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A GIS as a Decision Support System for Planning Sustainable Mobility in a Case-Study

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Abstract

In this study we support the strategic environmental assessment process of the Coordination Plan of the District of Naples through the selection of an indicators set to monitor and evaluate the planned actions towards a sustainable mobility in the District. This process is implemented inside a GIS and its reliability is tested by linguistic hedges modelled from fuzzy sets.

Keywords: Fuzzy set, GIS, Indicator, Linguistic hedge, Sustainable mobility

1 Introduction

The appraisal of projects, plans and programmes has been an increasingly important element in the quest for sustainable development. In the last two decades, in response to the limitations of a project-based approach, practises such as strategic environmental assessment (SEA) and sustainability appraisal have been promoted.

The adoption of the European “SEA Directive”, Directive 2001/12/EC, is one of the highest profile policy development that has accompanied this shift.
Mobility is a major component in ensuring freedom of movement and good quality of life. It is strictly tied to the concept of sustainability, considering that more than 70% of European citizens live in urban areas. Enhancing sustainability is the attempt to relieve the pressures of current environmental challenges and mobility-related problems that most European urban areas are facing. High traffic volumes, congestion, bad air quality, noise pollution, consumption of no renewable resources, a high level of greenhouse gas emissions, social exclusion and urban sprawl are significant challenges to achieve sustainable urban development. Road safety is also an important challenge because of the social and economic costs of road accidents. Therefore it is an essential component of a sustainable mobility.
Local authorities are primarily responsible for urban policies according to the principle of subsidiarity. Nonetheless, the European Union has played a key role since 2001, with the adoption of the “White paper on transport policy”. In order to offer specific help for promoting a new culture of urban mobility to local authorities, EU adopted a combination of policy intervention and guidance support. At a policy level, the Green paper “Towards a new culture of urban mobility” in 2007 and the “Action plan on urban mobility” in 2009 represent a milestone. With these two documents, the EC acknowledges the differences that exist between European cities, recognize that they all face similar challenges and stresses the need to implement an approach that should be as integrated as possible. Based on existing policy developments, the EC has also promoted several guidelines and instructions. CIVITAS (CIty-VITAlity-Sustainability Initiative) is probably one of the best known tool for helping European cities in implementing better integrated sustainable urban transport strategies. But there have been many other guidance initiatives, such as ELTIS, TERM, PROPOLIS, some of them dealing with the research of indicators for monitoring sustainable mobility plans [1÷6, 13].
In this study we support the SEA process of the Coordination Plan of the District of Naples through the selection of an indicators set to monitor and evaluate the planned actions towards a sustainable mobility in the District.

2 The Coordination Plan of the District of Naples

The District of Naples has a very high population density. The 5.816.999 inhabitants of Campania are the 9,7% of the national population, but the regional area is only the 4,5% of the national one. What’s more, the 52,8% of population in

Campania lives in the District of Naples, in an area that is only the 8,6% of the whole region. The density is 1.903 inhabitants/square kilometre, whilst in Milan (resp., Rome) we have a density of 927 (resp., 483) inhabitants/square km. As a consequence, accessibility to goods and services is the major theme for a land with the features previously described and sustainable mobility can be the only way to guarantee accessibility.

