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An accessibility planning tool for Network Transit Oriented Development: SNAP

Enrica Papa*
Università degli Studi di Roma Tor Vergata
Dipartimento di Ingegneria dell'Impresa
Email: *enpapa@unina.it*

Francesco Domenico Moccia*
Università degli Studi di Napoli Federico II
Dipartimento di Urbanistica
Email: *fdmoccia@unina.it*

Gennaro Angiello*
Università degli Studi di Napoli Federico II
Laboratorio Territorio Mobilità e Ambiente TeMA*Lab*
Email: *gennaroangiello@yahoo.it*

Pasquale Inglese*
Università degli Studi di Napoli Federico II
Laboratorio Territorio Mobilità e Ambiente TeMA*Lab*
Email: *pasqualeinglese@gmail.com*

Abstract
In the academic debate regarding the influences between urban form, built environment and travel patterns, a specific idea that has taken hold is that more compact urban development around railway stations, often referred to as Transit Oriented Development (TOD), contributes to the control of vehicle travel and to more sustainable metropolitan systems.
According to this general principle this work proposes a GIS accessibility tool for the design of polycentric transit oriented scenario: SNAP - Station Network Accessibility Planning tool. In the first part the state of the art on Transit Oriented Development policies in Europe is presented with a focus on three study cases. In the second part the SNAP tool is described, with remarks to the approach, the methodology and the used indicators. Furthermore the paper discusses an application to the metropolitan area of Naples.
Key words
Transit Oriented Development, accessibility planning, network analysis

1 | TOD: a network approach

This work starts from the hypothesis that the integration between transport, land use and environmental policies is an effective strategy for the sustainable and balanced development of metropolitan areas and can be a tool to mitigate the negative externalities of car dependence, urban sprawl and the dispersion of mobility trips in space and time (Banister, 2002, 2008; Cervero, 1998; Meyer & Miller, 2001; TRB, 2004; European Commission, 2007). In particular, the used approach focuses on major concept in transport and land use planning in the last decades and on what is considered one of the most promising strategies for advancing environmental sustainability, economic competitiveness and socially inclusive development in cities, known as TOD - Transit

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Oriented Development. According to TOD, transit and land-use developments are tightly integrated and more compact urban developments around transit stations can contribute to the reduction of vehicle trips and the creation of more livable communities. Transit Oriented Development has dual-purpose strategy: the creation of a high-frequency public transport system and regionally coordinated urban development program based around the stations on the rail network. Since 1990, TOD has become the dominant urban growth planning paradigm in the United States, where the concept of Transit Oriented Development is closely connected with the Smart Growth (SG) and New Urbanism (NU) approaches (Cervero, 2004; Dittmar & Ohland, 2004). Gradually, the notion has been transferred to other parts of the world and in particular to Europe, where it is often extended to a regional or network approach (Knowles 2012; Bertolini et al. 2012; Papa, 2006; Papa et al., 2008). In other word, the "European TOD" or "Network TOD" is viewed, under the right conditions, as offering the potential not only to create attractive places in station catchment areas, but in a broader geographical scale, also to shape polycentric cities and regions, mitigate urban sprawl and boost public transport ridership, (Newman & Jennings, 2008; Curtis et al., 2009; Geurs et al. 2012). While the North American TOD born in an "urban design" context and started from the single station area development, in the Europe this principle has been drawn-out at the regional scale.

The remaining of the paper is organized as follows. A brief review of network TOD in Europe is presented in in the following paragraph. Section 2 present the planning tool SNAP through the application to the realistic case-study of Naples (Italy), whose objective, at current research stage, is limited to exploring the potentiality of the tool. Section 3 sums up some conclusions.

