A TOD Classification of Metro Stations: An Application in Naples

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Abstract Due to extensive use of private cars, cities are facing negative social and environmental impacts, including poor air quality, noise, health issues. Responding to these urgent challenges, some metropolitan areas are building new metro lines and stations. Certain studies demonstrate that a number of factors of the station's catchment areas may influence public transport use. Starting from this premise, this chapter applies a cluster analysis with the aim of understanding and classifying station areas. In details, the contribution proposes (i) a literature review on indicators used for station areas analysis; and (ii) a method to identify station areas typologies. The study proposes an application at the sixty-two rail stations of the city of Naples, where several interventions have been recently carried out on the urban rail network and in station areas, within an integrated land-use and transport planning approach.

1 Introduction

Urban rail systems have had the role of shaping metropolitan areas and providing a sustainable alternative to private car use. A considerable body of professional and academic research has analysed the factors influencing rail public transport use. Evidence suggests a compelling conclusion: while transit fares, safety and service quality have a significant impact on transit ridership (Redman et al. 2013), in the long run, public transport ridership is also influenced by attributes of the station catchment areas (Ryan and Frank 2009; Ewing and Cervero 2010; Lindsey et al. 2010; Sung and Oh 2011). These factors can indeed provide the necessary (albeit insufficient) conditions for shaping transit use, without which, urban rail policies would have

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limited effects (Suzuki et al. 2013). An assessment of such attributes around railway nodes could provide interesting insights for policy formulation aimed at changing public transport use through land use policies.

The integration of land use and transport policy around station areas has not just the potential to influence public transport use, but also to generate development returns that could help fund infrastructure improvements and enable sustainable high-density development.

Those are the principles of a Transit Oriented Development (TOD) approach (Bertolini et al. 2012; Cervero 2004; Dittmar and Poticha 2004), which are currently on the agenda of many metropolitan areas.

Studies show how each city and various different stations, could apply a TOD approach in diverse ways (Lyu et al. 2016). Context-based TOD typologies are thus essential to identify a more targeted set of strategies.

In the light of these issues, the primary objective of this study is to provide a simple and replicable GIS-based methodology for analysing station areas and their TOD classification. By classification, we mean a particular set of land-use and transport attributes of station areas. The identification of station areas classification is the first step towards the identification of integrated land-use and transport policy.

Using a similar methodology already applied in other studies (Singh et al. 2014, 2017; Atkinson-Palombo and Kuby 2011; Masoumi and Shaygan 2016; Papa et al. 2016), we propose a set of indicators describing TOD attributes and an application of Cluster Analysis that identify TOD classification of station areas. This methodology is applied in the city of Naples where several interventions have been carried out on the urban rail network with the opening of new stations and the re-development of associated urban areas, both in the central and peripheral areas of the city. Since 1994, as better explained in Sect. 3, Naples has been implementing an integrated approach to land use and public transport planning based on the integration of new lines and stations with urban development interventions or the renewal of station areas. For this reason, Naples has been selected as a study case for this research.

The remainder of this chapter is organised as follows: Sect. 2 proposes a literature review of TOD indicators, Sect. 3 describes the study area, the indicators used in the application and data sources, Sect. 4 discusses the methodology and the spatial analysis tools used in this study, while Sect. 5 demonstrates the results of the cluster analysis. The final section summarises the conclusions and proposes future research directions.

2 Literature Review: TOD Indicators

Quantifying the TOD degree of urban environments around railway stations requires measuring the attributes that might influence public transport use and the identification of significant indicators. Cervero and Kockelman (1997) propose a well-known model, called the 3Ds—land use density, diversity and urban design—as factors affecting public transport use. The relevance of these 3Ds factors is also emphasised in other studies (Calthorpe 1993; Curtis 2009; Lund et al. 2004; Evans and Pratt 2007; Ewing and Dumbaugh 2009; Renne 2009a, b) and can be summarised as follows:

- *Density* reflects the intensity of opportunities for interaction within a station area and its effects on travel demand. High densities are fundamental to supporting high-frequency public transport services. High density development around stations leads to high demand and customers patronage. Studies demonstrate however, that compact developments results in negative consequences for public health (Naess 2013);
- *Diversity* relates to the presence of different land uses (e.g. housing, offices, public services). Diversity produces a balanced demand for public transport over time (reducing differences between peak and off-peak periods) and space (in terms of direction of flow) while contributing to the vitality of an area;
- *(Pedestrian-oriented) Design* includes a range of elements that promote walking. Station areas characterised by highly connected street networks, small block sizes, and a continuous footpath system promoting access to stations on foot, thus increasing public transport ridership.