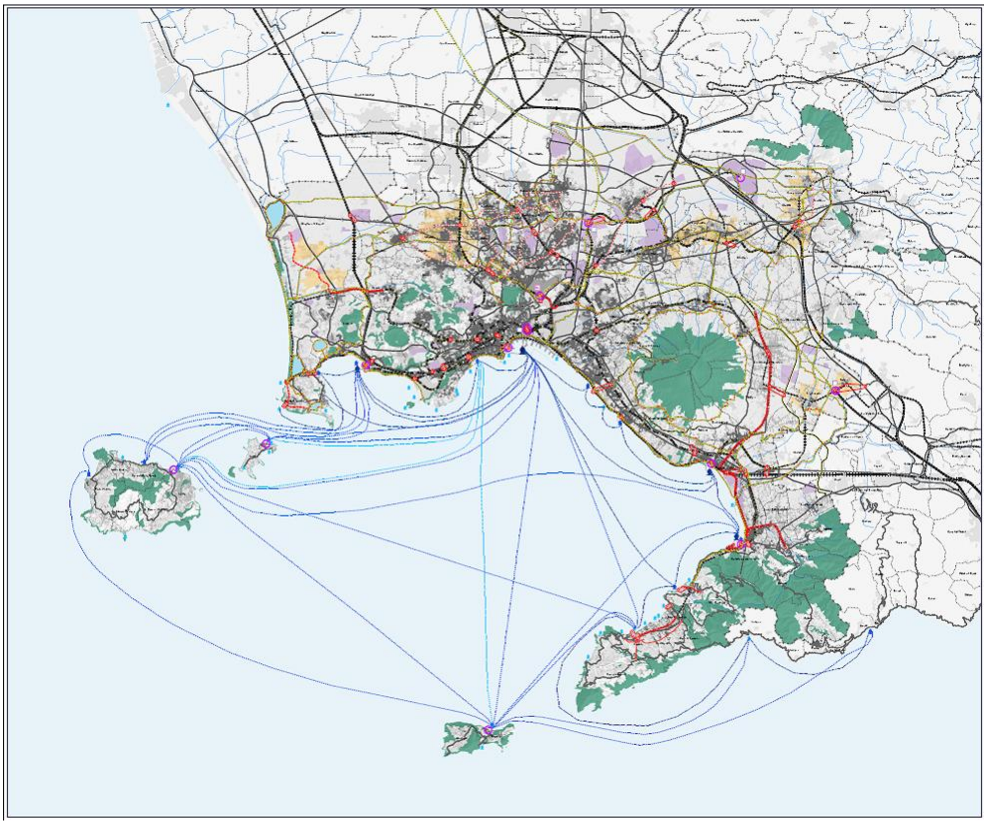

Fig. 1. The Coordination Plan of the District of Naples: mobility table

The Coordination Plan of the District of Naples, so called PTCP – Piano Territoriale di Coordinamento Provinciale- outlines the main features of the territorial development in its 92 municipalities [13]. It takes as a starting point the high concentration in the city of Naples and the high density of the shoreline and develops a net consisting of a set of centres with different level of services to support movement of people and goods. These centres are placed close to the poles of

transportation infrastructures. According to [9], the realisation of a polycentric scheme through the PTCP is supported by the completion of the integrated rail system by Regione Campania, so that the District planning action is focused on the development of services and high density housing in the connection poles, avoiding suburban sprawl and reducing private motorised transport.
The PTCP of Naples attempts to reduce and rationalise the need of mobility at the same time, trough the best exploitation of the projects at national and regional level, such as the high speed railway between Rome and Naples and the regional railways system, and the integration between urban planning and existing infrastructures. In this direction, the PTCP finds out three components:

- Naples with the little towns in the immediate surroundings: they must be considered as a whole and must be connected by the subway;
- towns with a strong commuting phenomenon: their identity must be strengthened to let them become intermediate poles of the connection net;
- towns with strong identities and specific functions, such as Nola and Giugliano: they must become the centre of local mobility and main poles for the connections to Naples and to the other major cities of the Region.

According to the plan, the District of Naples will be directly responsible for localisation and realisation of modal interchange stations, interchange parking lots, district cycle track, short connections, such as funicular railways and lifts. The realisation of these actions will complete the mobility net.

3 The selection of indicators

The Planning Code of the PTCP prescribes that the offices in charge of the Plan and of the Geographical Information System should evaluate the performance of the plan during its realization, in order to verify if the goals are achievable and if corrective actions should be taken into account. The Environmental Report attached to the Plan prescribes to link each topic of the plan to a unique index resulting from a set of specific indicators [13]. Considering that the plan has not been approved yet and that major changes could still take place according to the new political guidance of the District, we examined sustainable mobility applied to 2 out of 11 areas which the district has been divided into. The main aim of this research is highlighting the method to build indices. We selected an indicators set suitable to the area of the District of Naples, in order to obtain a unique index for sustainable mobility, through the valuation and the weighting of the selected indicators. We applied this method to the North Naples Area and Giuglianese Area (Fig. 2) because they lack mobility infrastructures according to the plan itself. The goals of the Plan linked to sustainable mobility are summarised in Fig. 3.

