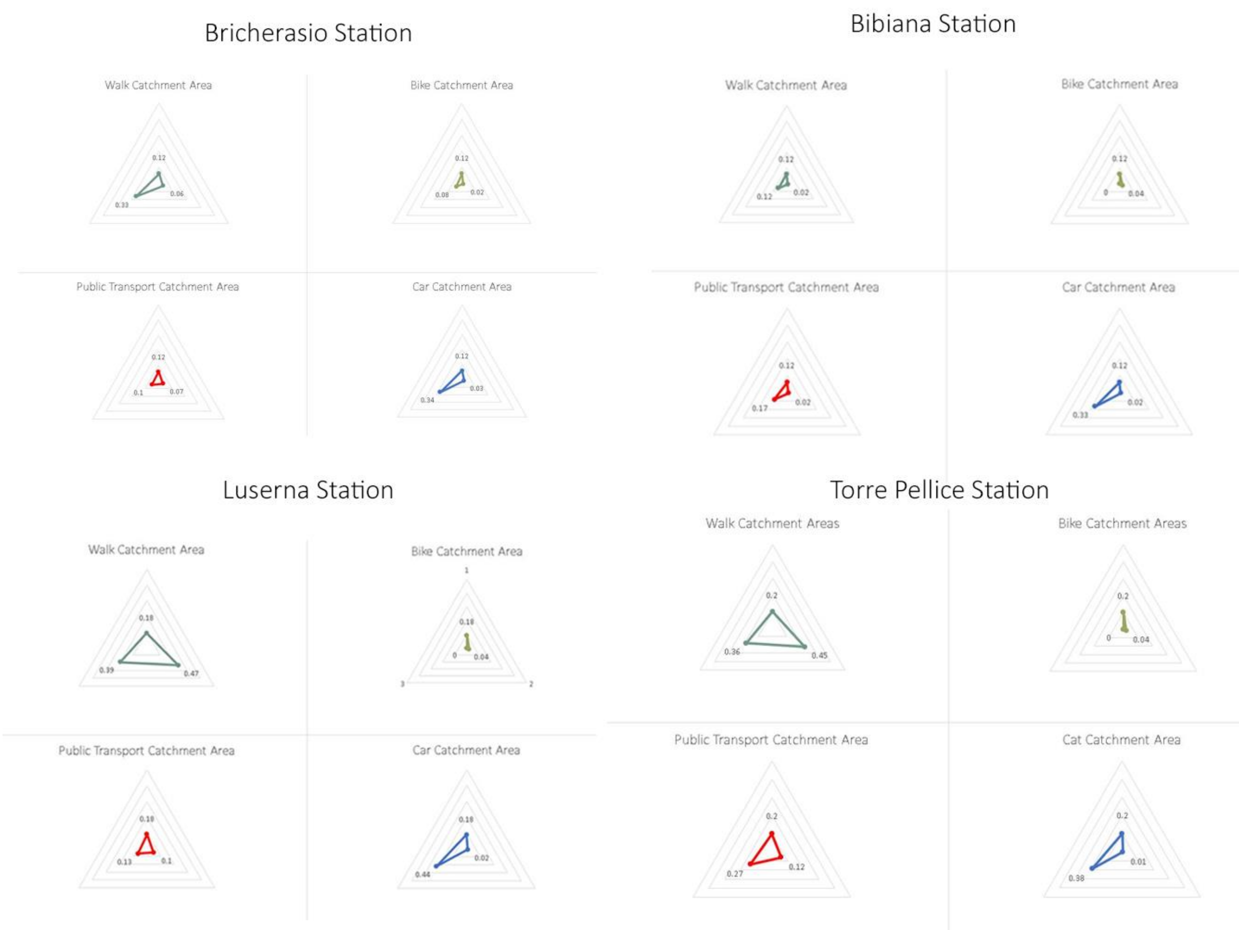

Figure 4-24 Detailed Radar Diagram-Bricherasio, Bibiana, Luserna, and Torre Pellice Stations (elaborated by author)

Figure 4-24 Shows the low accessibility in main transportation (node value) for all the stations, so here an enhancement of the services is also advisable. Besides that, the stations also share low feeder transportation scores in the case of bike and public transportation, indicating low accessibility of the stations for these two modes. Considering walk feeder transportation, exception can be observed in the case of Luserna and Torre Pellice stations that have moderate pedestrian accessibility due to the position of the station in the most urbanized part of the municipalities while the stations Bricherasio and Bibiana which are located further from urbanized areas, are less accessible through walking. Moving to place value (land use density). Luserna and Torre Pellice have an acceptable density in walk catchment area, while Bricherasio and Bibiana would require densification in walking catchment areas. For all the stations, a great potential can be observed in terms of land development in bike, public transport, and cat buffers. However, similar to the case of the rural stations, attention must be paid to the neighbouring municipalities in the case of bike and car catchment areas as they exceed the municipal boundaries, besides these stations are located in the mountainous part of the region. So extra attention must be paid to the development constraints related to the topography. Having said that, any increase in land-use must be followed by a great enhancement of railway and other transportation mode accessibilities.

4.5 Stations before and after COVID-19: A Comparison

4.5.1 4.5.1. General Node-Place Model

In section 3.2.2.2. and 3.2.2.3, four indicators were added based on the review of the literature related to public transportation after COVID-19 pandemic (see section 2.4) the additional indicators are as follows (table 4-25):

Table 4-25 Additional indicators related to the COVID-19 pandemic (elaborated by author)

	Additional Node Indicators
N1	*Availability of hygiene measurements at the transit stop*
N2	*Number of entrances and exits*
N3	*Availability of night train*
	Additional Place Indicators
P1	*Availability of open space within the walk catchment areas*

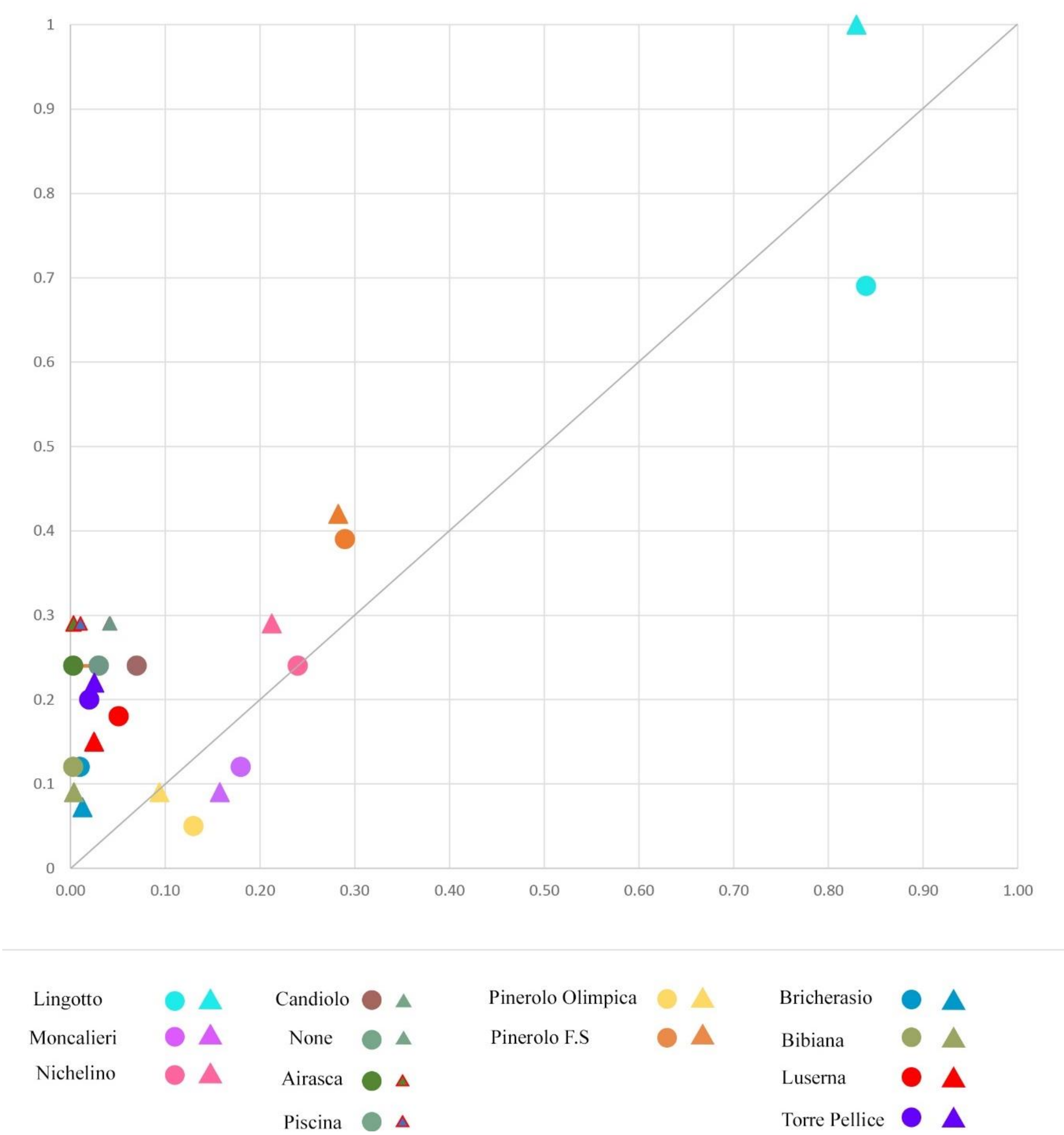

Figure 4-25 Differences between the scores on general node place model (elaborated by author)

First glance at the diagram (4-25) shows that the node value in the stations Lingotto, Nichelino, Candiolo, None, Airasca, Piscina, Pinerolo Olimpica and Pinerolo Torre Pellice increases, which makes sense because in two of the additional indicators (availability of hygiene and night train) all of them score zero and for the remaining indicator, only Pinerolo F.S score 1, while the rest score similar 0.5 value. It can be interpreted that the lack of these measurements in the stations, has weakened the overall performance of the stations as a node. On the contrary, stations, Moncalieri, Luserna, Bricherasio and Bibiana score less on the node value, this is directly related to the averaging method and the amount of value in stations, because the values of those three indicators are similar to the rest of the stations, except Pinerolo F.S. This can be considered as a shortcoming of the model to communicate a meaningful result for these stations. Similarly for the place value, does not give us any indication to compare two scenarios firstly because the values are generally low, and secondly the averaging method fails to exhibit a meaningful result.

4.5.2 4.5.2. Detailed Node Place Model

Limitations of the general node place model, leads us to a more in-depth analysis. In this part only walk catchment area is considered because the additional indicator for the place values were only applied in walk catchment area. Figure 4-26 shows in most of the cases, removing the additional node indicators resulted in a higher node value. This means the stations are generally not suitable in a pandemic situation. Absence of the hygiene measurements is one of the most important factors to be considered in all the stations. The figure also shows that some stations (like Moncalieri, Pinerolo Olimpica, Bricherasio and Bibiana) experience a decrease node value. This again, is in fact the problem of averaging method for small numbers. Looking at the place values the stations with the availability of open spaces score, less in the second scenarios. However, the availability of the land, does not necessarily indicate the potential for further development especially for the objective purposed in the thesis (for instance satellite office). Here, a more in-depth analysis is needed.

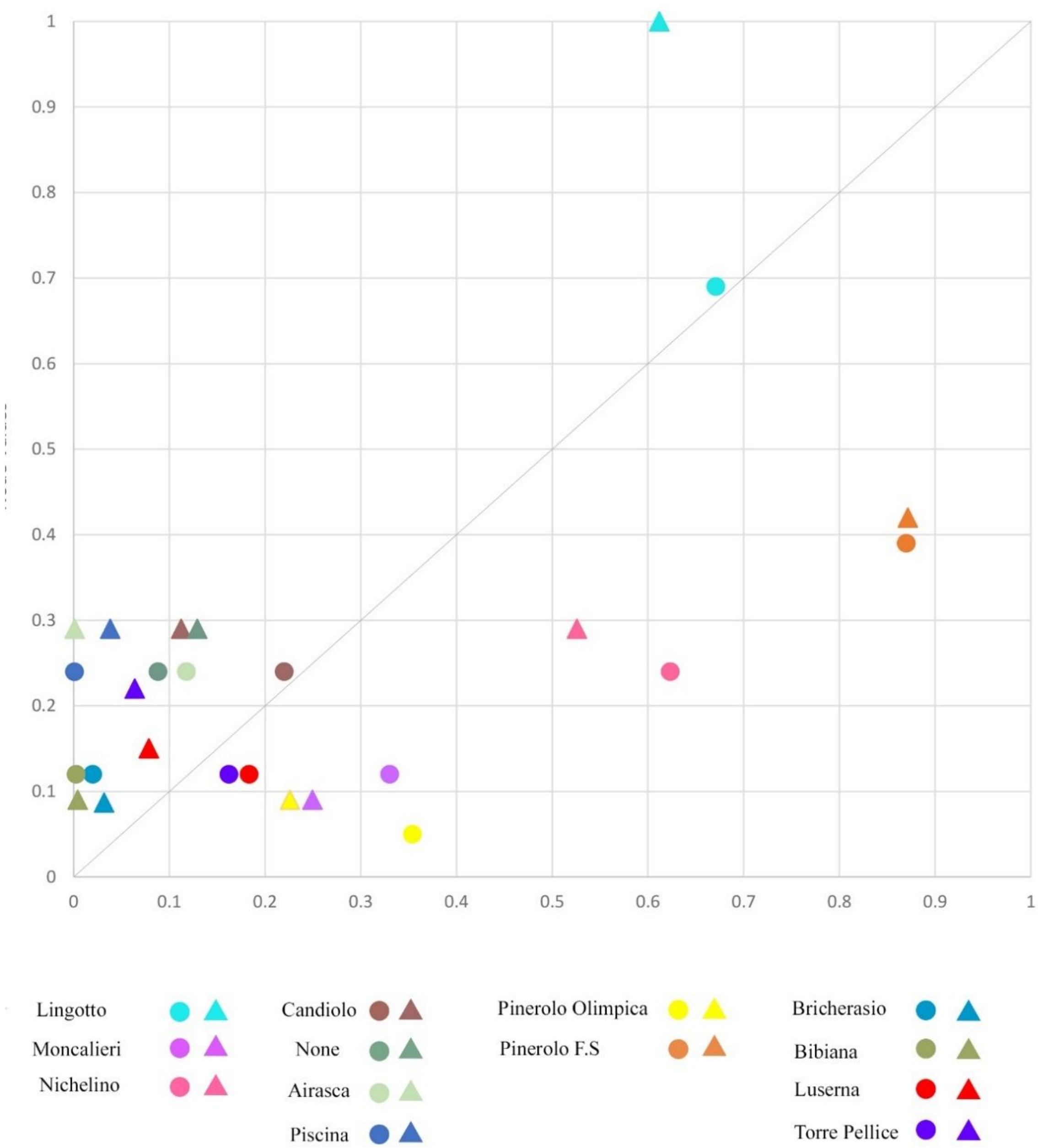

Figure 4-26 Differences between the scores on detailed node place model (elaborated by author).