Besides the 3Ds factors, another important aspect that has been considered in recent literature relates to the intensity of economic activities in the catchment areas of stations. The reason for this is that higher economic activities lead to higher levels of travel activity and a higher public transport modal split.

Each of these factors can be measured in various ways, resulting in different indicators. To identify meaningful measures, we reviewed indicators proposed in the literature, as described in Table 1.

The articles reviewed have been selected from a broad assortment of literature according to the following criteria: (i) articles published in the last seven years in (ii) highly ranked academic journals and (iii) only focusing on factors affecting transit use in station areas.

The literature review suggests the recurrence of some indicators that could be clustered in four main categories: density, geographical proximity, functional mix and property values. The indicators used in this study reflect this categorisation.

Table 1 TOD indicators used in literature

	Residents density	Jobs density	Economic Activity density	Entropy	Job-housing balance	Land use mix	Street density	Intersection density	Average block length	Distance to the city center	Proximity of activities at the station	Average travel time	Number of business	Property values	Employment levels
Atkinson-Palombo and Kuby (2011)						•					•			•	
Bhattacharjee and Goetz (2016)	•	•	•			•							•		•
Cao and Porter-Nelson (2016)						•								•	
Cervero and Kang (2011)	•	•		•					•		•			•	
Hess and Almeida (2007)										•	•			•	
Duffhuers et al. (2014)	•		•	•		•							•		
Lyu et al. (2016)	•	•	•	•				•	•		•	•			
Hasibuan et al. (2014)	•				•	•									

(continued)

Table 1 (continued)

Higgins and Kanaroglou (2016)	•	•		•	•		•				•			•	
Jun et al. (2015)	•	•		•		•	•	•							•
Kamruzzaman et al. (2014)	•					•			•			•			
Kerkman et al. (2017)	•	•				•				•					
Monajem and Nosratian (2015)	•	•			•						•	•			•
Mulley and Tsai (2016)										•			•	•	
Nasri and Zhang (2014)	•	•		•					•	•	•				
Pagliara and Papa (2011)														•	
Reusser et al. (2008)	•					•									•
Singh et al. (2014)	•	•	•	•		•		•							•

(continued)

Table 1 (continued)

Singh et al. (2017)	•		•	•				•			•	•	•		•
Sohn and Shim (2010)	•	•				•	•	•		•					•
Sun et al. (2016)	•	•	•				•	•	•			•	•		
Sung and Oh (2011)	•		•	•		•	•		•	•		•			
Vale (2015)	•	•			•										
Zemp et al. (2011)	•	•											•		
Zhao et al. (2011)	•				•						•				

3 The Study Area

The study area corresponds to the administrative boundary of the city of Naples (see Fig. 1), the third largest city in Italy, with an urban population of 956,919 inhabitants, and one of the highest residential densities in Europe of 8,273,34 inhabitants per square km (Istat 2011). The urban structure of the city is characterised by a predominantly historical urban fabric.

The socio-economic structure of Naples is in a structural crisis, and influenced by the surrounding urban hinterland. The city has an extensive urban rail network, with low levels of service. The rail transport system has 62 stations and 79.4 km of track. There are six different lines.

Since 1994, the Naples Municipality has implemented an integrated approach to land use and transport planning based on the integration of new lines and stations with associated urban development and renewal (Cascetta and Pagliara 2008). *Land Use Strategies*, approved in 1994, was the first planning document that guided urban development towards an integration of new transport infrastructure with urban transformational processes.

Following this, the Naples Council developed further plans, such as the *Municipal Transport Plan* (1997), the *Primary Road Network Plan* (2000), the *100 Stations Plan* (2003) and the new *Urban Spatial Plan* (2004). At the same time the Regional and Provincial authorities approved some normative and programmatic tools, includ-