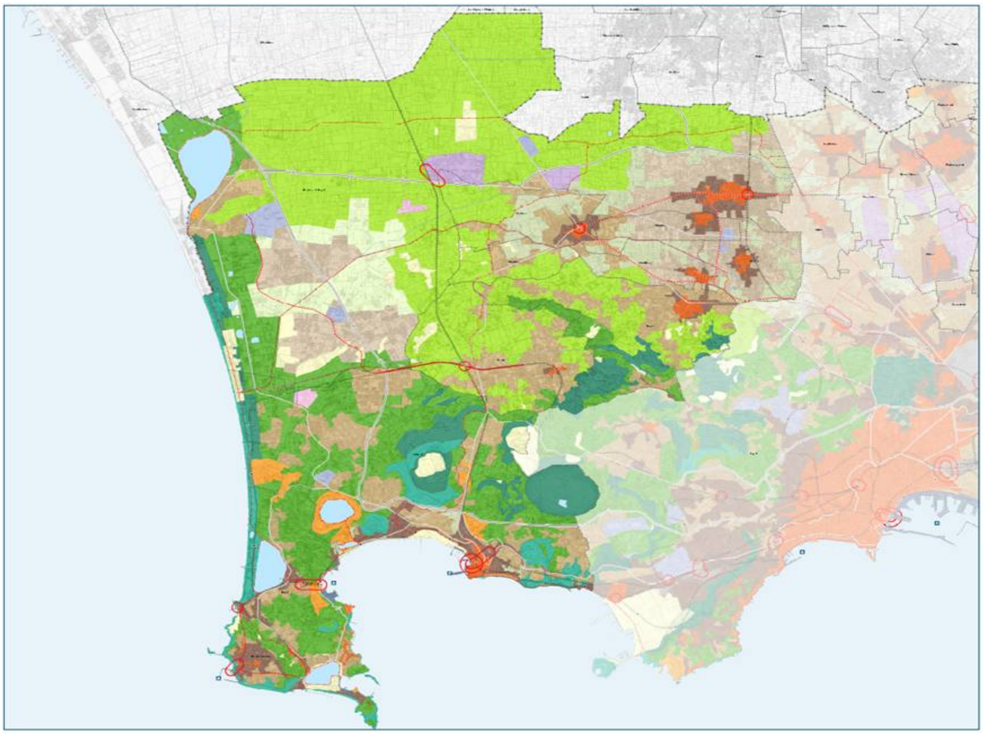

Fig. 2. Coordination Plan of the District of Naples: the Giuglianese Area

The selection of 22 indicators for sustainable mobility is the result of the intersection between the lists available in scientific literature and the databases available for the District of Naples. According to the PTCP Environmental Report, the use of existing databases is highly recommended to avoid double checking, which would result in a waste of public funds.

Lists of indicators applicable to sustainable mobility can be found in studies applied to urban development and to transportation system as well. Indeed, there are only few applications for sustainable urban mobility [8]. Indicators lists area are available in several EU initiative. We have selected and analyzed in detail the following ones:

- European Common Indicators: the initiative was promoted in 1999, and resulted in the selection of ten indicators related to sustainable urban planning; some of them, such as local mobility and passenger transportation, are directly tied to sustainable mobility;
- TISSUE, Trends and Indicators for monitoring the EU thematic Strategy on Sustainable development of Urban Environment: it was developed from 2004 to 2007; it analyzes the indicators developed within the V Programme in the DPSIR (driving forces, pressure, state, impact, response) framework; the selected indicators are divided in five areas, one of them is dedicated to mobility;
- TERM, Transport and Environment Reporting Mechanism: developed since 1999, the main goal of the initiative is defining an indicators list related to transport field and applicable to EU members; the list of indicators is updated and monitored on a yearly base;
- PROPOLIS, Planning and Research of Policies for Land Use and Transport for Increasing Urban Sustainability: developed from 2000 to 2004, it tested and integrated land use and transport policies, tools and comprehensive assessment methodologies to define sustainable long run urban strategies and to demonstrate their effects in European cities [6].