5 A CLOSER LOOK AT THE RURAL STATIONS

5.1 MUNICIPALITY STUDY

As it is now clear, the homogeneous results of the place value in rural stations, do not communicate a unique indication for TOD implementation in each of the cases. Here, it can be argued that a real understanding would be possible through a case-by-case analysis, that is not limited to only station catchment areas, but considers the whole municipality (Staricco, Vitale Brovarone, 2018). Hereby, this chapter tries to compare the development strategies obtained from node-place methodology (increasing the population and job density) with the development framework of Regulatory General Plan (*Piano Regolatore Generale* or PRG) which is the main planning tool for defining municipal developments. To achieve this objective, the section starts with a morphological analysis of the municipalities, investigating the built environment features, and arrangement of the buildings. In the next step, it identifies the available open spaces within the walk and bike catchment area, considering the areas identified by the zoning plans. Finally, a table summarizes the analysis and gives recommendations based on the findings. It is also important to note that first, the availability data varies among the municipalities. Hence, the extent of analysis differs case by case. Following finding is based on the data that is publicly available on the website of municipalities, and Piemonte Geoportal. Second note is about the catchment areas; While the thesis should have considered all four catchment areas that have been discussed in the previous chapter, the priority has been given to walk and bike catchment areas due to the time constraints and the complexity of such extensive analysis. Finally, since the thesis is particularly interested in low density areas, the analysis is limited to the stations located in rural and mountainous municipalities (Candiolo, None, Airasca, Piscina, Bricherasio, Bibiana, Luserna and Torre Pellice). Ideally, stations in the medium density towns (Moncalieri, Nichelino and Pinerolo) would be discussed as well.

5.1.1 Candiolo [49]

Candiolo is located in 14 kilometers distance to the south of metropolitan city of Turin on a rural plain. Considering the urban morphology, municipality is dominated by agricultural and forestry zones in the west, south and northern areas. Natural Park of *Stupinigi* covers a vast area in the center and continues to the north and north-west of the territory. Agricultural lands are in the central area to the southern border. Urbanised zone is rather small and agglomerated in the eastern to the southeast of the municipality, Candiolo station is located on the border of urbanised zone. Looking at the station area, it is mostly surrounded by small plots of low-rise residential settlements, followed by commercial use that are agglomerated in the central part of the urban core (most of the shops are in the main streets *Via Torino* and *Via Pinerolo*). The bigger plots mostly have industrial land-use. Two industrial sites are located on the borders of urbanized area, four others are located on the western border of the municipality. Other bigger plots include one military site adjacent to the station, on the other side of the railway. Two remaining plots are open spaces, one of them is adjacent to the industrial sites on the western border of the municipality, and the other one is on the southern part of the municipality close to the residential zone. Looking at the PRGc, most of the residential plots within the urban core have been already reached the development limit (*zone di tipo B*) and cannot be more exploited. Developments are allowed in few plots within the urbanized zone, mostly for residential purposes (red mosaics) but these plots have been also developed to some extent as figure shows, leaving a few spaces for further urbanization. Similarly, in the case of industrial developments, the spaces are mostly occupied already. Overall, based on the current planning tool, there is not much potential for further urbanization. However, there are other open spaces that have not been identified by PRG can be spotted. Considering the walk catchment area, the open space in the south-west of the urbanized core, at the moment is a passive green field. This area is subject to development for public services (mostly playgrounds). Ideally, if the land-use of this area could be changed in favor of tertiary/industrial activities, it would enhance the density and increase the number of commuting

[49] All data retrieved from http://www.comune.candiolo.torino.it/ and https://geoportale.sportellounicodigitale.it/GisMaster/Default.aspx?IdCliente=001051&IdSer=1

travels of the station by employees. For the bike catchment area, a great portion of the open spaces are subject to constraints as part of Stupinigi natural park. An open space can be spotted close to the industrial zones on the west border of the municipality. PRGc identified this area as public service but given its proximity to most of the industrial sites, this area could be exploited for further industrial development. Here, an issue can be seen in the case of bike catchment area, as it goes beyond the Candiolo boundaries to the adjacent municipalities. This means a true analysis of the whole catchment area would need a more complex consideration in a wider geography that considers the development plans of neighboring municipalities as well. If the analysis would be extended to the neighboring towns, other development opportunities might emerge. In conclusion, there is a few potentials for densifications in the case of Candiolo station especially considering more commercial activities, but deeper investigations in the zoning regulation is needed.

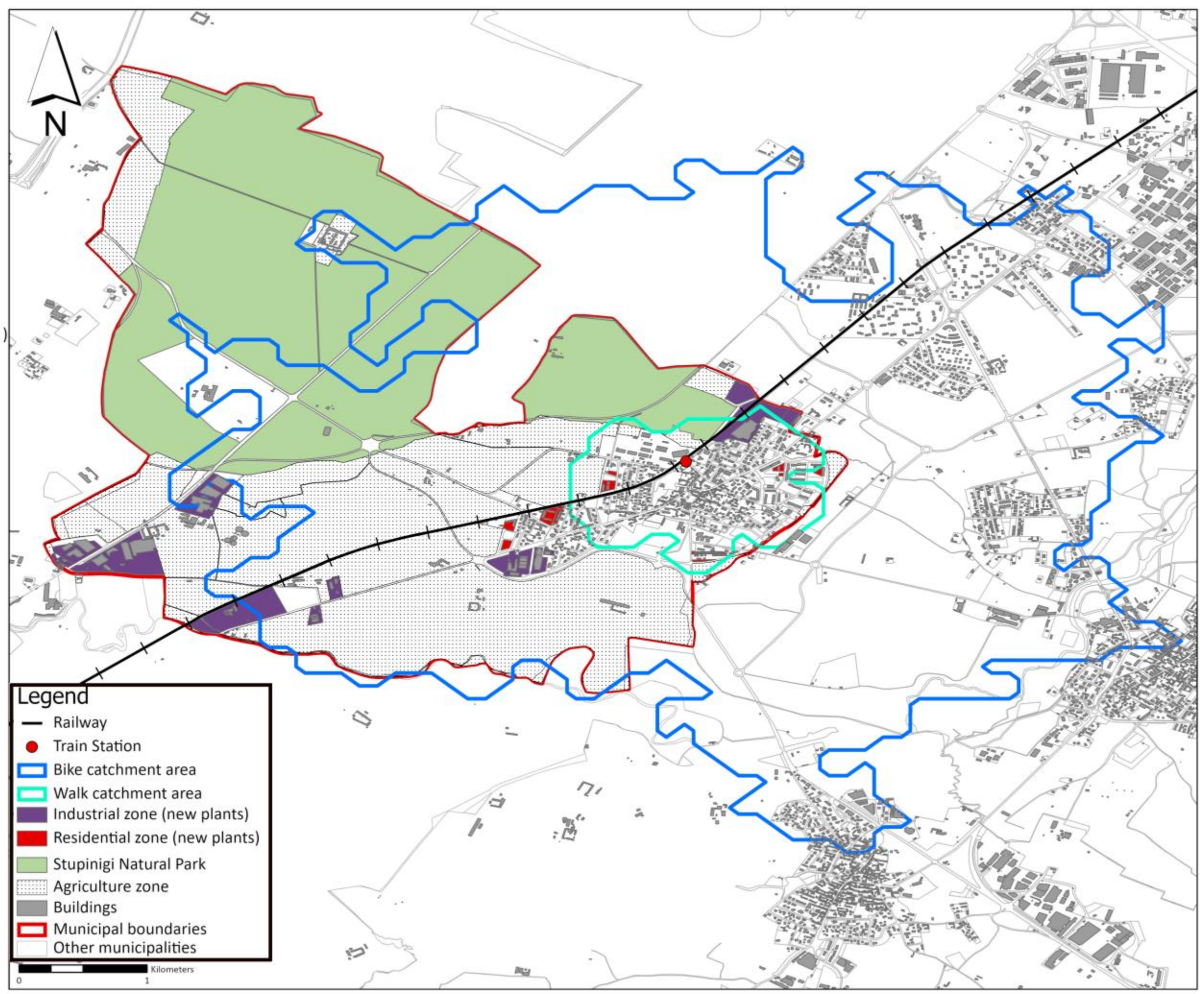

Figure 5-1 Open spaces identified by PRGc for residential and industrial development (elaborated by author based on PRGc)

5.1.2 None[50]

From a morphological point of view, None municipality is also dominated by agricultural lands, while more industrial zones can be spotted compared to Candiolo. In addition, the settlement pattern differs from Candiolo municipality. The urbanized core is located in the center to south of the territory (station is on the border of this area), while six rural cores are located the northern and eastern part of the municipality (*Palermo, San Dalmazzo, Patagna* and *Cascinetta Ronaza* in the north, *San Ponzio, Cravario* in the east). As said, compared to Candiolo, None municipality has more industrial zones and hosts more industries. Adjacent to the station in the north, there are two industrial sites that are also subject to more expansions. The residential zones are located in the center of the municipality, and industrial zones are located in the continuation of residential plots both from the northeast to the border with Candiolo and along the provincial road to the west close to the border of Airasca. Unfortunately, the indications on the PRG, are rather vague, especially about the open spaces available for further developments. However, some issues can be highlighted based on the available data: First, almost all the open spaces available in the southern border of urbanized core are subject to spatial constraints and are labeled as *Aree Inedificabili.* There are also two open spaces inside the urbanized core that are considered as undevelopable, which reduces the chance of density enhancement in the urban core. As for the residential lands, the municipality plan already foresees some completion and expansion opportunities within already existing residential lots, but same as in the case of Candiolo, the portion of such spaces are small compared to the whole area and would not significantly change the land-use intensity for this sector. Another interesting issue is about open spaces within the urbanized core labeled as *Aree Servizi*, some of these areas consist of already existing public services and are subject to further development. Others are passive open spaces. These areas may have the potential for further urbanization especially for commercial use, but any suggestions should be based on more in-depth investigation with more reliable data. Final point is about the industrial zones, as figure 5-3 shows, the opportunities have been already envisioned regarding expansion and compilation

[50] All data retrieved from municipality website http://www.comune.none.to.it/

of the industrial zones, these areas are located in a short distance from transit node within the bike catchment area, which could increase the role of None station as a trip attractor for new employees. Finally, it can be suggested expanding the industrial activities even more, by transforming the agricultural zones available between the industrial sites, however, such densification should be analyzed on the provincial level. Another suggestion could be to move the industrial development from adjacent municipality without station, into the municipality catchment area (Staricco, Vitale Brovarone, 2018), this also would require a comprehensive analysis on the neighbouring municipalities. Overall, the expansion of industrial activities seems to generate the most opportunity for the None station. Other than that, the open spaces are either subjected to spatial constraints or belong to agricultural activities.

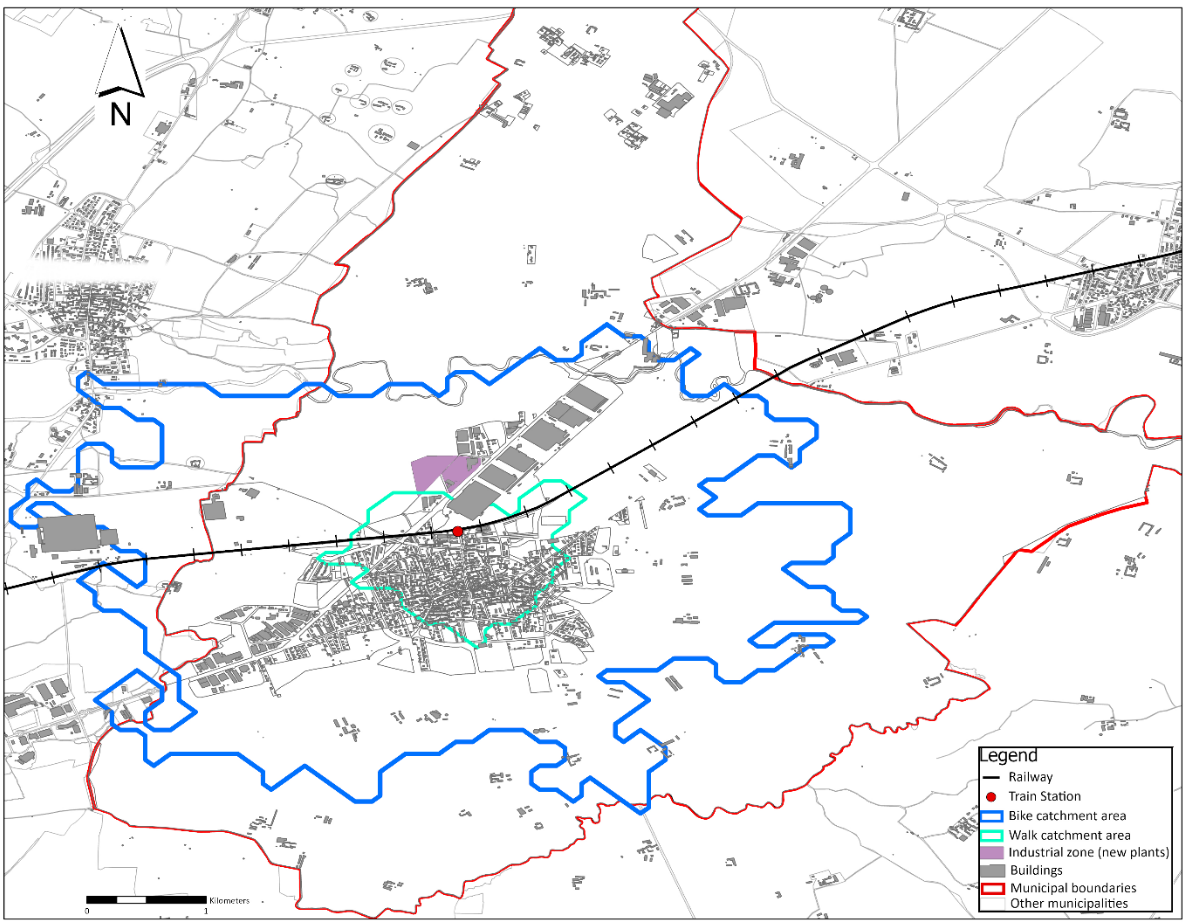

Figure 5-2 Open spaces development identified by PRG (elaborated by author)

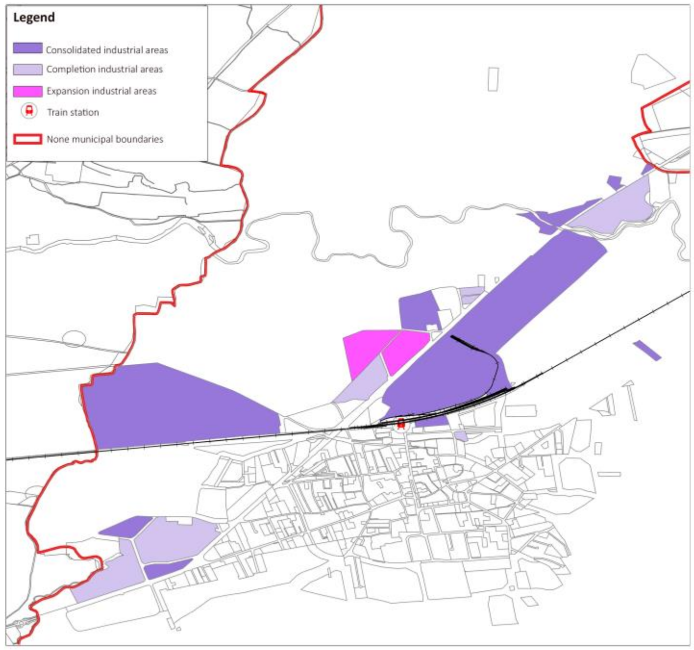

Figure 5-3 Industrial zones in None (elaborated by author)

5.1.3 Airasca[51]

Airasca territory is also strongly dominated by agricultural lands. From where the of railway line passes to the northern part of the municipality, the land is almost fully covered by agricultural farms. The urbanized core is agglomerated in the center, around the Provincial roads. The industrial zones on the east side of the municipality are a bit far from the urban core and is adjacent to the industrial sites on the west of None municipality. Another industrial zone can be spotted on the west side of urban core, with agricultural areas act as a buffer between the industrial sites and residential plots. Looking at the station area, a road (*via Stazione)* directly connects the station to the urbanized core to the south. The southern neighborhoods of the station, include some residential villas that are subject to compilation (albeit a very small portion), a productive zone that is subject to more expansion, and a football playground. There is a rather large greenfield on the east side of *via Stazione* (south-east of the station) which PRGc envisioned as a private green area intended to be used for public use.