1.1 | Network TOD: experiences in Europe

In Europe, TOD is not just a recent phenomenon. In the late 19th and early 20th centuries a close association can be recognized between the development of streetcar (electric tram), underground and commuter railway routes and star-shaped urban forms. After the Second World War, and until at least the 1970s, in the northern Europe capitals planners were able to orient suburban development into satellite conurbations along transit served corridors. In recent years a "second generation" of European TOD is spreading in many European metropolitan areas (Crawford, 2000; Givoni & Banister, 2010). In order to give an overview of the regional cities development in Europe, we report a synthesis of three study cases where TOD policies have been implemented in the last 20 years: Munich, the South Wing of the Randstad area and Copenhagen.

Within the "Perspective Munich" plans (City of Munich, 1995, 2005, 2007) the City of Munich started an urban planning process which is based on the principles of Network TOD. In particular, in response to an increasing demand for land, the city recognizes to be functioning only within wider city region delimitation: the megacity region of Munich. In this perspective Munich assumes the responsibility to sustainably deal with its resources in order not to foster unwanted urban sprawl and not to increase mobility with private cars. The main tasks are to prevent the increasing CO2 emissions, to face the accelerated climate change and even the increasing costs of commuting mobility and infrastructure. In light of this, both regional and city level adopted a targeted, forward-looking approach to the use land resource: to give priority to inner city developments on brownfields, to increase housing density and adding new variety in city districts that are already well developed, and increase density of urban development in the immediate catchment areas of public mass transport, promoting polycentric development.

Another paradigmatic example is the South Wing of the Randstad area, where local and regional governments, Dutch Railways (NS) and the national rail network manager voluntarily work together since 2006 to implement an ambitious regional Transit Oriented Development program called *StedenbaanPlus* (Balz & Schrijnen, 2011; Geurs et al., 2012). The Randstad South Wing is one of the most densely populated areas in Europe with 3 million inhabitants located in the Western part of the Netherlands. The spatial structure is polycentric and population densities are spread out over many cities and towns such as The Hague and Rotterdam and many smaller centers. StedenbaanPlus aims to densify urbanization around more than 30 railway stations and improve access of station areas for bus and slow modes. The aim is to increase rail ridership to a level which allows NS to increase the local train frequency from 4 to 6 trains per hour. The StedenbaanPlus approach is aligned to the Draft National Policy Strategy for Infrastructure and Spatial Planning, in which spatial and infrastructure developments are to be better coordinated and integrated (Ministry of Infrastructure and Environment, 2011; I&M, 2012).

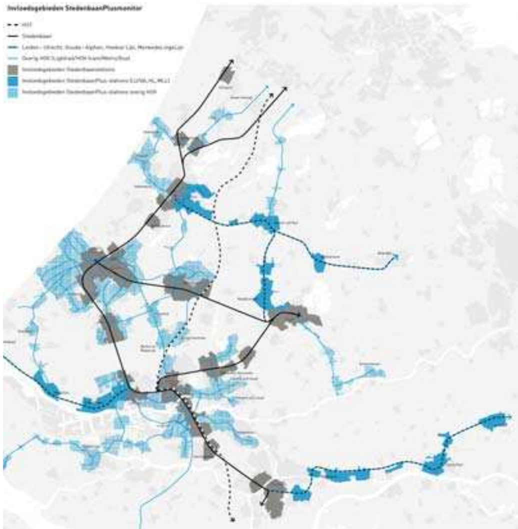

Figure 1. *The Network TOD strategies in the Stedenbaanplus plan for the South Wing of the Randstad area- The Netherlands.*

The third study case which is based on NTOD principles has been defined for the Copenhagen city region in the FingerPlan 2007 (Danish Ministry of Environment, 2007), a national planning directive for Greater Copenhagen, entered into force in August 2007. The plan is based on the “revitalising station proximity principle” formulated in a dialogue with the famous Finger Plan of Copenhagen, a well-known reference for planning of cities worldwide (Knowles, 2012). The Finger Plan has been the principal planning tool for the development of the capital region since its formulation in 1947. The FingerPlan 2007 establishes a framework for development in Greater Copenhagen and promotes urban development in close connection with the development of transport infrastructure and transport services. Since the first finger plan was adopted in 1947, the aim has been to concentrate urban development in the fingers created by the suburban railway network and the radial road network and to keep the green wedges between the fingers undeveloped. The new plan is built on the finger city structure created through the first finger plan in 1947 and concentrates settlement along transport corridors leading to the towns outside the City of Copenhagen with special consideration for providing public transport services. A new feature of the Finger Plan 2007 is promoting environmentally sound location by requiring location near stations. Large office workplaces exceeding 1.500 sqm of floor space will generally have to be located within 600 metres by foot from the closest station. The principle of requiring location near stations is expected to reduce car transport and reduce the environmental burden by considerably reducing carbon dioxide emissions.