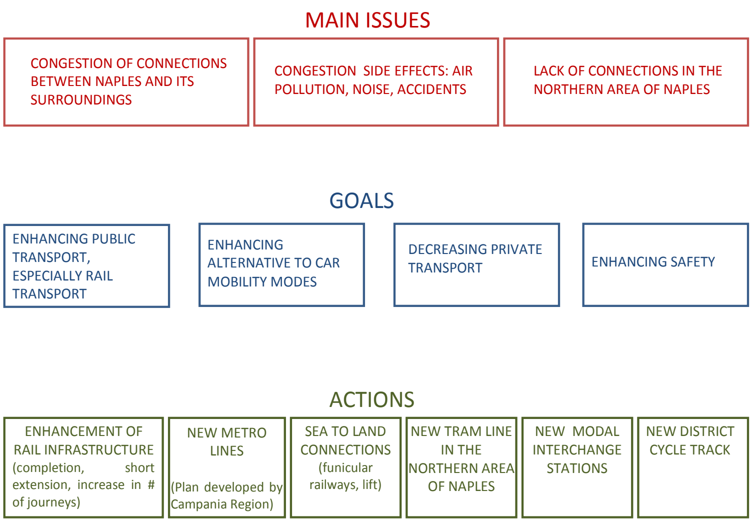

Fig. 3. Mobility in the Coordination plan: issues, goals and actions

List of indicators can be found in literature as well. Litman [7] lists 39 indicators divided into three groups (fundamental, optional and expert). Jeon and Amekudzi [5] analyse 16 studies related to transport indicators and get a list of 16 elements. Costa et al. [3] identify a list of indicators through a internet research and then select a final list of 24 items resulting from a weighting process via analytical hierarchy process with an expert team. Barker [2] analyzes the San Antonio – Texas - transport system, using per capita miles-vehicle travel as a key indicator. All the phenomena connected to congestion are linked to this indicator and strategies for increasing sustainability are suggested.

Moreover, all national and local databases available for the District of Naples have been analysed, in order to verify if they could contribute to the definition of the indicators. At a national level, ISTAT, the Italian Institute of Statistics, ISPRA, the Institute of Environmental Protection, and ACI, the Automobile Club of Italy, have been very helpful to define some of the selected indicators, such as the percentage of people either walking or biking to school or to work and the percentage of cars respecting emission thresholds. At a local level, we analyzed the database of ARPAC, the Regional Agency for Environmental Protection. It monitors a wide set of pollutants that are directly tied to mobility. The pollutant detection units net is not widespread in the whole Region. In fact it is designed to monitor pollutants in the five main towns. However it has been helpful to define trends and thresholds for each indicator. The District of Naples has a complementary pollutant detection net: it has not been fully developed yet but it is going to be increased to cover most of the area. The results of the monitoring activities are published by the Environment Section of the District.

The District is also undertaking several actions in the field of road safety: a database of roads accidents, seriously injured and deaths has already been developed. However it should be updated. Finally, the District of Naples is responsible for the local public transport companies through its Transport Section. Its database has been very helpful to define several indicators, such as the percentage of people living within 300 meters from a bus stop and the yearly public funding for local public transports.

We can say that one of the strength of this study has been the integration of all the databases available in the District of Naples in a planning perspective via the GIS.

To select indicators, two approaches can be used: bottom up and top down. In the former, indicators are selected by citizenship and stakeholders. This approach enhances the transparency of the process and the social learning during the appraisal process. In the latter, indicators are selected by technicians: this is the approach that has been adopted in this study, according to the PTCP Planning Code.

The first result of the research is the list of 22 indicators (Table 1) for monitoring sustainable mobility in the District of Naples.

4 Getting the indicators

In order to get the indicators, it is necessary to process the available data in a geographical framework through GIS. Hereby it is reported the procedure to get one of the selected indicators: the percentage of people living in a walking distance from a metro/railway station. The European Environmental Agency defines *walking distance* as a length that can be covered in fifteen minutes, that means more or less 300/500 metres. The data available to process this indicator (Fig. 4) are the shapefiles of the District railways system and of census islands, and the database of national census.