[51] All data retrieved from municipality website https://www.comune.airasca.to.it/

Figure 5-4 highlights the residential developments that are recognized by PRGc. As it can be seen, almost all these developments are outside of the walking catchment area. One solution could be to move these developments inside the catchment area (Staricco, Vitale Brovarone, 2018) to increase the urbanized surface within the station area.

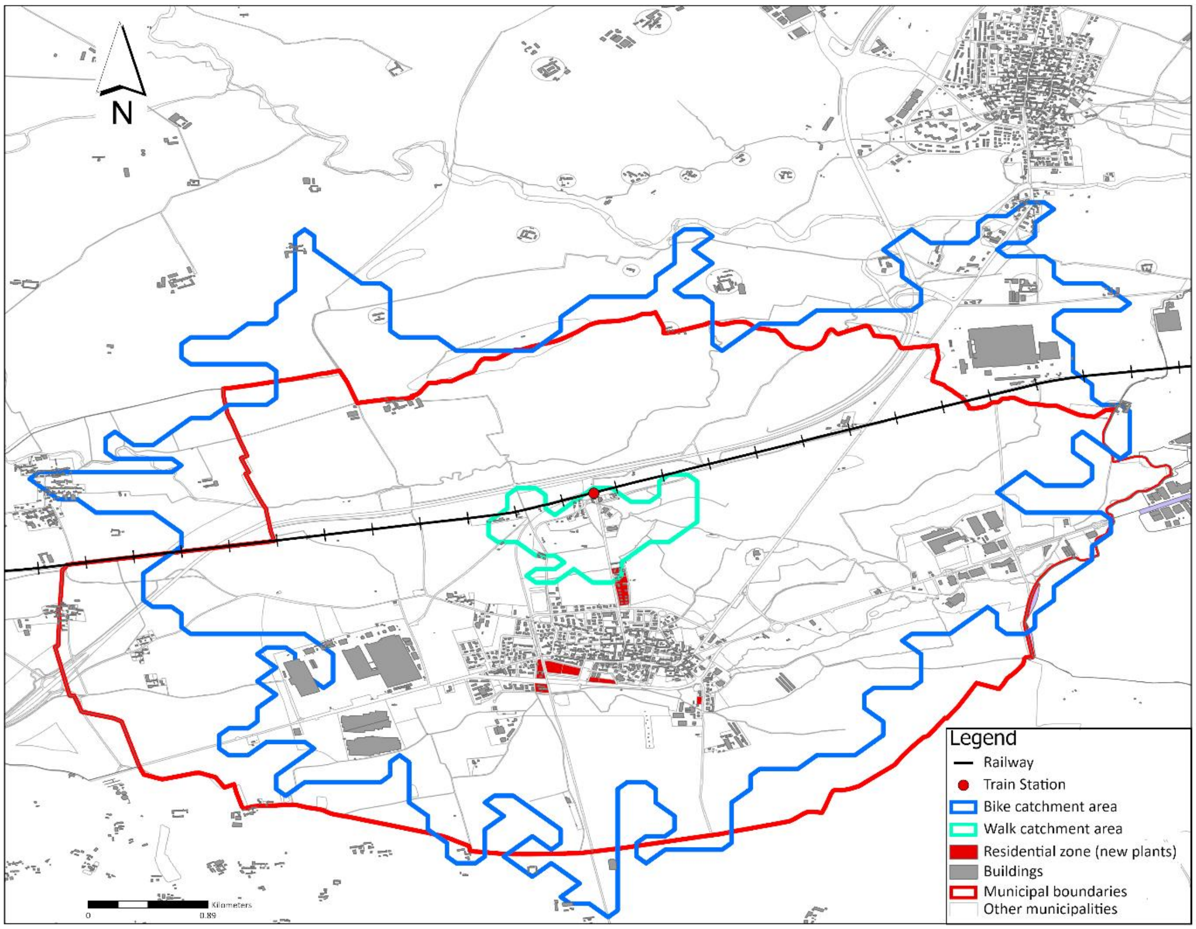

Figure 5-4 Residential developments in Airasca, based on municipal development plan (elaborated by author)

Considering non-residential activities, some opportunities can be spotted within both walk and bike catchment areas. We can divide the urban developments in three parts as shown by red circles on figure 5-5: first part is the urbanized core, where residential areas are also located. Comparing this part to walk catchment area, three open spaces can be found adjacent to the station. First, an agricultural lot that is intended to be used as 'urban gardens. According to the plan, no urbanization can be considered in this area. Another open space is a private green space, intended to be used as a public service. Theoretically, this area can be exploited for further urbanization. The last open space is the area behind the already existing industrial site which can also be exploited for further industrial development. Overall, it seems that modifying the PRG in favor of more urbanization, would increase the possibility to enhance the density within walk. Moving towards the south, within the bike catchment area, three plots are labeled as private greens subject to public use. These blocks are at the moment passive open spaces and while the possibility of urbanization in these lots needs to be more investigated, they could provide the opportunity to increase the density of the catchment area. Moreover, in the north-west part of the urbanization core, an area is envisioned for recreational activities, this area also has the potential to increase the intensity of activities and can also benefit from proximity to the station. Similar to walk catchment area, increasing the density would be possible through modifications on the PRG.

Two remaining parts are mostly consisting of industrial zones, and both are located on the borders of bike catchment area. Looking at the production zone on the west part of the municipality, two lots are already envisioned for further development for production activities. If the development happens here, it will also increase the intensity of the activity in municipality. It may also increase the chance of more attracted trip by new employment opportunities. Moving to the other the productive zone in the eastern area of the municipality, no space for further development can be identified. However, considering the proximity to the None industrial area, it can be said that the development opportunity of this zone falls within the territory of None. Final point is about the surface covered by bike catchment area. As figure shows, the catchment area includes parts from neighboring municipality (industrial sites on the western border of None). This again, proves the necessity of a cooperative approach in planning all the stations buffer (Staricco, Vitale Brovarone, 2018). In general, Airasca municipality exhibits some potentials to enhance the land use intensity within the municipality however, as said before, future development would need rethinking the zoning plan of the municipality, and the neighboring municipalities as well.

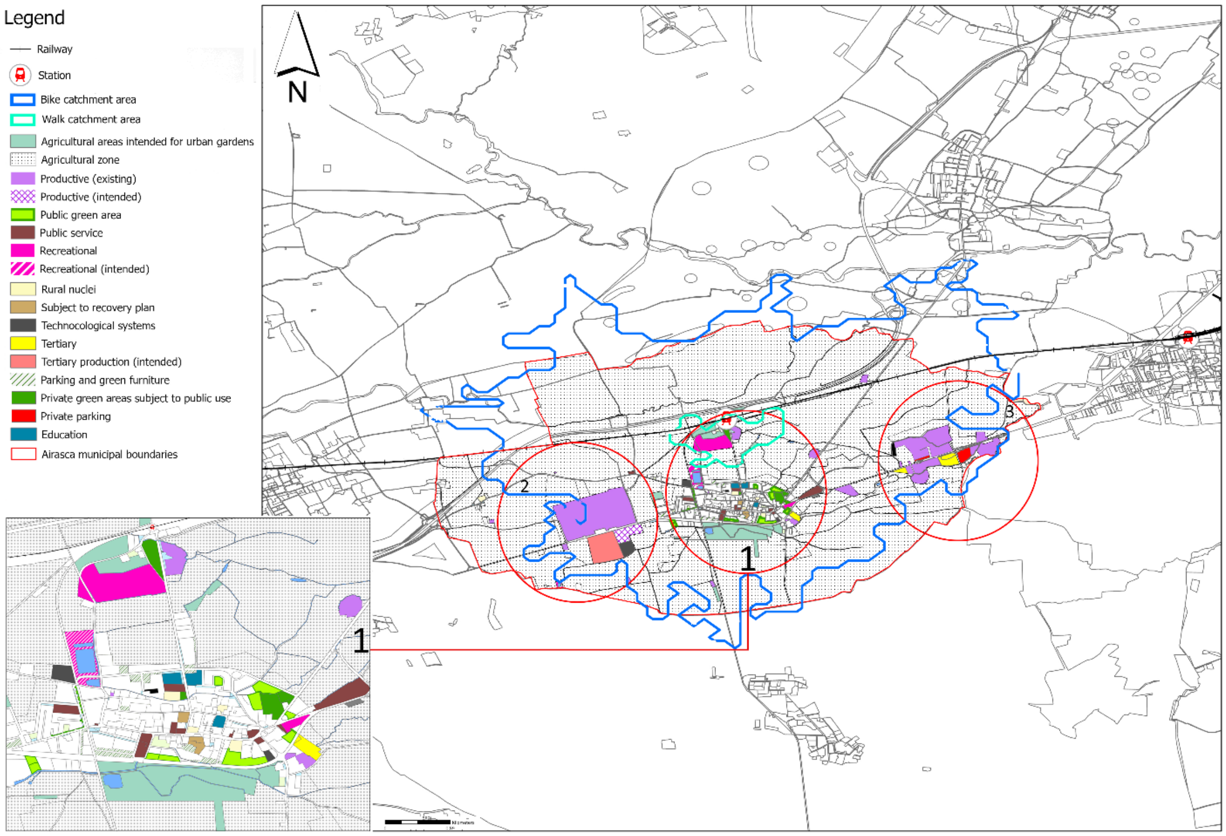

Figure 5-5 Non-residential developments in Airasca identified by municipal development plan (elaborated by author)

5.1.4 Piscina[52]

Piscina municipality is dominated by agricultural areas on plain surface. From a morphological point of view, Piscina municipality consisted of previously detached urban zones, that are now partially attached through new development in the central part of the municipality. Still, some old settlements (hamlets mostly consist residential plots, and some small productive lots) can be spotted. The distances between rural parts and central urban area, are filled with agricultural lands. The newly built area mostly consists of low-rise residential settlements and some commercial buildings in the center of the municipality. Industrial areas are in the north and southern part of the

[52] Data retrieved from municipal official website https://www.comune.piscina.to.it/it-it/home

urbanized core. The industrial zones in the northern part are adjacent to the station and center of the town, while the southern zone is further. Piscina is a particularly interesting case because first, the portion and of available open spaces subject to new development, in the catchment areas, are more compared previous municipality. Figure 5-6 shows the open surfaces identified by municipality plan as buildable area for residential and industrial purposes. If these developments happen, they will increase the density mostly and may positively affect the number of commuting trips by train. The part of bike buffer within municipality boundaries is mostly filled with agricultural lands, and the identified open spaces would not significantly increase the land use intensity in this area. However, another point about the bike buffer is that it goes beyond the municipal boundaries. So again, a more precise analysis would consider neighboring municipalities as well. In this case, more opportunities may emerge.

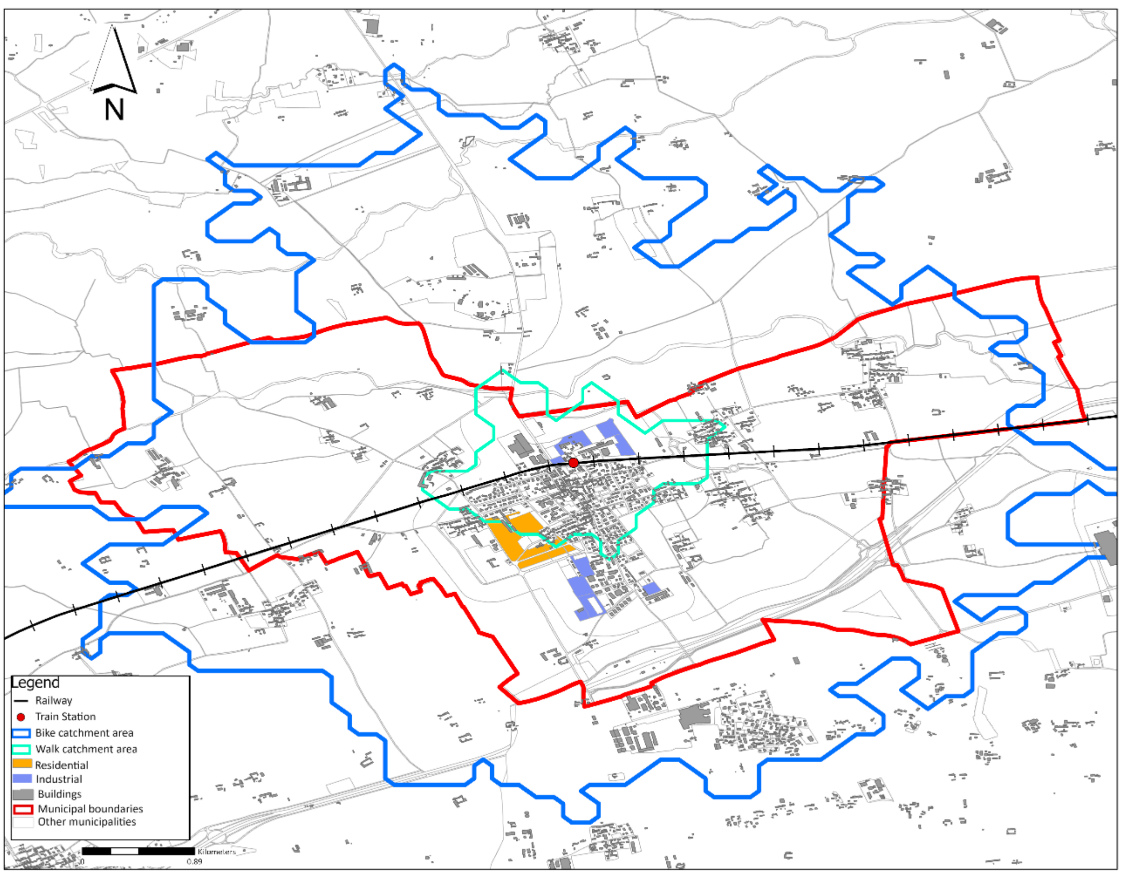

Figure 5-6 Open spaces and designated land use identified by municipal plan of Piscina (elaborated by author)

5.1.5 Bricherasio[53]

Located in the mouth of the *Val Pellice* where *Pellice* stream flows on the east, Bricherasio topography is partially flat and partially hilly. Similar to previous municipalities, Bricherasio is dominated by agricultural land use. However, the settlement pattern is different from rural municipalities discussed in the previous parts. Most of the built environments are located center of the valley, in the vicinity to the provincial road (*Strada Provincale 161*), that is subject to revision and redevelopment based on the spatial constraints dictated by the current zoning plan, environmental framework[54]. Station is located on the border of the historic zone, surrounded by residential plots where no further development can occur. Two private green spaces can be also identified on the two sides of station area. In the northern part of the historic zone, green open spaces can be found on a hilly topography, which according to the PRG plan are part of public services with development limits. The southern part of built environment is dominated by residential use (mostly new blocks) until the border with Luserna municipality. Looking at the figure 5-7, three plots can be identified for further residential densification. As it can be seen, these areas fall outside the walk catchment area. Theoretically, these developments can be moved inside the buffer to increase the land-use density. However, attention must be paid to spatial constrains due to special topography and environmental characteristics of the area. Considering non-residential developments, opportunities for industrial and tertiary developments can be identified adjacent to the existing industrial zones. Part of these developments are inside the walk catchment area, while the rest are outside the buffer. The potentials for the bike buffer are even less. Open spaces are either subject to environmental preservation or belong to agricultural activities. In general, given the special geographical characteristics of the valley, an intense urbanization cannot be foreseen in this area.