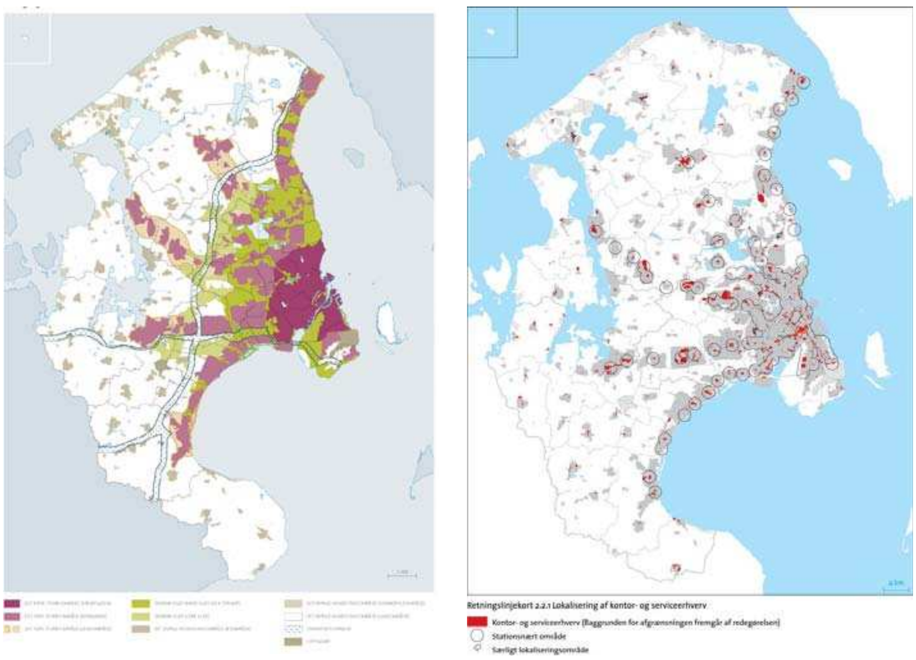

Figure 3. *The vision for the Greater Copenhagen defined in the FingerPlan2007 (to the left) and in the previous 2005 Regional Plan (to the right).*

2 | SNAP: an accessibility tool for Network TOD scenarios definition

The study cases presented in the previous paragraph are just some examples of most diffuse development strategy in European cities and city regions. We can say that in the majority of development plans of European city regions it is commonly asserted that polycentric compact developments around transit nodes is the urban development strategy most able to sustainably accommodate growth by reducing car use, travel distances and conserving land. The Network Transit Oriented Approach is used and applied in many different contests, but with the same policy measures.

In order to support the decision making processes based on NTOD and polycentricism principles we have developed a GIS accessibility tool which is based on the node-place model (Bertolini, 1999) and which is able to support the design of urban development according to network accessibility and activity density standards.

The tool, called SNAP tool (Station Network Accessibility Planning tool – www.snaptool.it) helps planners in developing transport rail system in combination with spatial development strategies. In other words, it helps defining densification scenario in line with sustainable transport infrastructures and services perspective and polycentric regional planning strategy. The basic elements of SNAP tool are:

- rail network: metro and regional rail lines and stations;
- rail station catchment areas: cluster of census tracks whose centroid is within the 500m buffer areas from the station exits;
- socio-economic data linked to the census tracks.