INDICATORS			Dimension weights	Indicator weights
Environment	1	Maximum value of CO	30.05	7.39
	2	Maximum value of NO_2		5.50
	3	Maximum value of O_3		4.09
	4	Maximum value of particulate		5.88
	5	Maximum value of SO_2		4.93
	6	percentage of cars respecting emission thresholds		2.26
Economy	7	Yearly Public Transport funding	21.43	10.06
	8	percentage of vehicles/square km		3.38
	9	No. of inhabitants/ No. of cars		4.13
	10	No. of inhabitants / No. of motor bikes		3.85
Society: liveability	11	Yearly No. accidents	15.29	4.55
	12	Yearly percentage of seriously injured and deaths		3.48
	13	percentage of accidents/area		1.66
	14	percentage of seriously injured and deaths/area		1.38
	15	percentage of people exposed to harmful noise		4.21
Society: accessibility	16	percentage of people walking/biking to school/work	33.23	5.07
	17	percentage of people living within 300 meters from a bus stop		6.07
	18	percentage of people living within 500 meters from a metro station		7.86
	19	Bicycle track length/inhabitants		3.13
	20	Bicycle track length/main roads length		2.76
	21	Railways and main roads length/area		3.18
	22	Railways length/area		5.16
		TOTAL	100	100

Table 1. Selected indicators list and results of weighting process

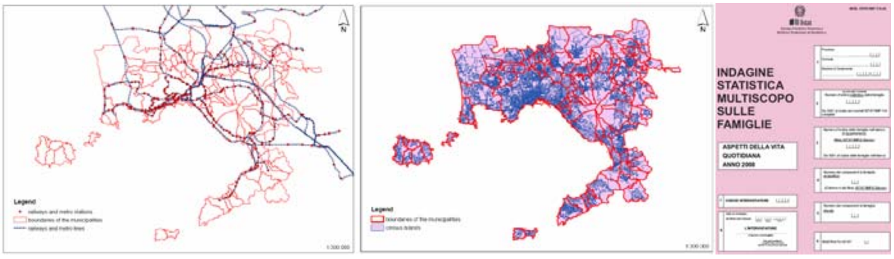

Fig. 4. Shapefile of rail tracks and stations, shapefile of census islands in the District of Naples, cover sheet of Italian census questionnaire

Firstly the census data base was joined to the shapefile of census islands on the base of the islands Id. Then the average population has been calculated in every island (Fig. 5).

Secondly, a new feature class containing the geographic subset of our case study has been created by clipping the District data set on the boundaries of the analysed area (Fig. 6).

Thirdly buffer polygons have been created at 500 meters distance around the stations feature. The optional dissolve has been performed to remove overlapping buffers (Fig. 7).

Then the buffer shape file has been used as clip feature of the census islands. As a result we obtained the areas of census islands contained within buffers. Finally we calculated the number of inhabitants within a walking distance from stations as the product of average population within census islands and the areas of census islands contained in the buffer. The calculus of percentages is the ratio between the number of people in the buffer areas and the total people living in each town multiplied by 100 (Fig. 8).