---

[53] Data retrieved from municipal official website https://www.comune.bricherasio.to.it/it-it/home and https://geoportale.sportellounicodigitale.it/GisMaster/Default.aspx?IdCliente=001035&IdSer=1

[54] The intervention consists of distmantling of a section of old road system (abandoned construction of S.P. 161) and its recovery of the surrounding area by means of resuse of the land for furthur road development

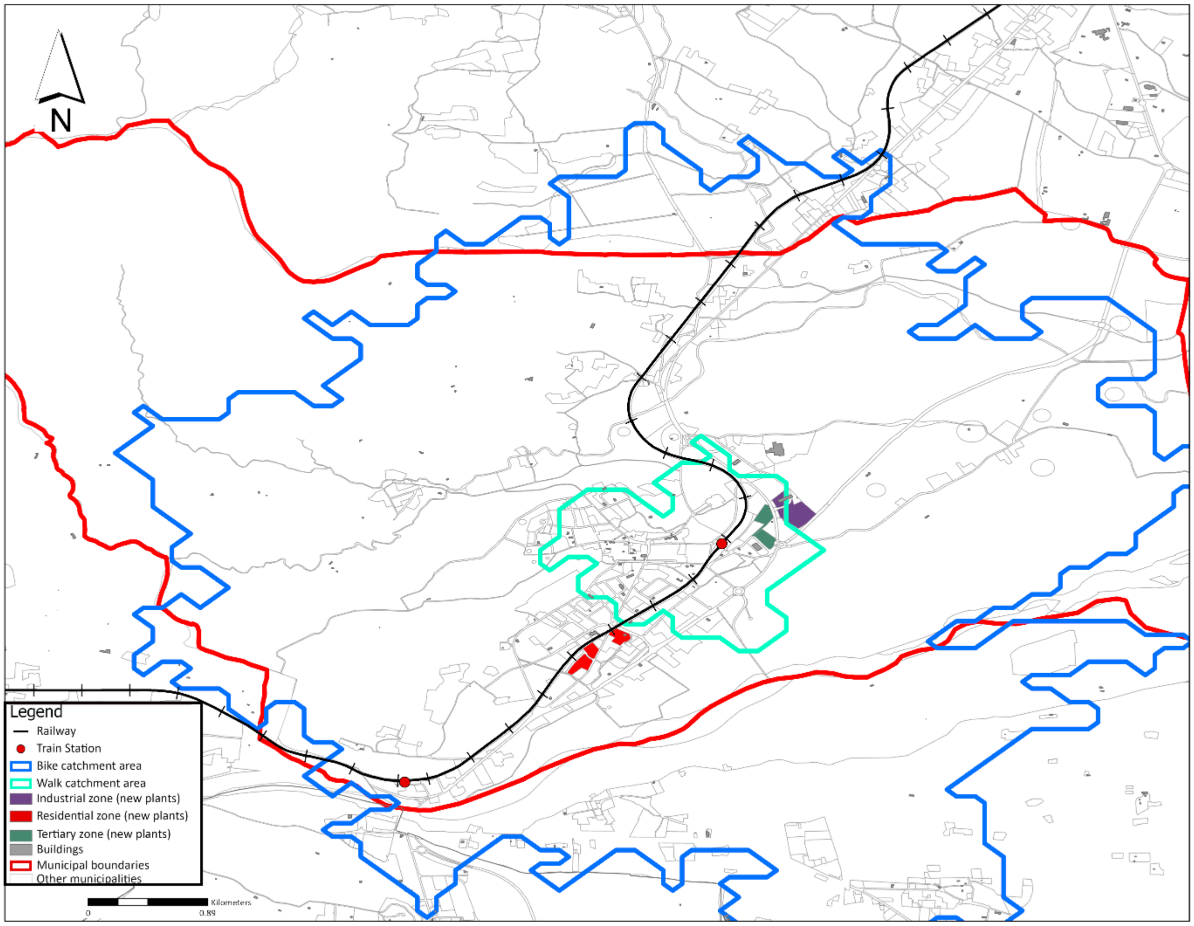

Figure 5-7 Development opportunities identified by municipal plan of Bricherasio (elaborated by author)

5.1.6 Bibiana[55]

Bibiana municipality is on the minimum altitude of Val Pellice. The municipality has both flat and hilly topography. Hilly parts are on the west side of the territory and plain topography can be found the eastern side. Pellice stream passes on the northern border of the territory. This municipality is dominated by agricultural zones. Settlement follows the same pattern as Bricherasio, and the urbanized core agglomerated in the main valley, located in the northern area of the municipality, and is stretched along the main road that comes to the town from Bricherasio, and goes to *Bagnolo Piemonte* to the south. Considering the urbanization potentials, open spaces can be identified close to the northern border of the municipality within the walk catchment area. This big plot consists

---

[55] All the data has been retrieved from municipality website http://www.comune.bibiana.to.it/

of already existing productive blocks and is already under construction for new productive and residential accommodation. Looking that the Bibiana PRGc (figure 5-8), more development opportunities can be found within the already existing low density residential blocks. Part of this developments are inside the walk catchment areas, and some are inside the bike catchment area. Overall, it seems that more densification is possible and already identified. Considering nonresidential activities, the municipality only recognize industrial areas that are already existed within the residential zones. But the portion of these areas compare to all the open spaces is still small. Looking at the municipality, other Greenfields can be identified, but there is no indication about the rest of open spaces in the current zoning plan. It must be said that Bibiana station is also an interesting case, because it is located on the border of three municipalities (Bricherasio, Bibiana and Luserna). On the west side of the station, there is an industrial site in the territory of Luserna that is subject to the further expansion. This could positively impact the ridership of Bibiana station because the expansion parts are in the same distance between Luserna and Bibiana stations. Further suggestion could be to continue this expansion from Luserna to the industrial zone in the south of the station (multipurpose area in the figure 5-8). Again, such densification should be investigated in a provincial level. Finally, the issue about bike buffer crossing beyond the municipal boundaries exists here as well.

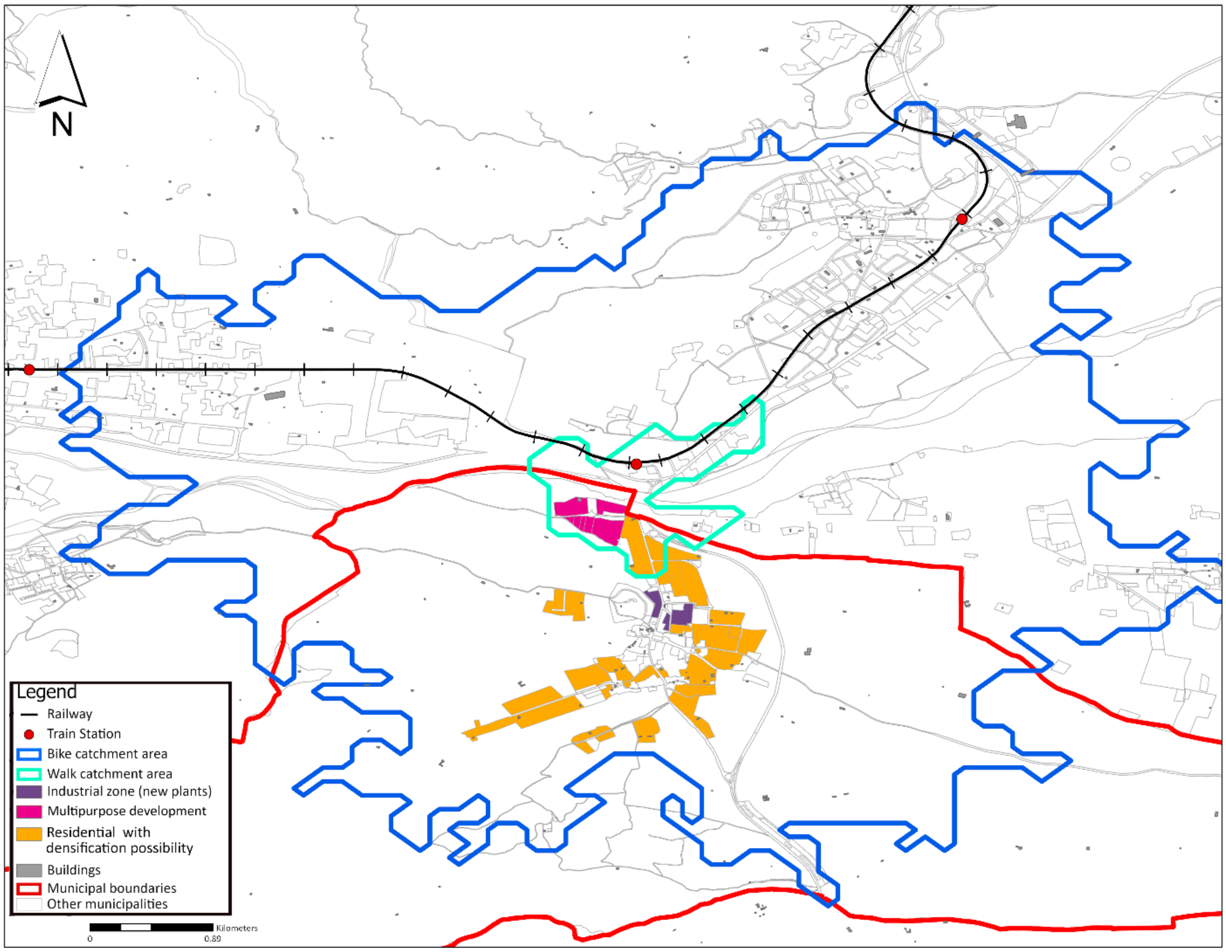

Figure 5-8 Development opportunities identified by municipal plan in Bibiana (elaborated by author)

5.1.7 Luserna[56]

Luserna municipality is in the middle of *Val Pellice,* where it crossed by two streams *Pellice* and *Luserna.* Pellice stream divides the settlements into two parts. On the north side of the river, the recent built environment is in the plain surface on the bottom of the valley while old urban center is on the hilly part of *San Giovanni*. On the other side of Pellice river, there is the *Luserna* area at the foot of the hills. Station is located within the most urbanized area. Although the station area is dominated by residential blocks, the diversity of the activities around it is considerably higher compared to other stations. Activities include commercial, offices, schools, parks and other public

[56] All the data has been retrieved from municipality website https://www.comune.luserna.to.it/

open spaces, and even industrial sites. Considering the development opportunities, unfortunately, the latest PRG of Luserna is not accessible now. The only version publicly available is the interactive map on Piemonte Geoportal[57]. The map shows some of the open spaces within the urbanized core are subject to expansion for further developments mostly for residential purposes. Three plots are identified for multipurpose land use which can contribute to increase the density in bike catchment area. The map also illustrates some considerations for industrial developments within the bike buffer. A huge area can be spotted on the eastern side of the municipality has been identified for industrial expansion as figure 5-9 shows. Overall, despite having some opportunities, still a great portion of open spaces are not identified for any further developments. Part of this areas are subject to spatial constraints due to the typology, but others could be exploited. One example is an open space between the urbanized core and industrial site in the east side of the municipality could be transformed into industrial or tertiary zone, but this also requires more investigation on a provincial scale.