These basic elements are required for the definition of the station areas (SA) network which the tool is based on. Station areas are the station catchment areas defined by a 500 meters buffer from the rail station exit. This distance corresponds to the maximum time that transit users are willing to spend from the station to their final destination (Calthorpe, 1993). The tool defines different clusters of station area, according to the equilibrium between land use intensity and the network accessibility levels. To each cluster of equilibrium between these two characteristics corresponds different development opportunities.

In particular the tool allows the delineation of the most suitable station areas for the settlements of new activities in function of the following criteria:

- to increase density of urban development in the immediate catchment areas of rail transport, giving priority to inner-city developments on brownfields;
- to increase housing density in city districts that have high rail network accessibility;
- to promote polycentric development along rail network.

The tool implementation can be divided into three main steps, as described in the following paragraphs.

2.1 | The density and the network accessibility indexes

The first step of the tool implementation is the estimation of a density index and a network accessibility index. The Accessibility Index of a station area is measures using the Closeness Centrality index, which as the name implies, measures how centrally each graph element is located with respect to its position and centrality in the graph (Sabidussi, 1966). The Accessibility Index can be calculated with the use of different software or GIS tools, as the Urban Network Analysis (City Form Lab, 2012) or yED (yWorks GmbH, 2012). The network accessibility of the station *i* with respect to the Search Radius *r* it is estimated by the following formula:

$$C_i^r = \frac{1}{\sum_{j \in V-\{i\}; d[i;j] \le r} W_j d[i,j]} \quad (1)$$

where:

$d[i,j]$ is the shortest path distance between the node i and j on the rail network;

W_j is the weight of the destination node j (i.e. the total number of jobs of the station catchment area);

The density index of a station area is the mean value of the census tracks density that belongs to the station exit buffer of 500m. The station area density index is strictly related to the definition of the station area. The density index of each station *i*, made by the census tracks *k*, and it is calculated by the following formula:

$$Dens_i = \frac{\sum_k inh_k}{\sum_k Sup_k} \quad (2)$$

where:
inh_k is the population of the census track *k* that compose the station area *i;*
Sup_k is the total surface of the census track *k.*

2.2 | The station areas clusters and the development potential

The second step of the SNAP implementation consist in the comparison of the value of the two indexes for each station area, according to the Node-Place XY chart (Bertolini, 1999) which display station area as data points in the chart space according to the X and Y values for the value series. In the XY (scatter) chart the x value series corresponds to the "place index" of station areas (the density index) and the y value series corresponds to the "node index" of station areas (the network accessibility index). In particular the indexes values have been classified into a three folded scale according to the 33^{rd} and 66^{th} percentile in high, medium and low values. Based on these classifications, the XY chart has been divided into nine regions that correspond to seven station area series group or clusters (see Figure 4) that are described as follow.
Two main categories can be identified: the balanced and unbalanced station area. The balanced areas belong to the central part of the chart and can be articulated into:

- Balanced: these areas show equilibrium between the land use intensity and the transit accessibility and both indexes assume values close to the study area average value. In these areas urban renewal policies are suggested without increase of activities density.
- Balanced - stressed: in these station areas density and the accessibility indexes are very high. These areas are characterized by congestion and very intensive use. In these areas interventions of urban requalification are proposed.
- Balanced - dependent: in these station density and the accessibility indexes are very low. In these station areas actions to sustain increase both the node and the place aspect are suggested.

The unbalanced station areas belong to the side parts of the chart and can be divided into unbalanced node (where the transit accessibility index is higher that the land use index) and unbalanced place, where the contrary is true. They can be articulated into:

- High unbalanced node: these station areas are characterized by low activity density and very high value of network accessibility. These station areas have an extraordinary development opportunity, as they have a central position in the rail transit network and vacant land to be transformed within the catchment area.
- Unbalanced node: these station areas have a low activity density and a high value of network centrality; for this reason have a great potential to be transformed and to increase the land use in their catchment area.
- High unbalanced place: these station areas are characterized by very high activity density and low network accessibility index. In these area interventions to increase network centrality are suggested (increase the transit level of service).
- Unbalanced place: these station areas have a high activity density and a low value of network centrality. In these area interventions to increase network centrality are suggested (increase the transit level of service).