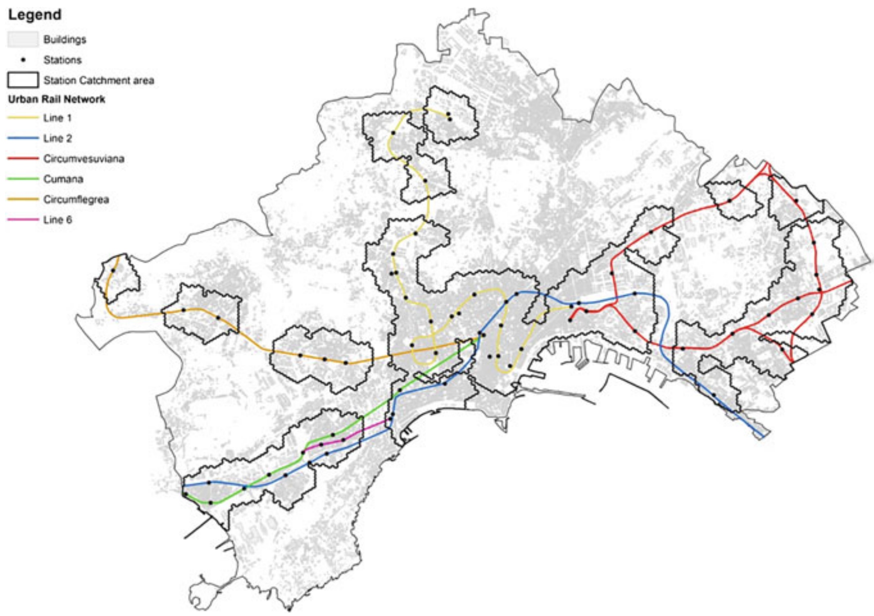

Fig. 1 Study area: the administrative boundaries and the urban rail network of the city of Naples

Table 2 Naples's Metro Network

Metro line name	Number of stations	Line length [km]
Linea 1	18	18.0
Linea 2	10	17.9
Circumvesuviana	16	22.2
Cumana	8	8.4
Circumflegrea	7	10.7
Linea 6	4	2.2
Total	**62**	**79.4**

ing the *Regional Law of Reform for the Mobility System* (2002) and the draft of the *Provincial Coordination Territorial Plan* (2007), which further encouraged the implementation of land use transport integrated policy. In these plans, the authorities underline the urgency of fostering the interconnection between transport and urban components. One of the innovative elements of these policies is the role of the urban railway transport network in supporting the renewal and development of central and peripheral areas (Cascetta and Pagliara 2008).

With this integrated approach, the metropolitan area of Naples benefitted from substantial investments that involved the construction of new metro lines and stations (Table 2). This generated an increase of public transport accessibility levels supporting redevelopment processes. The new *Urban Spatial Plan* for Naples identifies a specific strategy (Scope N° 30) for stations and interchange nodes. For these areas, the plan identifies interventions which seeks to "maximize accessibility, the redevelopment of buildings and roads and the introduction of new services that can support the localisation of new economic activities" (Comune di Napoli 2004).

4 Methodology

The methodology used in this study consists of five steps aimed at identifying a set of TOD indicators and TOD typologies of station areas. A desktop GIS package (ArcGIS 10.5) was used to develop this GIS-based procedure.

Step 1. Identifying the transport network. Open Street Map (OSM) was used as the primary data source to identify the pedestrian and public transport network. This platform provides open access spatial dataset using contributions from Internet users. It has been extensively used as a source of spatial data in many applications. However, the accuracy and the completeness of OSM data depends, among other things, on the number of contributors (Haklay 2010). To measure walking routes to transit stations, some topographic corrections were made to the original data and some missing street links where manually added.

Step 2. Defining the spatial unit of analysis. The diverse data sources that make use of different spatial units of analysis could potentially be problematic when measuring socio-economic data within a walking distance of a transit stations (Papa

Table 3 TOD indicators used in this study

Category	Indicators
Density	Population density
	Job density
	Economic Activities density
Proximity	Population proximity
	Job proximity
	Economic Activities proximity
Functional Mix	Population-job mix
	Entropy
	Land use mix
Property value	Housing property value
	Commercial property value
	Services property value
	Industrial property value

and Bertolini 2015). Consequently, we have selected a hexagonal grid element (with a sidelength of 50m) as the spatial unit of our analysis (Papa et al. 2017). We then allocate data to grid cells using the area-ratio method (Gutiérrez and García-Palomares 2008);

Step 3. Defining station catchment areas. Station catchment areas are broadly based on an understanding of how far people are willing to walk to ride public transport. One critical aspect to consider when defining station catchment areas is the threshold which determines the station's radius of influence. Various radii has been used in the literature. As already applied in other studies focusing on Naples, in this research we used 500 m radius that corresponds to an eight-minutes walking time (Pagliara and Papa 2011). Using the ArcGIS ERSI Network Analysis tool, catchment areas around each station were identified;

Step 4. Calculating indicators. The final set of indicators measured for each station is illustrated by the following Table 3. This selection of indicators reflects the literature review results. These indicators are those that can most easily be measured in the Italian context. In fact, all the data used to estimate these indicators are freely open accessible in the Italian context (see Table 4). The set of indicators include three different diversity measures: the entropy index, the mixed-use index and the jobs-housing balance. The entropy index measures the location of the different types of jobs, the mix use index measures the presence of different types of public services jobs, the jobs-housing balance measure the presence of both jobs and residents.