[57] http://www.geoportale.piemonte.it/geocatalogorp/index.jsp

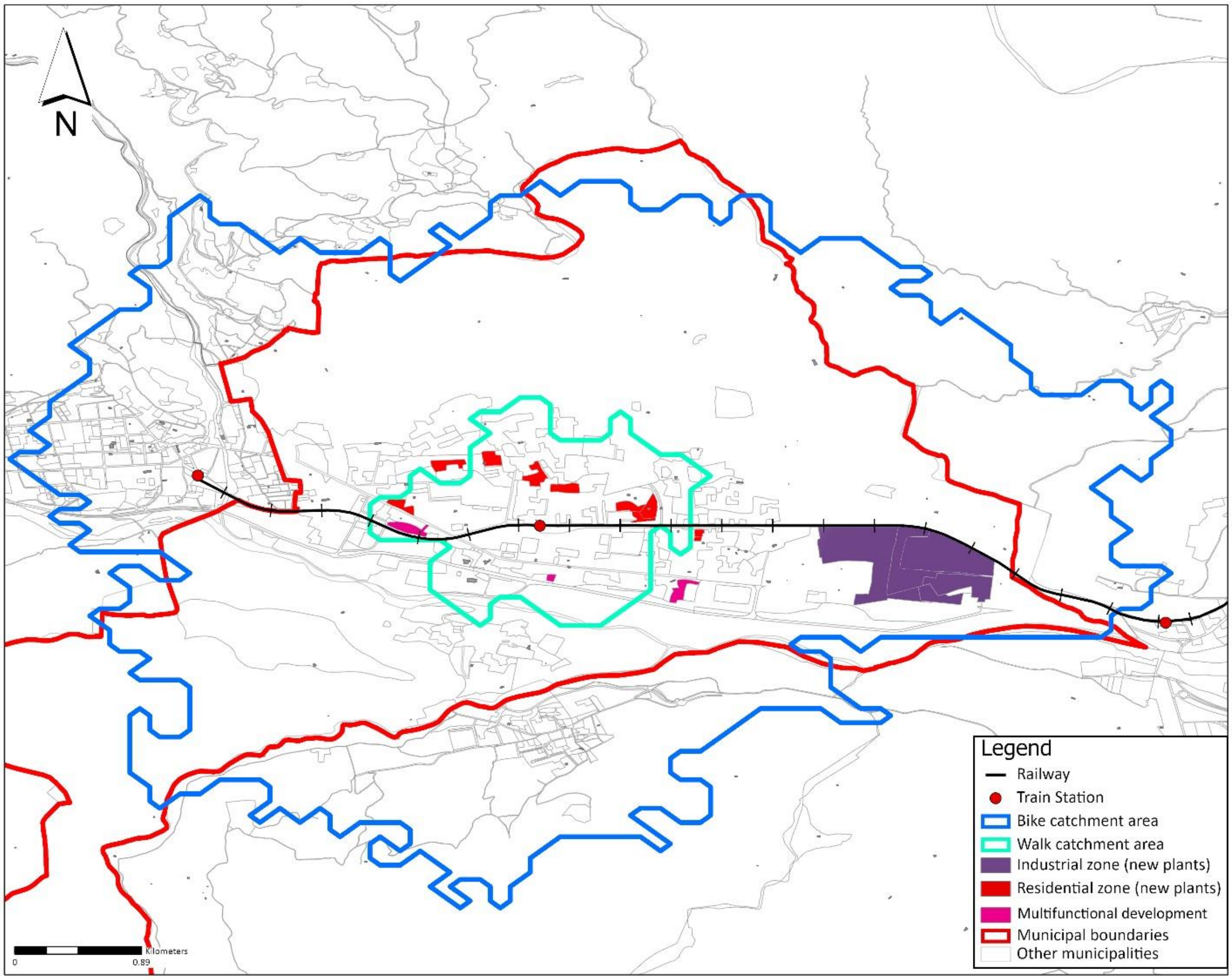

Figure 5-9 Developable area identified by municipal plan of Luserna (elaborated by author)

5.1.8 Torre Pellice[58]

Torre Pellice can be considered as the continuation of Luserna municipality. Surrounded by two alpine spurs from north and the south, the built environment is crossed by the provincial road that comes from Pinerolo and goes to *Bobbio Pellice* town on the west. Settlements located in the middle of the valley around the road, with older buildings in the short distance from the Provincial

[58] All the data has been retrieved from municipality website https://www.comune.torrepellice.to.it/ and Geoportale https://geoportale.sportellounicodigitale.it/GisMaster/Default.aspx?IdCliente=001275&IdSer=1

roads and the more recent constructions on the northern parts of the valley. Industrial areas can be seen on the south of the provincial road. Currently abandoned Torre Pellice station is located in the *Piazza Stazione Ferroviara* within the historic zone in a short distance to the entrance of the municipality from the East. The diversity of activities in Torre Pellice station area is somehow similar to Luserna station. It is dominated by residential use, but non-residential activities including commercial, industrial and some public services can be identified. Moving from the station square to the main road in the middle of the valley towards the west, the density of land use (mostly residential with some public services) gradually reduces where finally reaches to the open spaces outside the inhabited centers. Open areas mostly have agricultural and forestry functions. Given the special typology of the town, the opportunities for extensive urban extensions are limited. Historic zone is rather dense and has been developed in a linear along the provincial road. In this area, there is not that many opportunities to increase the urbanized surface. Looking at the map (Figure 5-10), some plots are suitable for further residential densification within the walk catchment area. Another open space on the edge of walk catchment area is identified for industrial development. Moving to the western sides of the town, other small residential plots can be spotted within the bike buffer. Most of these plots are already under construction.

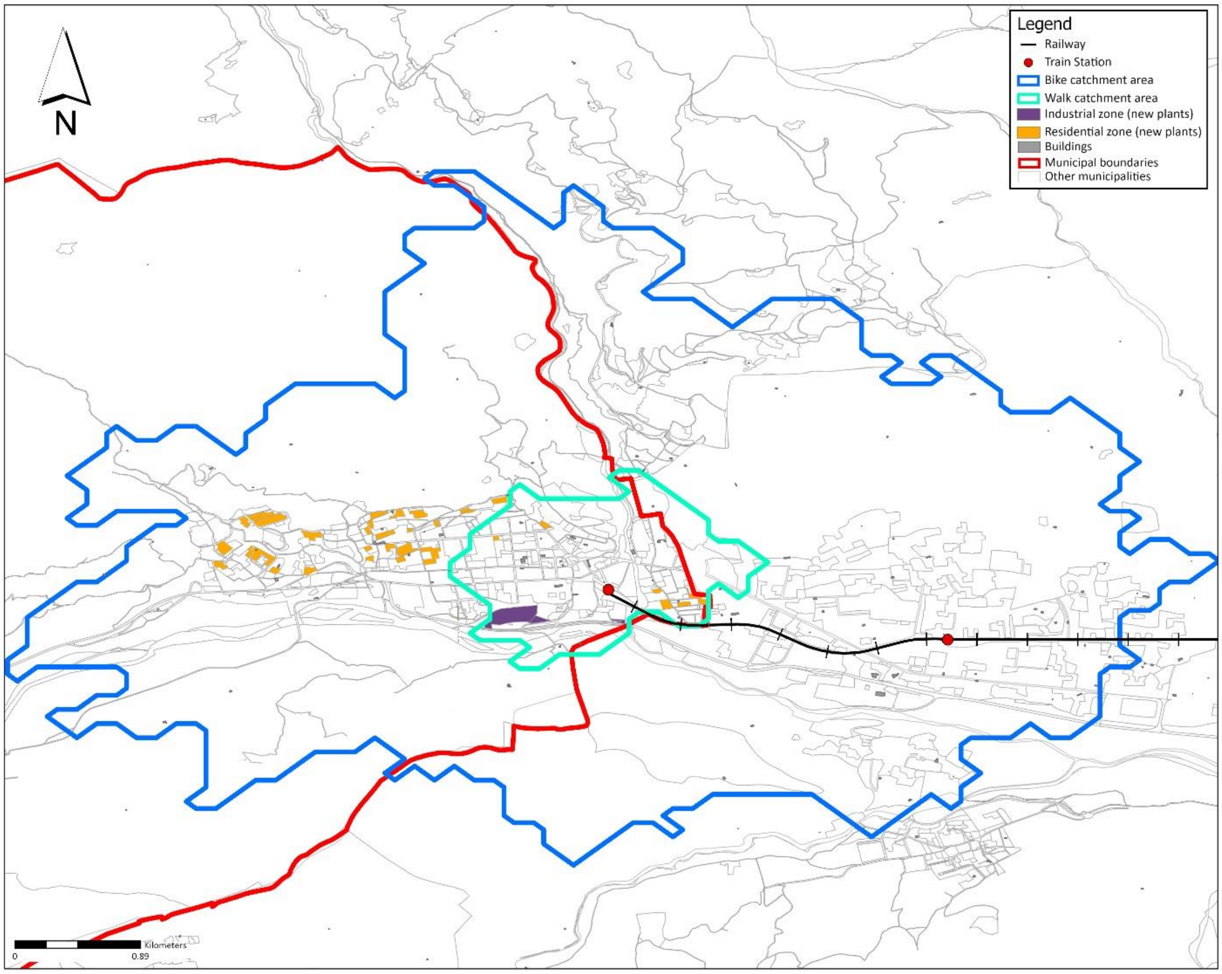

Figure 5-10 Developable areas identified by municipal plan in Torre Pellice (elaborated by author)

5.2 Possible TOD in Low Density Area

Municipal study in the section 5.1 shows that the opportunities for densification cannot be overestimated in rural municipalities. Despite the availability of open spaces, a great portion of them is subject to spatial constraints, due to environmental or topographical limitations. In any case, following tables compares the strategies obtained from node place walk and bike catchment areas in terms of increasing the urbanized surface analysis in chapter 4, with the municipal analysis presented in section 5.1.

Table 5-1 Possible TOD in Candiolo (elaborated by author)

Candiolo	
Suggested planning strategy by Node-Place analysis	- Significant enhancement in residential and job density within bike catchment area.
Developments identified by the PRG	- Residential densification is only allowed in small plots within the already existing residential blocks. - Industrial development is identified in the areas where there are already existing industrial activities close to the border of the municipality.
Development Constraints	Constraints stem from zoning plan: - Natural Park covers a vast area of the municipality. Urban development is not possible in this area due to environmental constraints. - Agricultural zones cover significant part of the territory. Developments have not been considered in this area. - Open spaces with no spatial constraints are designated for other land uses (For instance two Greenfields, one on the edge of urbanised core and other one close to the industrial site are reserved for public services). - No development has been foreseen in terms of commercial and tertiary activities. Constraints stem from catchment area: - Most of the identified development falls outside of the walk catchment area. - Bike catchment area goes beyond the territory of municipality.

Evaluation and recommendations

Based on the findings of node-place analysis, residential and employment density already have an acceptable situation for TOD development in walk buffer while the density enhancement should be applied within bike catchment area. Having said that, there is not much potential for increasing the urbanized surface in Candiolo municipality. A more transit-oriented development would require re-thinking the <u>land use of available Greenfields</u>, maybe <u>transforming a part of open spaces</u> designated for public services to residential, industrial, and commercial activities, or <u>transforming the agricultural zones</u> adjacent to the urbanized core in favor of such land uses within bike buffer. However, given the fact that further densifications may not be possible based on the Provincial Plan of Turin. Another important note regarding the bike catchment area is the necessity to search for development opportunities in the neighboring municipality. This would require <u>a cooperative approach to development planning</u> in all the municipalities within the area.

Table 5-2 Possible TOD in None (elaborated by author)

	None
Suggested planning strategy by Node-Place analysis	- Moderate enhancement population and job density in the walk catchment area of the station. - Significant enhancement in the population and employment density within bike catchment area
Developments identified by the PRG	- Minimal possibility of residential development among already existing residential zones. - Industrial expansion has been foreseen adjacent to the already existing industrial zone.
Development Constraints	Constraints stem from zoning plan: - Urbanization is not allowed on the border of the urbanized core despite the availability of Greenfield, especially in the southern part of the town. - Some passive open spaces are labelled as 'service area' while no further indication is discussed. - No development has been foreseen in terms of commercial and tertiary activities. Constraints stem from catchment areas: - Bike catchment area covers part of neighbour municipality that are outside of the scope of this analysis

Evaluation and recommendations

Based on the findings of the methodology, walking catchment area needs a slight densification while bike buffer scores very low and needs further consideration. First and foremost, the indications on PRG do not communicate well. Plan would need an update, especially considering the Greenfields that are left undefined. One suggestion can be to re-elaborate the land use of such areas for further densification. This requires a cooperative approach between different planning tools on different scales (local, provincial, and regional). In general, there is not much opportunity to increase the residential density in both walk and bike catchment areas. PRGc only identifies industrial development as the municipality already hosts considerable portion of industrial activities. Still, the development falls outside of the walk catchment area. So, one suggestion is to move industrial expansion within open spaces available within the walk buffer to improve the density. Moreover, there is another industrial zone within the bike catchment area that falls outside of the municipality territory (within the territory of *Rivalta di Torino*) hence, out of the scope of this analysis. A more comprehensive analysis includes the neighbour municipality in terms of industrial developments.

Table 5-3 Possible TOD in Airasca (elaborated by author)

Airasca	
Suggested planning strategy by Node-Place analysis	- Major densification in the walk catchment area. - Significant enhancement in population and job density within bike catchment area.
Developments identified by the PRG	- Residential developments in the southern part of the urbanized core. - Industrial expansion in proximity of already existing industrial site in the west side of the territory. - Open spaces claimed to be transformed for public services but left undeveloped.
Development Constraints	Constraints stem from zoning plan: - Strong presence of agricultural lands around the station. - Strong presence of Greenfields around the station. Constraints stem from catchment areas: - Bike catchment area covers part of neighbour municipality that are outside of the scope of this analysis

Evaluation and recommendations

Methodology proves that both walk and bike catchment areas need major enhancement in terms of residential and employment densities. However, despite the availability of Greenfields, PRG does not envisioned considerable development opportunities in the Airasca terriotory. The zoning plan should be updated if TOD implementation is desired. It is important to mention that station area is far from urbanized core and almost fully covered with open spaces and agricultural lands. One suggestion could be to move the residential development inside the walk catchment area to at least, increase the urbanized surface close to the station without altering the amount of land consumption. Another suggestion is to transform the land use of agricultural area between the urbanized core and the station to industrial/ commercial to increase the density in bike catchment area. This would of course need a further investigation in provincial plan. Other suggestion is to transform the land use of private Greenfields that according to the plan, are envisioned for public services in favour more urbanization. The industrial zone on the east can be even more extended and connected to the industrial sites in None municipality. This of course requires cooperative approach for planning the industrial development in both municipalities.

Table 5-4 Possible TOD in Piscina (elaborated by author)

Piscina	
Suggested planning strategy by Node-	- Slight enhancement in residential and population density within walk buffer.

Place analysis	- Major enhancement in population and employment density for bike catchment area.
Developments identified by the PRG	- Residential developments in open space in southwest of the urbanized core. - Industrial developments in the open spaces located in the southern area of the urbanized core.
Development Constraints	Constraints stem from zoning plan: - Agricultural zones cover significant part of the territory. - No development has been foreseen in terms of commercial activities. Constraints stem from catchment areas: - Bike catchment area covers part of neighbour municipality that are outside of the scope of this analysis

Evaluation and recommendations

Municipality has moderate potentials for further developments both in terms of residential and employment densities. In the case of walk buffer, already identified developments would improve the density to a medium level for TOD implementation. In the case of bike catchment however, foreseen developments would not significantly improve the density values. If TOD implementation is desired, agricultural lands on the edge of urbanized core could be transformed in favour of land uses that increase the density to an acceptable extend. A considerable part of bike catchment area goes beyond the municipal boundaries. So, understanding the real TOD potential of the station requires further analysis on the neighbouring municipalities.

Table 5-5 Possible TOD in Bricherasio (elaborated by author)

	Bricherasio
Suggested planning strategy by Node-Place analysis	- Major enhancement in residential and population density within walk buffer. - Major enhancement in population and employment density for bike catchment area
Developments identified by the PRG	- Minimal residential development in within new residential constructions. - Industrial and tertiary development within already existing industrial/commercial zone.
Development Constraints	Constraints stem from zoning plan: - Station area is surrounded by private open spaces. - Agricultural zones cover significant part of the territory. - Hilly topography limits the development.

	- Open spaces are subject to environmental protection. Constraints stem from catchment areas: - Bike catchment area covers part of neighbour municipality that are outside of the scope of this analysis.
Evaluation and recommendation According to node place analysis, Bricherasio would need a significant enhancement in population and employment density for both walk and bike buffers. However, the PRG plan have not envisioned such development. In the case of walk buffer, the opportunities become even more limited due to the environmental constraints. All the open spaces in the buffer are labelled as protected area. Another issue that deters development is the hilly topography. Indeed, more opportunities may emerge if the analysis includes adjacent municipalities covered by bike buffer.	