In any case the development potential and the suggested intervention have to be verified for each station in a second step project design, taking into account the real availability of vacant land and the presence of natural and environmental hazard constrains.

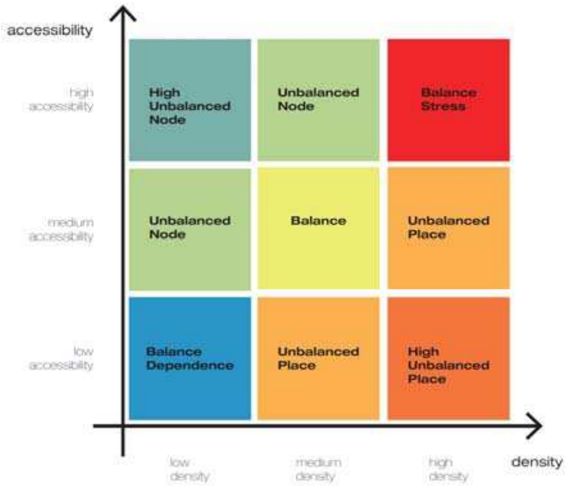

Figure 4. *The seven station area series group*

2.3 | An application of SNAP tool to the Naples metropolitan area

We choose to test the SNAP tool at the Naples metropolitan area for several reasons. The first is related to the structural urban contest: the high density of rail infrastructures and inhabitants, with its relevant commuting problems makes this area a fertile region for TOD strategy implementation and success. In the area indeed emerge the need to define polycentric development scenarios, to densify urbanization around railway stations and improve access of station areas for bus and slow modes. Another peculiar characteristic is that inside the area is defined the "red zone", that, being close to mount Vesuvius, is considered at high risk in case of a volcanic eruption. In this area the population needs to be dislocated and so in the all Naples metropolitan areas there is a need to define new location for residential settlements.
Another reason is that we can compare the result of the SNAP tool with the proposal of the ongoing regional and province plans that propose several policies oriented to a better integration of land-use and transport planning. In this way it was possible to verify or not the correct output of the tool.
In the following figures the study area, the network accessibility indicators and the density accessibility indicators are represented for each station area. In particular the "Closeness centrality to jobs" is referred to a search radius of 15 km. Furthermore, in table 1 the area series group and aggregated values of density and accessibility indexes are showed.

Table I: Station *area series group and aggregated values of density and accessibility indexes*

Station area series group	Inhabitants within 500 m station exit	Workplace within 500 m station exit	Inhabitants density within 500 m station exit	Station	Density index	Accessibility index
	n.	*n.*	*inh/ha*	*n.*		
Balanced	121.774	18.190	145,49	17	0,33	0,49
Balanced - dependence	163.669	35.029	52,38	91	0,12	0,17
Balanced - stress	271.628	81.549	282,66	17	0,63	0,83
Unbalanced node	233.954	71.905	126,84	36	0,28	0,54
Unbalanced place	154.291	30.368	138,41	24	0,31	0,22
High unbalanced node	29.616	32.438	55,19	24	0,12	0,72
High unbalanced place	33.122	8.511	230,61	3	0,52	0,19
total	**1.008.054**	**277.990**	**106,69**	**212**	**0,24**	**0,36**