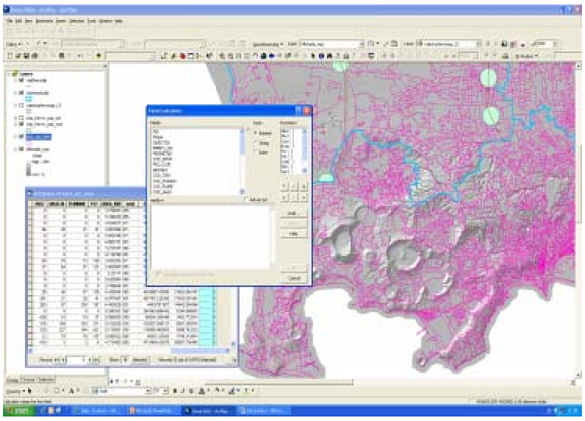

Fig. 5. Join of census database to the shapefile of the census

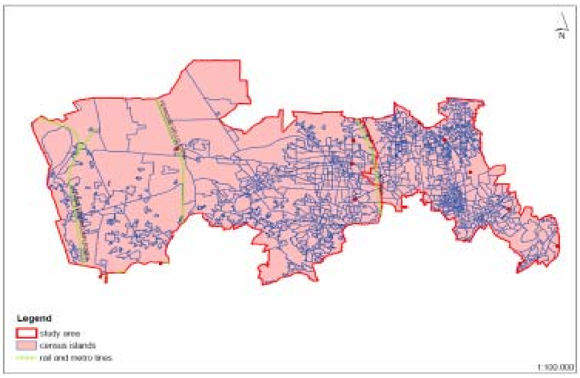

Fig. 6. Clip of the dataset on the study area

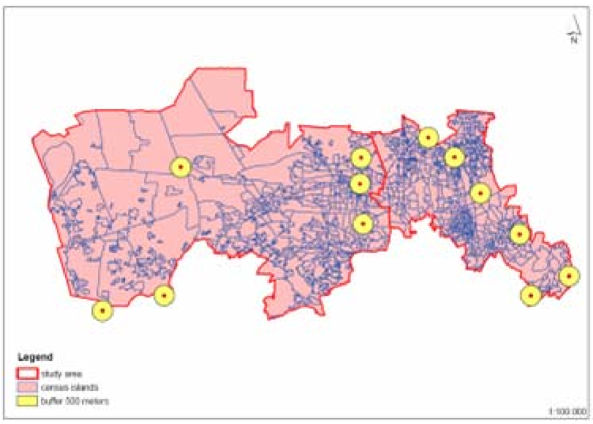

Fig. 7. Buffer of the metro/railways stations

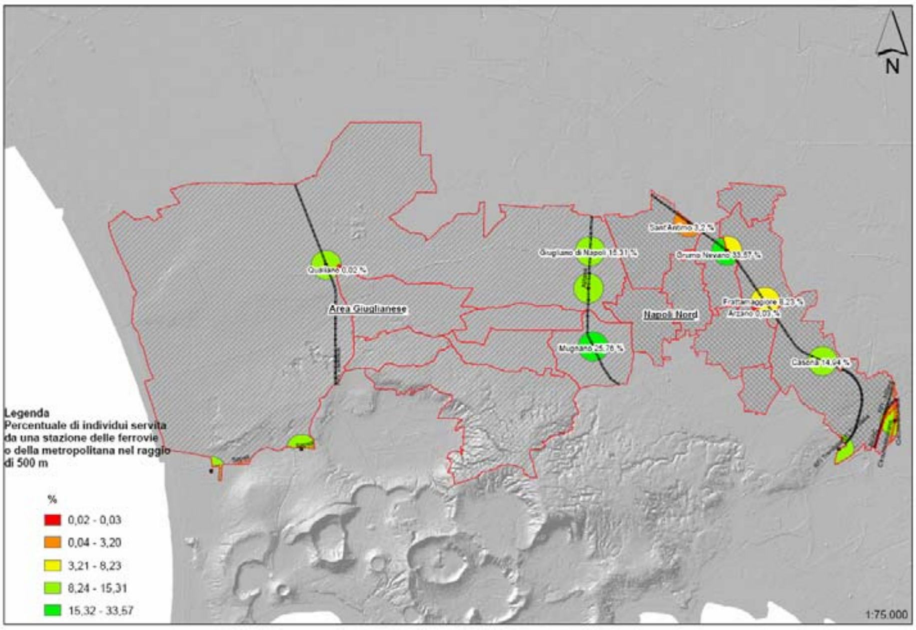

Fig. 8. Intersection of census islands with station buffers and percentage people within 500 meters from a rail station

5 Getting the index

In order to get the unique index for sustainable mobility, we evaluated and normalized the indicators first, and then weighted and aggregated them.

The indicator values do not have any common unit of measure. There would be no need of further processing to assess the plan, but the number of indicators to be taken into account is unpractical. To standardize onto a common scale the indicators and to enable the weighting, we have used functions valued in the interval [0,1].

There are several methods to define a function over the indicator values such as direct rating and indifference methods. For further details on this topic, see [14]. In the direct rating method, that has been applied to this case study, the worst and best x values correspond to the minimum and maximum values of the function: zero and one, respectively. The best and worst 'raw' indicator values have been established for each indicators according either to thresholds within laws and regulations, or to best and worst value registered in the area, in the Region and in the State. According to [6], not only should linearity be the starting point for value functions, but, if alternative scales for x are available, the one leading to the most linear value function should be adopted. In this study we adopted linear value functions.