Table 5-6 Possible TOD in Bibiana (elaborated by author)

Bibiana	
Suggested planning strategy by Node-Place analysis	- Major enhancement in residential and population density within walk buffer. Major enhancement in population and employment density for bike catchment area.
Developments identified by the PRG	- Residential densification within the existing residential plots. - Industrial densification within the existing industrial plots. - New multipurpose development (industrial/residential).
Development Constraints	Constraints stem from zoning plan: - Agricultural zones cover significant part of the territory. - Hilly topography limits the development. - Station is located on the border of three different municipalities - Undefined open spaces Constraints stem from catchment areas: - Walk catchment area covers portions of neighbour municipality. - Bike catchment area covers parts of neighbour municipality that are outside of the scope of this analysis.
Evaluation and recommendation Results of node place analysis suggests densifications in population and jobs in both walk and bike buffers. This can be partially delivered in both walk and bike catchment area with already envisioned developments. To enhance the residential density in walk area, one suggestion could be to move the identified residential development from urbanized inside walk catchment area. Another suggestion could be to extend the industrial expansion in Luserna to the walk buffer. For bike catchment area, undefined	

open spaces can be transformed to land uses that positively impact the density. It must be noted that part of the developments in Bricherasio and Luserna municipalities are covered by bike buffer, meaning developments in other municipality would also affect the density value of Bibiana.

Table 5-7 Possible TOD in Luserna (elaborated by author)

Luserna	
Suggested planning strategy by Node-Place analysis	- Significant enhancement in population and job density within bike catchment area.
Developments identified by the PRG	- Residential developments in small plots within the city centre. - Multifunctional development within open spaces. - Industrial expansion in already existing industrial site.
Development Constraints	Constraints stem from zoning plan: - Forestry and agricultural zones cover significant part of the territory. - Hilly topography limits the development Constraints stem from catchment areas: - Bike catchment area covers part of neighbour municipality that are outside of the scope of this analysis
Evaluation and recommendations Based on the node place methodology, densities of population and jobs should be enhanced in Luserna bike buffer to an acceptable level for TOD implementation. Development plan already allows some densifications within the urbanized core and in the industrial site. But the portion of these developments compared to all open spaces are relatively small. One suggestion is to extend the industrial expansion to the eastern edge of the municipality close to Bibiana station. It must be noted that the unavailability of data limits the possibility to comment on the available open spaces within the town, but in theory, there are open spaces, especially close to industrial site that can be exploited in favour of further densification. Here again, the geographical characteristics of the town acts as the development barrier as the northern forestry area of the municipality is impossible for more densification.	

Table 5-8 Possible TOD in Torre Pellice

Torre Pellice	
Suggested planning strategy by Node-	- Significant enhancement in population and job density within bike catchment area.

Place analysis	
Developments identified by the PRG	- Residential expansion on the west side of the municipality. - Minimal industrial expansion in the southern part.
Development Constraints	Constraints stem from zoning plan: - Forestry and agricultural zones cover significant part of the territory. - Hilly topography limits the development Constraints stem from catchment areas: - Bike catchment area covers part of neighbour municipality.

Evaluation and recommendations
Based on the node place results, densities of population and jobs should be enhanced in Torre Pellice bike buffer. Some opportunities have been already identified by PRGc as discussed. Other than that, the municipality does not have much potential for densification with respect to the hilly typography and dominance of forestry area.

5.3 FINAL INSIGHTS ON TOD IN RURAL STATIONS

From what has been understood throughout this chapter, the possibility of TOD implementation in low density areas is far more complex than can be discussed by node place model. Indeed, the municipality study proves chapter's initial argument about the heterogeneity of stations in terms municipality characteristics, the roles each of them has within the territory, and the necessity of providing a more holistic and cooperative approach in planning TOD. The analysis also shows that the potential for further densification should not be overestimated in these areas. Finally, it is important to have in mind this chapter only reviews the physical aspects of development that can be contribute to the place value. However certain activities (e.g., tourism) or significant destinations (e.g., presence of a stadium of skiing facilities) which are in fact a part of the station, and of course municipality's characteristics can also contribute to place values, whether improve them or condition them. More than that, socioeconomic factors can play an important role in determining the possibility of TOD implementations. One of the most important factors is market value which can indeed affect the future developments. Other factors include the lifestyle of residents, their travel behavior of residence and other demographic data that have not been discussed in the scope of this thesis.

6 CONCLUSIONS AND FINAL REMARKS

6.1 SUMMARY OF FINDINGS

Global warming, congestion, air and noise pollutions, spatial segregations are just few souvenirs brought by our car-oriented cities today. In the search for more sustainable, inclusive alternative for settlements, the very first objective of this work was set to investigate in the relationship between land use and transportation as a popular a strategy to reduce negative externalities produced by both domains. Among the tools presented in the literature, Transit-Oriented-Development (TOD) introduced by Calthorpe (1993) is believed to be an effective way to align urban developments and transit in such way that promotes sustainable travel choices and lifestyle through increasing the walkability neighbourhoods while organizing activities around transit nodes. To shed more light on the concept, a literature review was conducted in two simulations way. First a general literature review to understand the aforementioned concepts, and a deeper citation to build a theoretical framework for further analysis.

Among the various approaches towards TOD in the literature, the concluding point of this step revealed a great literature emphasize on the high-density urban core. This is in fact understandable, because in its principle, TOD values an intense urbanization with high rate of mix-used ness around the transit node. While this approach may enhance the sustainability and livability in dense urban cores, it neglects the fact that in the absence of more sustainable transportation alternatives, many residents in small towns rely solely on the cars, therefore, implementation of a TOD strategy does not seem so relevant in these contexts as well. The necessity for a transit-oriented approach in the context of Italy can be understand through the fact that 61% of its national territory is characterized by low accessibility to services (Forme, Livelli e Dinamiche Dell'urbanizzazione in Italia, 2017). At the same time, the urban development is not always possible as the result of zoning regulations dictated by Regulatory General Plan (Piano *Regolatore Generale)* or because developments conflict with natural preserved sites or historical heritage. From this point, the question of the thesis emerged about the potentiality or constraints of implementing TOD in low density Italian towns.

To answer this question, the theoretical framework was used to extract methods that evaluate the TOD-ness of existing stations. Citations showed the popularity of the 'Node-Place' model introduced by Bertolini (1999). Here, node value means the intensity and diversity of transport supplies and place value indicates intensity and diversity of the activities within the station 'catchment area'. Ever since its introduction the node place model has been enhanced in many ways as shown in the theoretical framework. Among the studies, the paper by Nigro et. al (2019) seemed to be aligned with the objective of the work. The main difference between the model introduced by Nigro et. al (2019) and other node place models is introduction of another dimension to the place value as 'feeder transport' accessibility that considered other modes of transportation such as bike, public transport (bus) and even car because, walking is not the way by which residence of small towns use to reach to the station. The adopted methodology was enhanced through two sets of additional indicators. First, the qualitative indicators about pedestrians' roads and bike lanes were substituted with quantitative and measurable indicators (length of the sidewalks and the ratio of the bike lanes). Second, a set of indicators were added based on post pandemic situation of public transport. Both group of additional indicators were extracted from the articles cited in the theoretical framework. The application of methodology reveals certain followings as listed below:

1. Except for high-density station (Lingotto), all the stations exhibit a low accessibility by the main transport mode (train). However, any improvement in the train services would require an update in the accessibility of walk, bike, and bus feeder transport. This of course, requires a vertical coordination between region and municipality.
2. Medium and low-density stations are extremely car dependent. Results of the radar analysis showed that almost all the stations have the highest feeder transportation value in car catchment area.
3. The quality of pedestrian infrastructure is low in most of the cases. The sidewalks are in a poor condition, and in some areas, disrupted by private houses. In rural municipalities, there is not much separation between walkable paths and car roads and the roads get extremely informal especially in the areas further from the centre.
4. The quality and quantity of bike lanes are extremely low. Even in the case of urban and suburban stations, the ratio of bike lanes to total roads do not exceed 0.12 in none of the

catchment areas. Many roads do not have adequate infrastructure for cyclist, and in the case of availability, the lanes are not well connected to each other and get disrupted by car roads.

5. Bus network is not well connected to the train nodes. Especially in the case of rural stations it is the most critical accessibility issue. The closest bus station to the rural station still takes more than 10-minute walk. It is confirmed by the results of the node place as these stations have the lowest score in case of bus feeder transport.
6. The physical condition of stations is generally poor; For instance, the Moncalieri station is abandoned, while the service is working. It lacks ticketing service, and adequate furniture. Users are directed to the platform through a back door.

After a holistic analysis of the railway, a municipal analysis was conducted with the focus on the rural municipalities walk and bike catchment areas with the aim of assessing the feasibility of applying the strategies obtained by methodology with the municipal regulatory plan. The analysis shows that the portion of open spaces identified for further developments in the regulatory plan do not meet the density requirements of TOD. Unbuilt areas, despite being high in the quantity are subject to various constraints that limit further densifications. Moreover, in many cases, the areas covered by catchment areas go beyond the boundaries of municipalities. Therefore, densification strategies for these areas cannot be explained through the development plan of municipality where station is located and neighbouring should be realized as well. Figures 6-1 and 6-2 sum up all the findings for low density stations:

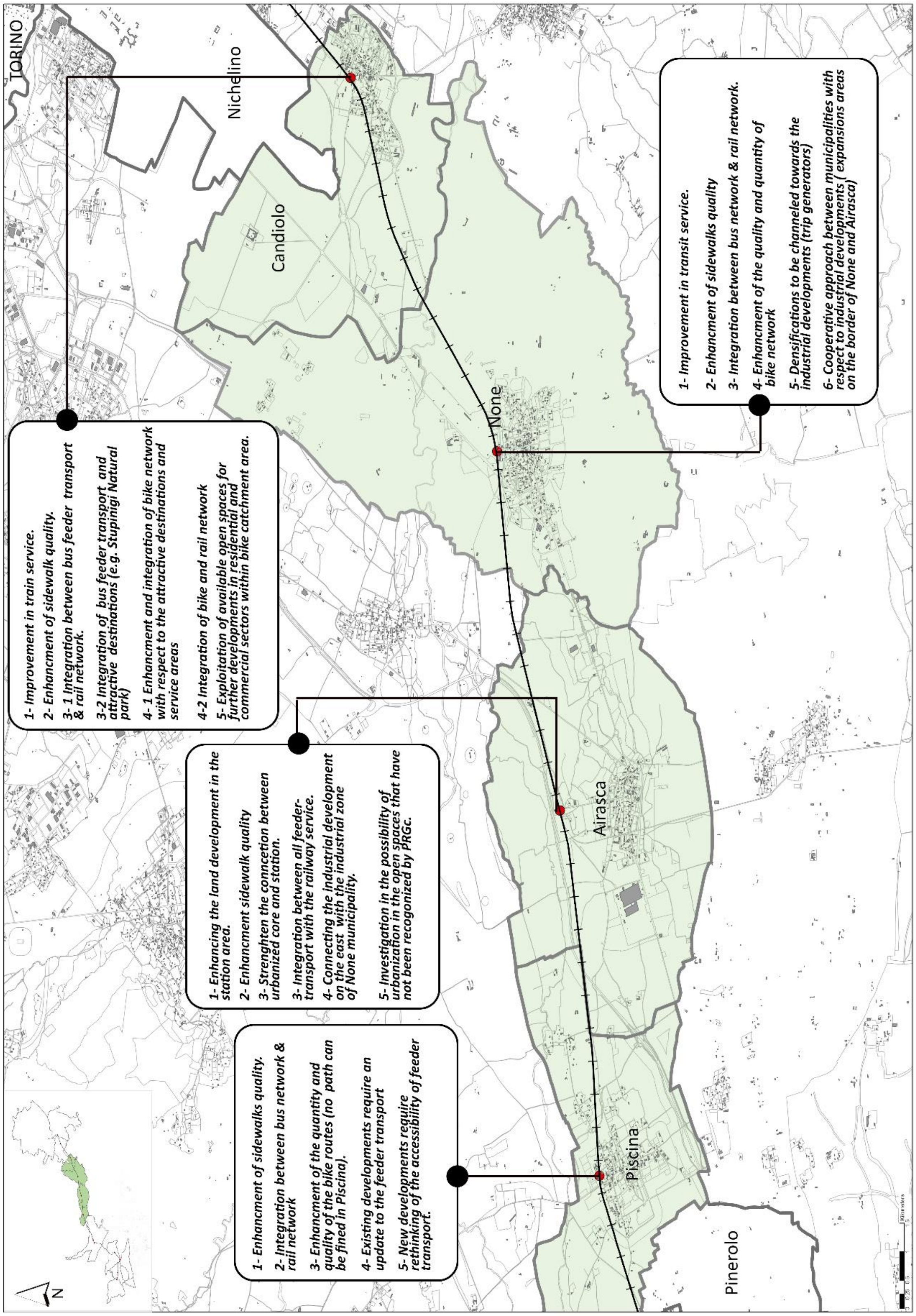

Figure 6-1 Final development suggestions for TOD in stations Candiolo, None, Airasca, and Piscina (elaborated by author)