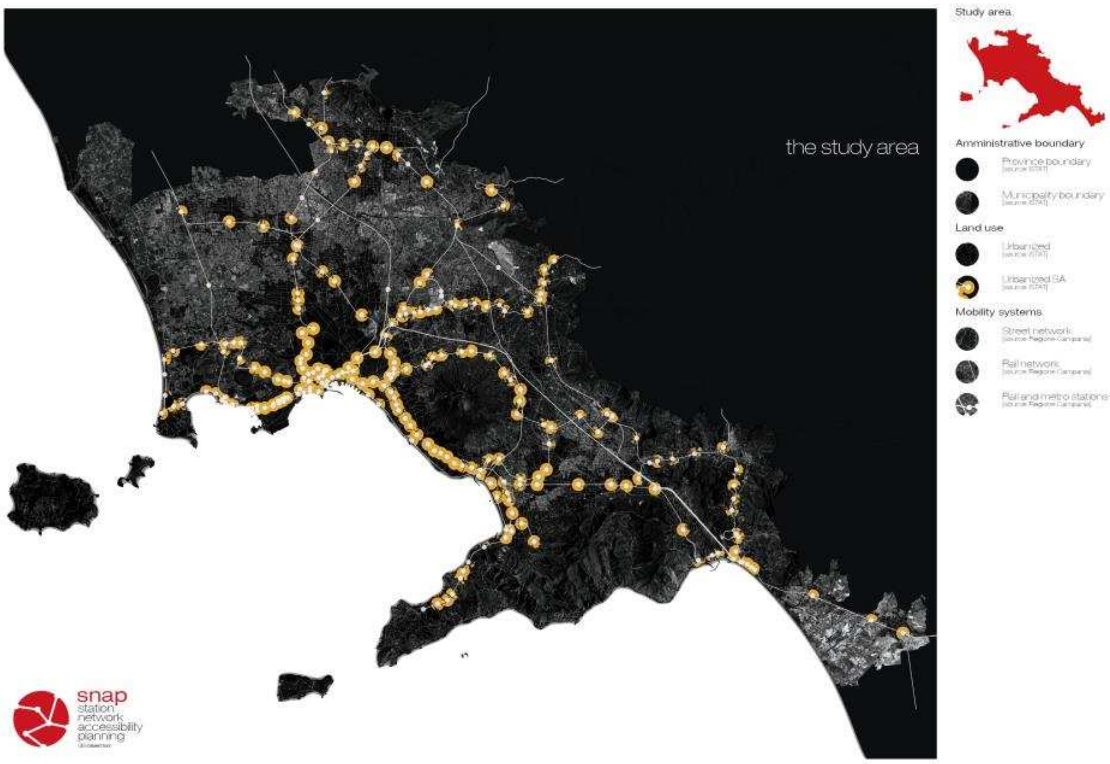

Figure 5. *The study area and the urbanized areas within the station catchment areas*