Using the ArcGIS ESRI Spatial Join Analysis tool, the following data was associated with each station: population and jobs (by sector); buildings footprints; street lengths; Euclidean and network distances from centroids (of the spatial unit) to the associated station. Following these steps, built environment indicators were calcu-

Table 4 Data sources

Data	Format	Source
Census unit area	Geometric (Polygon)	National Institute for Statistics ISTAT
Population	Alfa numeric	National Institute for Statistics ISTAT
Employees	Alfa numeric	National Institute for Statistics ISTAT
Economic Activity	Alfa numeric	National Institute for Statistics ISTAT
Property values	Alfa numeric	Tax Revenue Agency
Stations	Geometric (Point)	Open Street Map OSM
Walking street network	Geometric (Line)	Open Street Map OSM
Built environment	Geometric (Polygon)	Open Street Map OSM
OMI unit area	Geometric (Polygon)	Tax Revenue Agency

Table 5 Summary of the Cluster Analysis

Group	N° stations	Standard distance
I	17	0.256
II	8	0.584
III	7	0.684
IV	18	0.350
V	12	0.5038

lated for each station. Additionally, the value of the indicators was normalised to a 0 to 1 range.

Step 5. Classifying the station's catchment area. To identify station area typologies, we used the Arc GIS ESRI Grouping Analysis tool. The optimal number of groups was automatically determined by using the Calinski-Harabasz pseudo F-statistic (ESRI 2015). The final dataset consisted of 62 rows, one for each station area, and 13 columns, one for each indicator.

5 TOD Cluster Analysis Results

The final results of the cluster analysis were the identification of TOD categories of station areas. In the following tables, the main summary (Table 5) and the statistical results (Table 6) of the cluster analysis are reported.

The cluster analysis provided the identification of five TOD station areas clusters (Fig. 2): (1) Underdeveloped stations; (2) Jobs oriented stations; (3) Mixed central stations; (4) Medium Residential Stations; (5) Highly Residential Stations.

Table 6 Statistic result of the Cluster Analysis

Indicator	Average	Standard deviation	R^2
Activities density	0.3030	0.2771	0.8752
Activities proximity	0.2871	0.2581	0.8435
Land use mix	0.3648	0.2242	0.8382
Services property value	0.4175	0.2438	0.7939
Commercial property value	0.3935	0.2520	0.7828
Industrial property value	0.3190	0.2652	0.7593
Jobs proximity	0.2601	0.2609	0.7383
Jobs density	0.2554	0.2667	0.7310
Housing property value	0.3559	0.2463	0.7214
Entropy	0.2877	0.2125	0.7000
Population proximity	0.5081	0.2692	0.6650
Population-job mix	0.1509	0.1886	0.6591
Population density	0.4962	0.2731	0.6398

1. Seventeen stations classified in "Group I—Undeveloped Stations" are located in the peripheral areas of the study area, in east and north-west neighbourhoods. All indicators show values significantly lower than average values. Real estate values and densities are particularly low.
2. "Group II—employment oriented stations" is composed of eight stations. These are located in the hospital area (the line 1) and the east financial district. The positive indicators of the group show a density of employees situated close to the station above the average.
3. The seven stations of "Group III—mixed use central stations" are located in the central and historic neighbourhoods of the city. In these station areas, the density of economic activities is particularly high compared to the average of other stations. Real estate values for all land uses and the mixed use values are higher than the average.
4. "Group IV—medium value residential stations" station areas are located in neighbourhoods with a predominantly residential land use. The indicators of population density and proximity are higher than the average elsewhere, while the functional mix is low.
5. The indicators for the twelve station areas included in the "Group V—high value residential stations" have very high land values compared to the metropolitan average. These results indicate settlement densities and functional mixes higher near stations. Furthermore, in these areas, there are higher real estate values than other areas of the city.