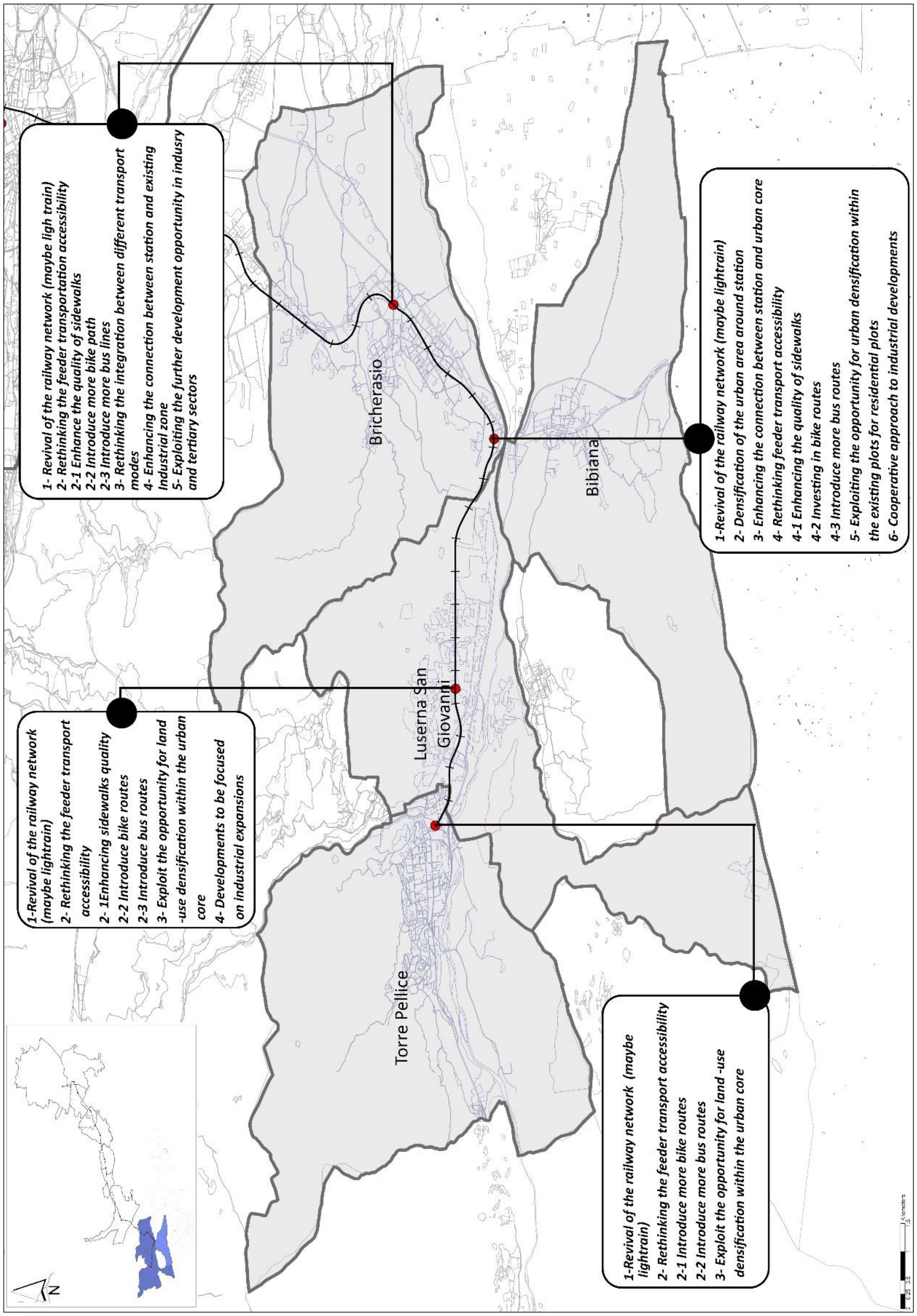

Figure 6-2 Final development suggestions for TOD in stations Bricherasio, Bibiana, Luserna, and Torre Pellice (elaborated by author)

6.2 Methodology Limitation and Further Elaboration

The implementation of the methodology showed a set of shortcomings with respect to the context of the case study. First issue is about conflicting catchment areas. Naturally, in a fixed time, distance travelled by bike, bus or car is much more than by pedestrians. This resulted in the catchment areas overlapping, considering the relatively short distance between them. In some cases, even five catchment area had overlays (Pinerolo stations). Here, the assumption was that all the areas have the same population, so the density values evenly distributed between the station. Such proximations might hinder the reality of density and its relationship with the station. For instance, in the case of Pinerolo stations, most of the population is agglomerated on the west of the municipality, closer to Pinerolo F.S stations. However, as the catchment areas of Pinerolo Olimipca station also covered those areas, the values have been distributed between two stations, while people may choose the bigger station. Here, using a more complex traffic model seems to be relevant. Second critic could be about the adoption of 12 minutes travel time and interconnectivity ratio. The aim of this thesis was to test the methodology, to see if it can work in another context as well so the same procedure is adopted. An alternative solution would be to choose a 10-minute travel time that is common in the most transportation studies.

Looking at the results of the node place analysis. It seems that node place analysis faced limitation in perceiving the stations individually, and only evaluated them detached from the context. However, it is important to have a more holistic perspective especially in the case of low density with less attractive (compare to stations in high density urban cores) surrounding. For instance, the stations Candiolo, None, Airasca and Piscina on one hand, and the stations Bricherasio, Bibiana, Luserna and Torre pellicle on the other hand, had almost same result because the capacity of transit services, land use and the accessibility to other transport modes are nearly identical. Consequently, planning strategies based on the node place model result were identical. This evaluation also hinders the fact that, these stations have very different characteristics when compared within the whole territory. Some of the differences were briefly pointed out in municipality analysis in chapter 5, but the issue needs to be further investigated to achieve more context-based results. Moreover, chapter 5 only evaluated the possibility to enhance population and employment density in walk and bike catchment areas. Ideally, bus and car buffers would be added to the municipality analysis however, this would require a more complex analysis and considering not just the municipalities with stations, but also adjacent municipalities.

Considering future improvement, the methodology can be elaborated particularly in case of place indicators. This study only used ISTAT date to calculate population and job densities, while other activities such as commercial and tourism can contribute to the place value. Significant destinations of each municipality (for instance Natural Park of Stupinigi in Candiolo, or Winter sports area in Torre Pellice) is another interesting criterion that affects the place value which can be integrated in the methodology. Integrating ecological and social consideration that can condition the TOD implementation is another factor that this methodology lacks. Market value is another important factor to be integrated due to its influence on the development. Other possible elaboration is related to post-Pandemic indicators. It must be noted that the choice of the indicators in this thesis was based on a little literature available about the issue. Most of these studies focus on the short-term effect of pandemic on public transportation and vice versa. However, this can be an interesting topic for future studies to assess the node and place performance of stations in a pandemic situation. Finally, another way to improve the result is to assign weight to each indicator depending on its relevance in different contexts. In this regard, it is important to note that planners are not the only stakeholders to identify which indicator is more important and which is not. The issue should be escalated to the politicians and even to citizens through participatory research to consider both more strategic and common views.

Nevertheless, given the simplicity of the methodology, it can only depict a general assumption about the station areas in need for further urban development, stations with the insufficiency of the transit services or even the need to enhance accessibility to the station where it is not even reachable.

7 BIBLIOGRAPHY

1. Abdullah, M., Dias, C., Mulay, D.Shahin, M., (2020). "Exploring the impacts of COVID-19 on travel behavior and mode preferences", *Transportation Research Interdisciplinary Perspectives,* Volume 8, 100255, ISSN 2590-1982, https://doi.org/10.1016/j.trip.2020.100255

2. Alarcon, F., Cho, Y.J.J., Degerstrom,A., Hartle, A., Sherlock, R., (2018). "The TOD Evaluation Method Evaluating TOD on Station Area and Corridors Scales". *University of Minnesota Digital Conservancy.* Derived from: https://conservancy.umn.edu/handle/11299/208305

3. Atkinson-Palombo,C., Kuby, M.J. (2011). "The Geography of Advance Transit-Oriented Development in Metropolitan Phoenix, Arizona, 2002-2007. *Journal of Transport Geography,* 19(2), pp 189-199

4. Austin, M., Belzer, D., Benedict, A., Esling, P., Haas, P., Minaitis, G., Wampler, E., Wood, J., Young, L., Sam, Z., (2010). "Performance-Based Transit- Oriented Development Typology Guidebook". Center for Transit-Oriented Development, Oakland, CA

5. Balz, v., Schrijnen, J., (2009). "From Concept to projects: Stedenbaan, the Netherlands." *In Transit-Oriented Developmentedited by C. Curtis, J. Renne and L. Bertolin*i, 75–90. Abingdon, Oxon: GBR Ashgate publishing Group.

6. Banister, D., (2005), "Unsustainable Transport: City Transport in the New Century", *Routledge Publishing*: New York, USA

7. Banister, D., (2008). "The Sustainable Mobility Paradigm", *Transport Policy Journal*, Volume 46. Pp 73-80

8. Barbieri, D.M., Lou, B., Passavanti, M., Hui, C., Lessa, D.A., Maharaj, B., Banerjee, A., Wang, F., Chang, K., Naik, B., Yu, L., Liu, Z., Sikka, G., Tucker, A., Foroutan Mir Hosseini, Naseri, S., Qiao, Y., Gupta, A., Abbas, M., Fang, K., Ghasemi, N., Peprah, P., Goswami, S., Hessami, A., Agarwal, N., Lam, L., Adomako, S. (2020). "A survey dataset to evaluate the changes in mobility and transportation due to COVID-19 travel restrictions in Australia, Brazil, China, Ghana, India, Iran, Italy, Norway, South Africa, United States". *Data in Brief.* Volume 33. 106459. ISSN 2352-3409

9. Beck, M.J., Hensher, D.A. (2020). "Insights into the impact of COVID-19 on household travel and activities in Australia-The early days under restrictions". *Transport Policy*. Volume **96**. Pp 76–93. ISSN 0967-070X https://doi.org/10.1016/j.tranpol.2020.07.001.

10. Bertolini, L., (1999). Spatial Development Patterns and Public Transport: "The Application of an Analytical Model in the Netherlands". *Planning Practice and Research,* 14(2), pp 199-210

11. Belzer, D., Autler, G., (2000). "Transit Oriented Development; Moving from Rhetoric to Reality". A discussion paper for The Brookings Institution Center on Urban and Metropolitan Policy and The Great

American Station Foundation. Derived from: https://www.brookings.edu/wp-content/uploads/2016/06/belzertod.pdf

12. Black, W. R, (2010). "Sustainable Transportation: Problems and Solutions", The Guilford Press Publishing: New York, USA.

13. Braswell, A., (2013). "Transit-Oriented Development: An Urban Design Assessment of Transit Stations in Atlanta". *Research paper presented to Georgia Institute of Technology*. Derived from: https://smartech.gatech.edu/bitstream/handle/1853/48754/DanielBraswell_Transit-Oriented+Development.pdf;jsessionid=9A80574AAC5609DE774E28EAD70CF7EB.smart1?sequence=1

14. Bucsky, P. (2020). "Modal share changes due to COVID-19: The case of Budapest". *Transportation Research Interdisciplinary Perspectives*. Volume 8. ISSN 2590-1982. https://doi.org/10.1016/j.trip.2020.100141.

15. Calthorpe, P., (1993) Calthorpe, P., Poticha, S., (1993). "The Next American Metropolis: Ecology, Community, and the American Dream". New York: Princeton Architectural Press

16. Caltron, I., (2009). *Histories of Transit-Oriented Development: Perspective on the Development of the TOD Concept*. University of California, Institute of Urban and Regional Development (IURD). Working Paper, No 2009, 02.

17. Campisi, T., Basbas, S., Al-Rashid, M.A., Tesoriere, G., Georgiadis, G. (2021). "A region-wide survey on emotional and psychological impacts of COVID-19 on public transport choices in Sicily. Italy." *Transaction on Transport Science*. Volume 2. https://doi.org/10.5507/tots.2021.010

18. Cartenì, A., Francesco, L., Martino, M., (2020). "How mobility habits influenced the spread of the COVID-19 pandemic: Results from the Italian case study". *Science of The Total Environment*. Volume 741. ISSN 0048-9697, https://doi.org/10.1016/j.scitotenv.2020.140489.

19. Caset, F., Teixeira, F.M., Derudder, B., Boussauw, K., Witlox, F., (2019). "Planning for Nodes, Places and People in Flanders and Brussels: Developing an Empirical Railway Station Assessment Model for Strategic Decision Making. *Journal of Transport and Land Use,* 12(1), pp 811-837

20. Cervero, R., Kockelman, K., (1997). "Travel Demand and the 3Ds: Density, Diversity, and Design". *Transport. Research Part D: Transport Environment*. Volume 2 (3), Pp 199–219. https://doi.org/10.1016/S1361-9209(97)00009-6

21. Cervero, R., (2002) "Built Environments: Toward a Normative Framework". *Transportation Research Part D*

22. Cervero, R., Murphy, S., Ferrel,C. Gogtus, N. Tsai, Y (2004). "Transit Oriented Development in the United States: Experiences, Challenges and Prospects". *Transport Cooperative Research Program.* Report 102. pp 99-116

23. Cervero, R. (2006). "Public Transport and Sustainable Urbanism: Global Lessons. "*University of California Transportation Center.* University of California, Berkeley, U.S.A.

24. Carlton, I., (2007) "Histories of Transit-Oriented Development: Perspectives on the Development of the TOD Concept: Real Estate and Transit, Urban and Social Movements, Concept Protagonist". *University of California, Berkeley.* p 20

25. Cervero, R., Guerra, E., Al, S., (2017) "Beyond Mobility". Island Press Publishing: Washington D.C, USA

26. Chen, X., and Lin, L. (2015). "Shanghai Hongqiao air-rail hub". *Habitat International 49*, 445- 453.

27. Chorus, P., and 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)*, pp45-58.

28. Cox, P., (2010). "Moving People: Sustainable Transport Development", Zed Book Publishing, London, UK.

29. Curtis, C. Renne, J, L. Bertolini, L. (2009) "Transit Oriented Development: Making It Happen". *Ashgate Publishing, Ltd.*

30. Deponte, D., Fossa, G., Gorrini, A., (2020). "Shaping Space for Ever-Chaning Mobility. COVID-19 Lesson Learned from Milan and Its Region". *Journal of Land Use, Mobility and Environment.* Special Issue. Pp 133-149. http://dx.doi.org/10.6092/1970-9870/6857

31. Edwing, R., Cevero, R., (2010). "Travel and the Built Environment. *Journal of the American Planning Association,* 76 (3), pp 265-294

32. Dijkstra, L., & Poelman, H. (2014). "A harmonised definition of cities and rural areas: The new degree of urbanisation" (Working Paper 01/2014). Retrieved from EU website: http://ec.europa.eu/regional_policy/sources/docgener/work/2014_01_new_urban.pdf

33. Echaniz, E., Rodríguez, A., Cordera, R., Benavente, J., Alonso, B., Sañudo, R., "Behavioural changes in transport and future repercussions of the COVID-19 outbreak in Spain". *Transport Policy.* Volume 111. Pp 38-52.

34. Ewing, R., Cervero, R. (2010). "Travel and Build Environment". *Journal of the American Planning Association*, 76(3), pp. 265-294. ISSN 0967-070X. https://doi.org/10.1016/j.tranpol.2021.07.011.

35. Greelings, H. Stead, D. (2002). Integrated Transport, Land-Use "Planning and Environmental Policy in European Countries". *European Journal of Transport and Infrastructure Research.* EJTIR 2. *3* pp. 215-232

36. Geerlings, H., and Stead, D. (2003). The integration of land use planning, transport and environment in European policy and research. *Transport Policy*, 10, pp. 187-196

37. Gkiotsalitis, K., Cats, O. (2021) "Public transport planning adaption under the COVID-19 pandemic crisis: literature review of research needs and directions," *Transport Reviews,* Volume 41. Issue 3, Pp 374-392, DOI: 10.1080/01441647.2020.1857886

38. Groenendijik, L., Rezari,J.,Correia, G. (2018). "Incorporating the Travellers' Experience Value in Assessing the Quality of Transit Nodes: A Rotterdam Case Study". *Case Studies on Transport Policy,* 6(4), pp 564-576

39. Guerra, E., Cervero, R., and Tischler, D. (2012). "Half-mile circle: Does it best represent transit station catchments? Transportation Research". *UC Berkeley: University of California Transportation Center* (2276), pp 101-109. Retrieved from: https://escholarship.org/uc/item/68r764df

40. Hasselwander, M., Tamagusko, T., Bigotte, J.F., Ferreira, A., Mejia, A., Ferranti, E.J.S. (2021). "Building back better: The COVID-19 pandemic and transport policy implications for a developing megacity". *Sustainable Cities and Society*. Volume 69. 102864. ISSN 2210-6707. https://doi.org/10.1016/j.scs.2021.102864

41. Herek, M. G., (2010). "Developing a Theoretical Framework and Rationale for a Research Proposal". In book: *How to write a Successful Grant Application.* Rockville, MD USA: Springer Publishing, pp 137-145

42. Higgins, C. D., (2015). "A Value Planning Framework for Predicting and Recapturing the Value of Rapid Transit Infrastructure" (Doctoral Dissertation). McMaster University.