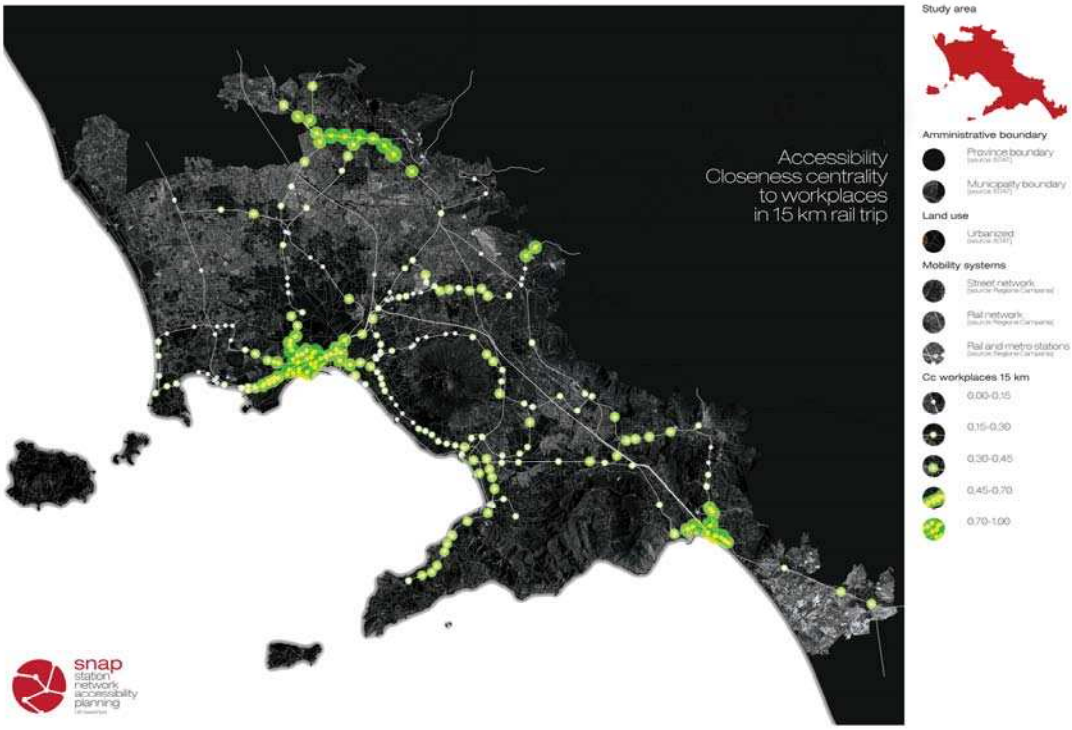

Figure 6. *Accessibility Index (Closeness Centrality to jobs with Search Radius r=15 km)*