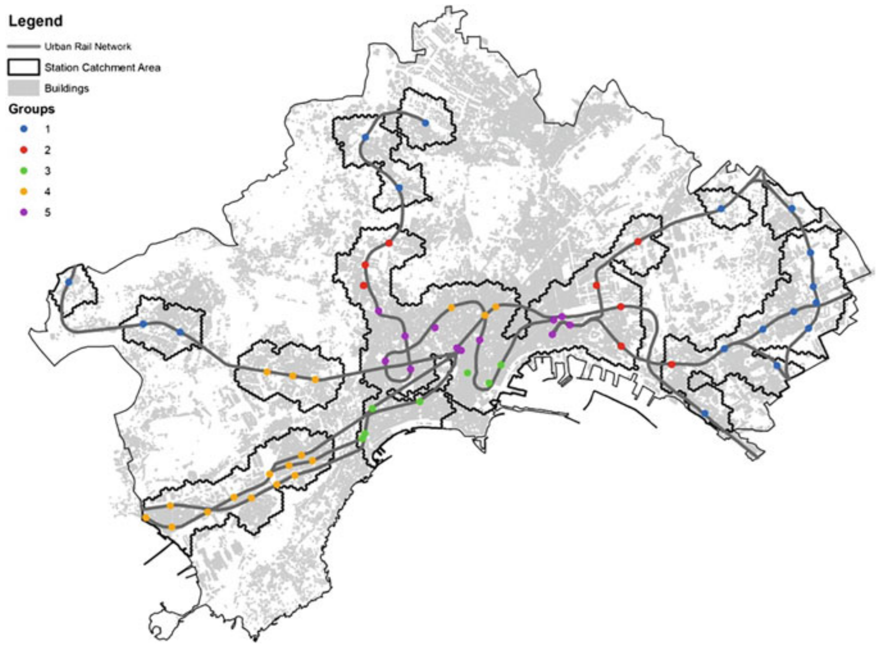

Fig. 2 The TOD station areas clusters

6 Conclusions

In this research, we developed and applied a GIS-based methodology for the classification of station catchment areas. By reviewing of international literature, we selected a set of indicators to analyse urban environments around urban railway stations to generate inputs for the future land uses and transport planning policies.

Furthermore, this methodology utilises the potentiality of spatial analysis and grouping tools of ESRI ArcGIS 10.5 (Fig. 3).

We believe that this GIS-based methodology represents a useful tool that could also be applied in other urban contexts to initiate a discussion for future uses.

Also, we applied this GIS-based methodology at the sixty-two urban rail stations in the city of Naples. The results could be useful for stakeholders involved in station areas transformation (local authorities, rail companies, private developers) to implement integrated land use and transport development strategies and projects. The similar characteristics of station catchment areas for the different groups could potentially allow local urban planners, designers and policymakers to develop a set of new strategies for each group. For the case of Naples, the results show an untapped potential for peripheral stations where the low values of density and functional mix indicators are important indications as input into decision-making processes.

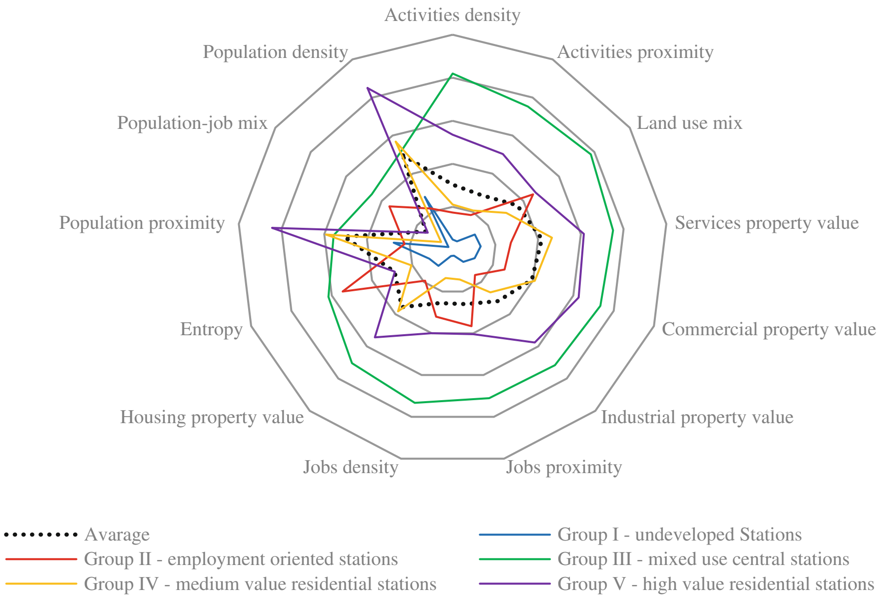

Fig. 3 The TOD station areas clusters, values of the indicators

As for the future research on these topics, to test the accuracy of GIS-based methodology, one future possibility might involve applying the model to different urban areas.

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