43. Higgins, C.D., Kanaroglou, P.S. (2016). "A Latent Class Method for Classifying and Evaluating the Performance of Station Area Transit-Oriented Development in Toronto Region" *Journal of Transport and Geography.* 56, pp 61-72

44. Holden, E., (2007). "Achieving Sustainable Mobility: Every day and Leisure-time Travel in the EU", Ashgate Publishing, Ltd, p. 5,

45. Holden, E., Gilpin, G., Banister, D., (2019). "Sustainable Mobility at Thirty", Journal of Sustainability. 11(7):1. doi: 10.3390/su11071965

46. Huang, R., Grigolon, A., Madureira, M., Brussel, M. (2018). "Measuring transit-oriented development (TOD) network complementarity based on TOD node typology". *Journal of Transport and Land Use, 11* (1), 304-324.

47. Ibraeva, A., Correia, G.H.A., Silva, C., Antunes, A.P., (2019). "Transit-Oriented Development: A Review of Research Achievement and Challenges". *Transport Research Part A: Policy and Practice, 132,* pp 110-130

48. Jeffery, D., Derudder, B., Witlox, F., Teixeira, F.M., Boussauw, K., (2019). “Planning for Nodes, Places, and People in Flanders and Brussels an Empirical Railway Station Assessment Tool for Strategic Decision-Making”. *Journal of Transport and Land Use, 12*(1). pp 811-837

49. Jenelius, E., Cebecauer, M., (2020). “Impacts of COVID-19 on public transport ridership in Sweden: Analysis of ticket validations, sales and passenger counts”. *Transportation Research Interdisciplinary Perspectives*. Volume 8. 100242, ISSN 2590-1982, https://doi.org/10.1016/j.trip.2020.100242.

50. Kamruzzman, M., Baker, D., Washington, S., Turrell, G., (2014). “Advance Transit Oriented Development Typology. Case Study in Brisbane, Australia. *Journal of Transport Geography, 34,* pp 54-70

51. Khare, R., Villuri, V.G.K. (2020). “Urban sustainability assessment: “The evaluation of coordinated relationship between BRTS and land use in transit-oriented development mode using DEA model”. *Ain Shams Engineering Journal.* September 2020. DOI: https://doi.org/10.1016/j.asej.2020.08.012

52. Knox, P., and Pinch, S. (2010). “Urban Social Geographies. An introduction”, Routledge Publishing.

53. Levinson, David M. Krizek, Kevin J. (2007). “Planning for Places and Plexus: Metropolitan Land Use and Transport”. *New York: Routledge Publication.*

54. Li, Z., Han, Z., Xin, J., Luo, X., Su, S., Weng, M. (2018). “Transit-Oriented Development Among Metro Station Areas in Shanghai, China: Variation, Typology, Optimization and Implications for Land-use Planning”. *Land Use Policy, 82,* pp 269-282

55. Liu, Y., Singleton, A., Arribas-Bel, D., (2020). “Considering Context and Dynamics: A Classification of Transit-Oriented Development for New York City”. *Journal of Transport Geography, 85,* pp

56. Lokku, P.S., Parsad, C.S.R.K. (2018). “Framework for Establishing Feasible TOD Locations: A Case Study in HyderAbad, India”. *International Journal for Traffic and Transport Engineering. 8*(2). pp 228-240. DOI: 10.7708/ijtte.2018.8(2).07

57. Lyu, G., Bertolini, L., Pfeffer, K. (2016). “Developing a TOD Typology for Beijing Metro Station Areas”. *Journal of Transport Geography*. Volume 55. Pp 40-50. ISSN 0966-6923. https://doi.org/10.1016/j.jtrangeo.2016.07.002Maclntyre, F. (2020). “*Will Coronavirus Kill Transit Oriented Development".* Retrieved from: https://www.entuitive.com/ensight-trend-home/will-coronavirus-kill-transit-oriented-development/

58. Millard-Ball, A., (2016). “Pedestrians, Autonomous Vehicles, and Cities,” Journal of Planning Education and Research. October 27, 2016, doi:10.1177/0739456X16675674.

59. Modn Noor, N. (2020). “ TOD planning analysis by GIS approach”.*Journal of Architecture, Planning and Construction Management. 10*(1).

60. Monajem, S., and Nosratian, F. (2015). "The evaluation of the spatial integration of station areas via the node place model; an application to subway station areas in Tehran". *Transport Research Part D: Transport Environment, 40*,pp 14-27.

61. MOOVIT, (2020) *"Compare average commute times Moovit public transit Index".* Retrieved from: https://moovitapp.com/insights/en/Moovit_Insights_Public_Transit_Index-countries.

62. Muller, P.O., (2004). "Transportation and Urban Form- Stages in the Spatial Evolution of the American Metropolis". *Transportation Research Board.* New York, USA. Pp 59-85ISBN: 1593850557

63. Nigro, A. (2017). "Land use and Transport Integration in Small Cities and Towns". Università' Degli Studi di Napoli Federico II. Retrieved from: http://www.fedoa.unina.it/12169/

64. Nigro, A., Bertolini, L., Domenico Moccia, F. (2019). "Land use and Public Transport Integration in Small Cities and Towns: Assessment methodology and Application". *Journal of Transport Geography.* Vol. 74. Jan 2019. pp 110-124

65. Newman, WG and Kenworthy, JR (1989) "Cities and automobile dependence: An international sourcebook". *Gower, Aldershot, England*.

66. Newman, WG and Kenworthy, JR (1996) "The land use-transport connection". *Land Use Policy*, 13 (1), pp. 1–22

67. Okumori, K. (2020). "Towards a new society brought about by the COVID-19 pandemic; Transit Oriented Development (TOD) as a Network Hub" Retrieved from: https://www.nikken.co.jp/en/insights/beyond_covid_19_07.html

68. Papagiannakis, A., Vitopoulou, A., Yiannakou, A., (2020). "TOD in the Southern European City of Thessaloniki Introducing Urban Railway: Typology and Implementation". *European Planning Studies,* DOI: 10.1080/09654313.2020.1724267

69. Park, J., (2020). "Change in Subway Ridership in Response to COVID-19 in Seoul Korea: Implications for Social Distancing". *Cureus.* Volume 12. Issue 4. doi:10.7759/cureus.7668

70. Peek, G. J., Bertolini, L., and De Jonge, H. (2006). "Gaining insight in the development potential of station areas: A decade of node-place modelling in The Netherlands". P*lanning, Practice and Research*, 21(4), pp 443-462.

71. Peterson, L., Brunn, E., Kenworthy, J., (2010), "Introduction to Sustainable Transportation: Policy, Planning and Implementation, Earthscan Publishing,

72. Pojani, D. Stead, D (2014). "Ideas, interests, and institution: explaining Dutch transit-oriented development challenges". *Environment and Planning.* Volume 46. Pp 2401- 2419

73. Pojani, D., Stead, D. (2018), "Past, Present and Future of Transit-Oriented Development in Three European Capital City-Regions". *Advances in Transport Policy and Planning.* Volume 1, pp 93-118

74. Przybyłowski, A., Stelmak, S., Suchanek, M. (2021). "Mobility Behaviour in View of the Impact of the COVID-19 Pandemic—Public Transport Users in Gdansk Case Study". *Sustainability.* Volume 13. Issue 364. 10.3390/su13010364.

75. Pucher, J., Lefèvre, C., (1996), "The Urban Transport Crisis in Europe and North America", Palgrave Macmillan UK,

76. Rasca, S., Markvica, K., Peter Ivanschitz, B., (2021). "Impacts of COVID-19 and pandemic control measures on public transport ridership in European urban areas – The cases of Vienna, Innsbruck, Oslo, and Agder". *Transportation Research Interdisciplinary Perspectives*. Volume 10, 100376, ISSN 2590-1982, https://doi.org/10.1016/j.trip.2021.100376.

77. Renne, J.L., (2005). "TOD: Developing a Strategy to Measure Success". Washington, DC: *The National Academies Press*. https://doi.org/10.17226/23319.

78. Reusser, D., Loukopoulos, P., Stauffacher, M., and Scholz, R. (2008). "Classifying railway stations for sustainable transitions–balancing node and place functions". *Journal of Transport Geography, 16(3)*, pp 191-202.

79. Rodrigue, J.P, (2006). "The Geography of Transport Systems". Milton: Taylor and Francis Group.

80. Rodrigue, J,P. (2020), "The Geography of Transport Systems". *New York: Routledge Publication*. pp 185-186

81. Schaefer, K., Tuitjer, L., Levin-Keitel, M., (2021). "Transport Disrupted- Substituting Public Transport by Bike and Car Under COVID 19". T*ransportation Research Part A: Policy and Practice.* Volume 153. Pp 202-217. ISSN 0965-8564. https://doi.org/10.1016/j.tra.2021.09.002.

82. Singh, Y.J, Fard, P., Zuidgeest, M., Brussel, M., van Maarseveen, M. (2014). "Measuring transit-oriented development: a spatial multi criteria assessment approach for the City Region Arnhem and Nijmegen. *Journal of Transport Geography, 35,* pp 130-143

83. Singh, Y.J, Lukman, A., Flacke, J., Zuidgeest, M.,van Maarseveen, M. (2017). "Measuring TOD around transit nodes-Towards TOD policy".*Transport Policy. 56.* pp 96-11. DOI: 10.1016/j.tranpol.2017.03.013

84. Sharifi, A., (2016). "From Garden City to Eco-urbanism: The quest for sustainable neighborhood development. Sustainable Cities and Society. 20, 16

85. Stalmachova, K., Strenitzerova, M. (2021). "Impact of the COVID-19 pandemic on employment in transport and telecommunications sectors". *Transportation Research Procedia*. Volume 55. Pp 87-94. doi.org/10.1016/j.trpro.2021.06.009.

86. Staricco, L., Vitale Brovarone, E., (2018). "Implementing TOD Around Suburban and Rural Stations: an Exploration of Spatial Potentialities and Constraints". *Urban Research and Practice.* https://www.tandfonline.com/doi/full/10.1080/17535069.2018.1541475

87. Staricco, L., Vitale Brovarone, E., "Teaching Land Use-Transport Interaction in Italy: Towards and Interdisciplinary Pedagogy". *Planning Practice and Research,* 33:4, 474-490, DOI 10.1080/02697459.2018.1548206

88. Stead, D., and Geerlings, H., (2005). "Integrating Transport, Land-Use Planning and Environment Policy. Views of practitioners from Denmark, England and Germany. Innovation, 18(4), 443-453

89. Stead, D., Geerlings, H., Meijers, E., (2003). Integrated land use planning, transport and environmental policy-making: an international comparison. Volume I. OTB Research Institute for the Built Environment, Delft University of Technology, Delft/Erasmus Centre for Sustainable Development and Management, Erasmus University Rotterdam, Rotterdam.

90. Strong, K.C., Ozbek, M.E., Sharma, A., Akalp, D.(2017). "Decision Support Framework for TOD".*Journal of the Transportation Research Board.* January 2017. https://doi.org/10.3141/2671-06

91. Tarasi, D., Daras, T., Tournaki., S., Tsoutsos, T. (2021). "Transportation in the Mediterranean during the COVID-19 pandemic era". *Global Transitions.* Volume 3. Pp 55-71. ISSN 2589-7918. https://doi.org/10.1016/j.glt.2020.12.003

92. Terpo, A., (2018). "Critical Literature Review on Addressing Transport Challenges with TOD", Research Center of Sustainability, Published by: TAW2018 International Scientific Conference, POLIS University Albania. Pp 525-533

93. Thomas, R. Bertolini, L (2014). "Beyond the Case Study Dilemma in Urban Planning: Using a Meta-Matrix to Distil Critical Success Factors in Transit-Oriented Development." *Urban Policy and Research.* Vol. 32. pp 219-237

94. Thomas, R., and L. Bertolini. (2015). "Defining Critical Success Factors in TOD Implementation Using Rough Set Analysis." *Journal of Transport and Land Use* . 10(1). pp . derived from: https://www.jtlu.org/index.php/jtlu/article/view/513

95. Thomas, R., Pojani, D., Lenferink, S., Bertolini, L., Stead, D., and van der Krabben, E. (2018). "Is transit-oriented development (TOD) an internationally transferable policy concept?". *Regional studies,* 59(9), pp. 1201-1213

96. Thombre, A., Agarwal, A., (2021). “A paradigm shift in urban mobility: Policy insights from travel before and after COVID-19 to seize the opportunity”. *Transport Policy.* Volume 110, Pp 335-353. ISSN 0967-070X. https://doi.org/10.1016/j.tranpol.2021.06.010

97. Vale, D. (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*, pp 70-80.

98. van Lierop, D., *Boisjoly, G., *Grisé, E., and El-Geneidy, A. (2017). Evolution in land use and transport research. In T. Sanchez (Ed), Planning Knowledge and Research. Routledge, New York, USA.

99. Vernet, N., Coste, A., (2017)/ Garden Cities of 21st Century: A Sustainable Path to Suburban Reform. Urban Planning, 2. 4. ISSN 2183-7635. doi.org/10.1016/j.tranpol.2021.01.005.

100. Vickerman, R. (2021). “Will Covid-19 put the public back in public transport? A UK perspective”. Transport Policy. Volume 103. Pp 95-102.

101. WBCSD. (2001). Mobility 2001. World Mobility at the end of the Twentieth Century and its Sustainability. Retrieved from: http://wbcsdservers.org/wbcsdpublications/cd_files/datas/businesssolutions/mobility/pdf/Mobility2001-WorldMobilityAtEnd20thCentury-FullReport.pdf

102. Wegener, M., Fu¨rst, F., 1999. Land-Use Transport Interaction: State of the Art. Institute fu¨r Raumplanung, Dortmund.

103. Yigitcanlar, T., Kamurzzaman, M., (2014). “Investigating the Interplay Between Transport, Land Use and the Environment: a review of the literature”. *International Journal of. Environmental Science and Technology.* Volume. 11. Pp 2121–2132

104. Zemp, S., Stauffacher, M., Lang, D., and Scholz, R. (2011). “Classifying railway stations for strategic transport and land use planning: context matters!”. *Journal of Transport Geography, 19 (4)*, pp 670-679.

105. Zhang, J., Hayashi, Y., Frank, L.D. (2021). “COVID-19 and transport: Findings from a world-wide expert survey”. *Transport Policy.* Volume 103. Pp 68-85. ISSN 0967-070X. https://doi.org/10.1016/j.tranpol.2021.01.011.