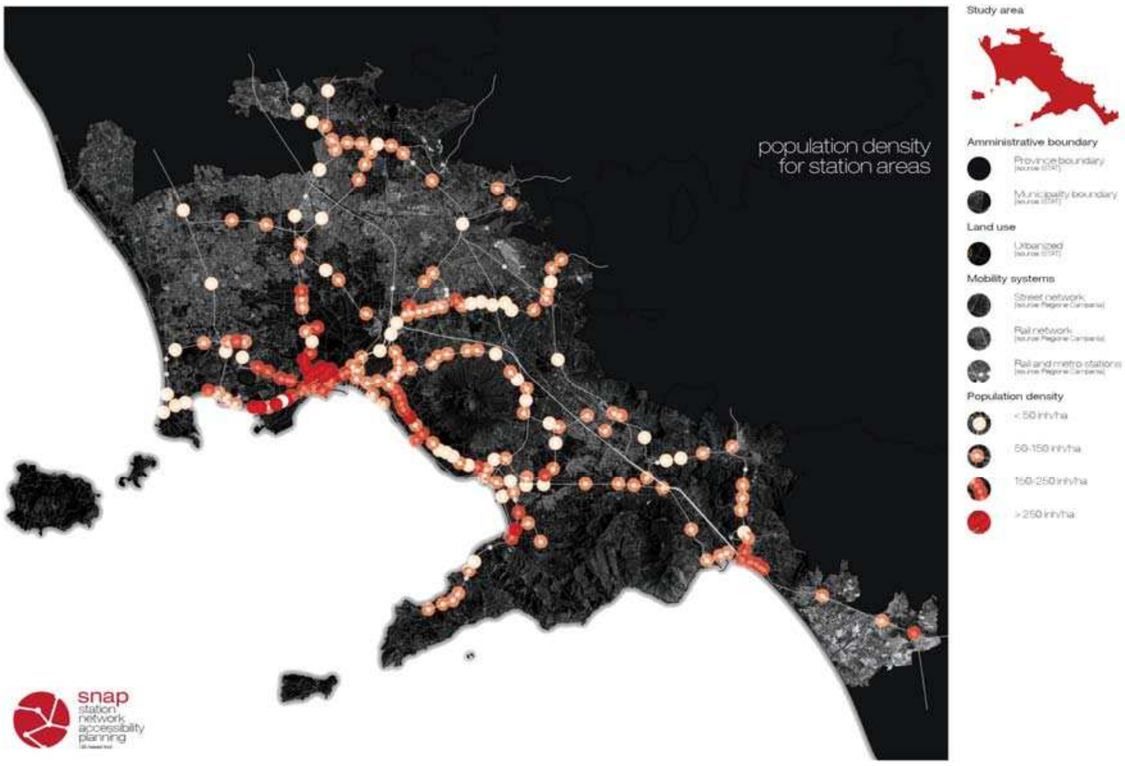

Figure 7. *Density Index (population density for station area)*

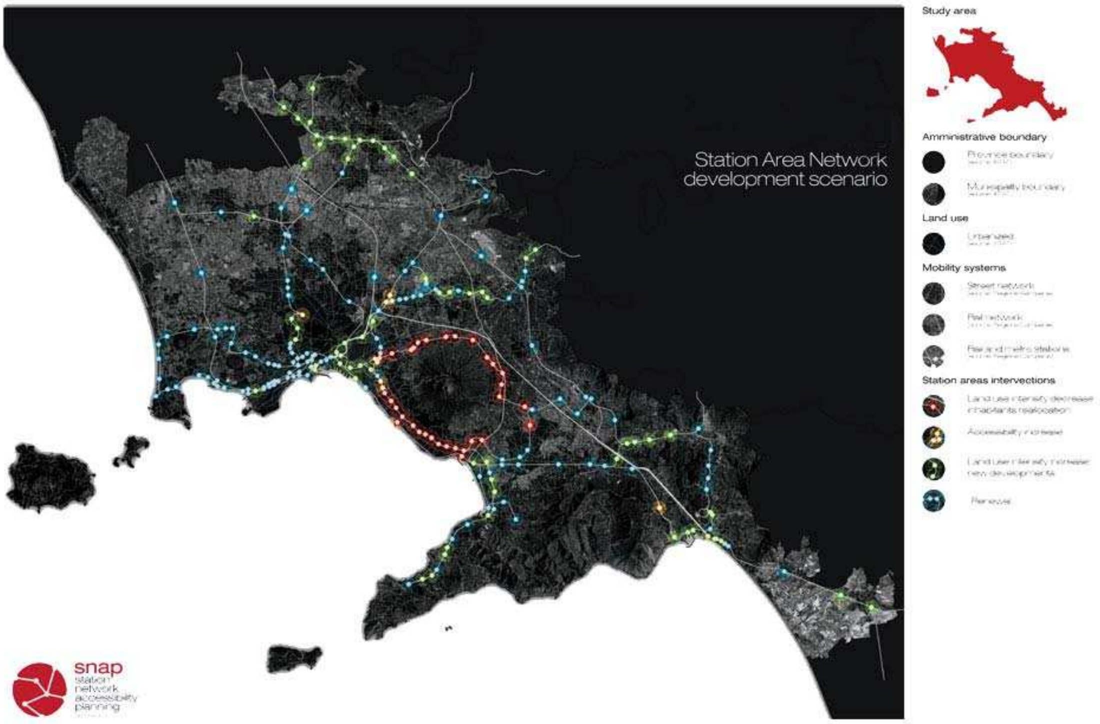

Figure 8. *The Network TOD scenario*

3 | Conclusions

The application of the instrument allowed the individuation in the areas of the lower Caserta Province and in the oriental zone of Naples (areas in green in Figure 8) as the most suitable areas for the localization of new activities in accordance to other studies developed with other methods (Moccia & Coppola, 2005). These results are furthermore mostly coherent with the strategies and interventions expected from the Province plans (Moccia, 2009), confirming the validity of the results obtained. At a closer exam of the catchment station areas, densification suggestion of the SNAP model cannot ever be achieved. Some other factors have to be considered regarding the prescriptions of the land use plans, the land regulations, vegetated land cover, urban morphology, public space and facilities. This means that a more complex analysis is required at a smaller scale. Combining this city knowledge with the SNAP results effective urban development or redevelopment may come out.
Nevertheless, on the regional scale, the great help given by SNAP is the broad view of the metropolitan network. Its usefulness consist in the systemic approach and the linkages of each localized action to the wider picture, letting the planner and decision makers to understand change both at the local as well as at the metropolitan level.
On a more pragmatic level, SNAP results select a limited number of target station areas where a deeper study can be carried on, ad decisions suggested. This simplification of the complex knowledge of large metropolitan areas is the more appreciable help in the regional planning tool set.

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