In Fig. 9 it is shown the function defined over one of the selected indicators: the percentage of people living within 500 meters from a metro/railway station. On the one hand, the point A represents the starting point of the improvement process of regional integrated rail system, that is the percentage of people already within a walking distance from a station . On the other hand, the point D represents the goal of the improvement process, that is the maximum percentage of people after the completion of the rail system. They assume value 0 and 1, respectively. The points B and C stand for the opening of new lines and stations of the regional rail system, that let the percentage increase.

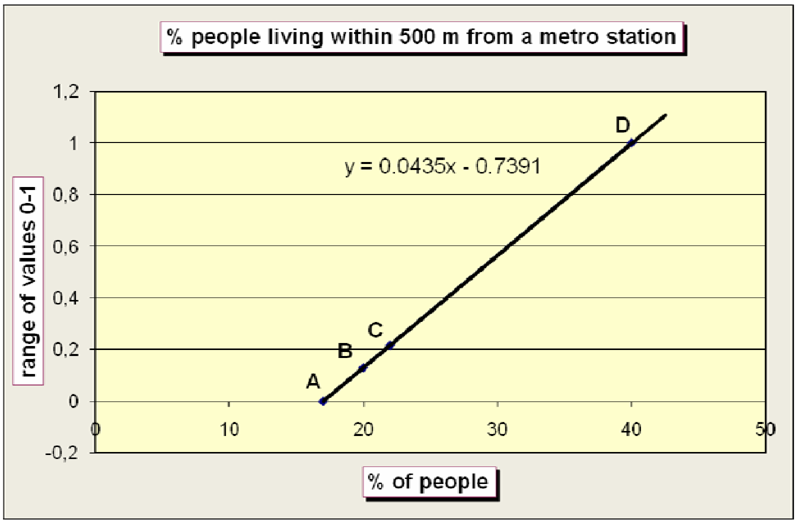

Fig. 9. Value function for the indicator: percentage of people within 500 meters from a train/metro station

Thus each indicator must be assigned a weight that determines its importance compared to the other indicators. Doing this, we determine how a change in indicators value affects the index. There are several methods to weight indicators, such as analytical hierarchy process (AHP), trade off, rating and ranking methods. For further details on this topic see [4] and [10]. This study applies a rating method named allocation of budget. The choice was based on feasibility: the use of the AHP method, that is very common in literature, would result too long. In addition, the high number of indicators could result in a high consistency ratio, that implies the repetition of comparisons. The weighting process started with a focus group within the GIS and Planning Offices. During this focus group, the list of indicators available has been presented and discussed. As a result of the debate, the list of indicators has been divided into four groups: environmental efficiency, economic efficiency, liveability and accessibility, which are part of the social dimension [2]. After a few days, the personnel was asked to fill in a questionnaire: they had to assign 100 scores among the four groups, and then to distribute them among the indicators. The data were processed and submitted to another focus group with the same personnel. They were asked to review the results of the weighting process and given the chance to change the budget allocation. Nobody changed the chosen scheme. The distribution of scores within the four groups is shown in Fig. 10. The weight of each indicator is reported in Table 1.

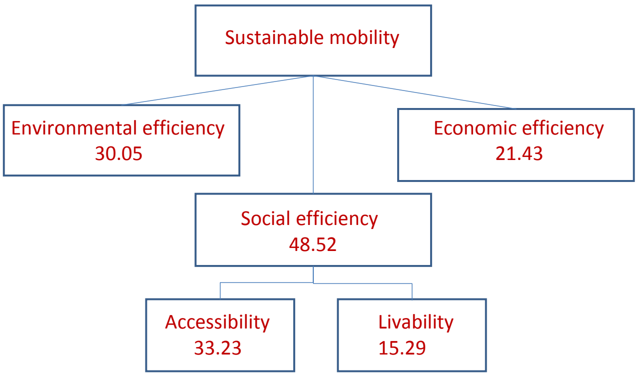

Fig. 10. Distribution of weights within the three dimensions of sustainability

Indicators are aggregated with the following function:

$$\textbf{\textit{Mobility index}} = \frac{\sum_{i=1}^{n} R_i \cdot \omega_i v_i(x_i)}{\sum_{i=1}^{n} \omega_i} \qquad (1)$$

where

N = number of indicators,

ω_i = weights of indicators,

v_I = value function,

x_i = raw indicators value.

At last, reliability index is applied to manage either uncertain or missing data. Usually, when some data are missing, the mean value is applied to complete the set. In fact, the results are affected by the low quality of data. Through the reliability index we manage data low quality, which is connected neither to consistency nor to statistical error.

Indicators related to air pollution are affected by missing data because of the incompleteness of the detection net. As a result, the weight of each indicator has to be reconsidered to reflect this uncertainty. The reliability index R assumes values in [0,1]. When R = 1, the data set is complete and the related indicator is highly reliable. When R = 0, there are no data available for the selected indicator, so it cannot affect the mobility index.

The reliability index for each indicator is given by the following ratio:

$$\boldsymbol{R_i} = \frac{m_i}{n_i} \qquad (2)$$

where

R_i = reliability index for indicator *I,*

$\boldsymbol{M_i}$ = number of data available for each indicator *i,*

$\boldsymbol{N_i}$ = maximum number of data for each indicator *i,*

i = indicator.

The maximum number of data for each indicator is given by the number of municipalities of the case study, i.e. 15. R_i always equals 1 except for the indicators related to air pollution:

Indicator # 1, maximum value of CO: $R_1 \equiv \frac{2}{15}$

Indicator # 2, maximum value of NO_2: $R_2 \equiv \frac{2}{15}$

Indicator # 3, maximum value of O_3: $R_3 \equiv \frac{1}{15}$

Indicator # 4, maximum value of particulate: $R_4 \equiv \frac{2}{15}$

Indicator # 5, maximum value of SO_2 $R_5 \equiv \frac{2}{15}$

The reliability for the mobility index is the result of the following function:

$$\boldsymbol{RI} = \frac{\sum_{i=1}^{n} R_i \cdot \omega_i}{\sum_{i=1}^{n} \omega_i} \qquad (3)$$

where

RI = reliability index for mobility indicator,

R_i = reliability index for each indicator *i*,

n = number of indicators,

ω_i = weight for each indicator *i*.

The reliability for the mobility index equals 0.87 in the step of the ex-ante analysis. Considering that the detection net for air pollution is going to be completed, in the short run it will get closer and closer to value 1. Fig. 11 shows the map of the mobility index resulting from the aggregation of data for each municipality of the North Naples and Giuglianese Area. Green colour represents a high performance of the plan actions. In contrast, red colour represents a bad performance. It must be pointed out that the map is the result of a hypothesis of a set of data during the realisation process.

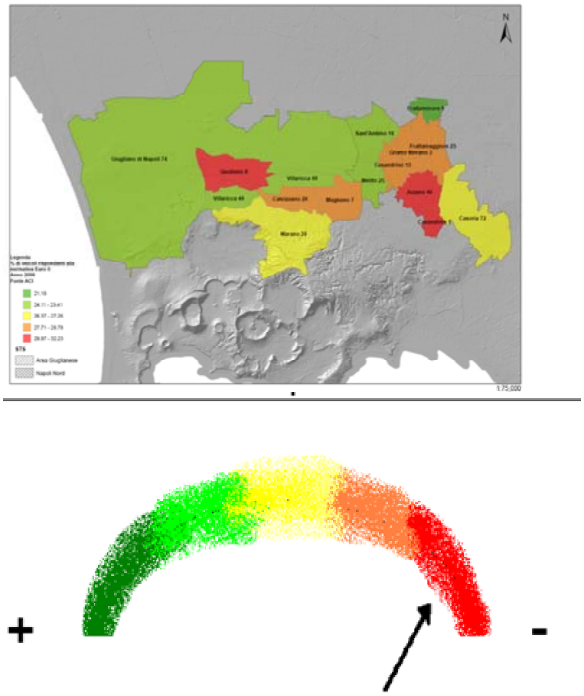

Fig. 11. Map showing the mobility index in the Giuglianese areas. Green (resp., red) stands for a high (resp., bad) performance

6 A fuzzy linguistic interpretation of the final reliability index

Often the analyst needs to have a linguistic interpretation of the reliability of his results. In fact, in many cases, the analysts can use different reliability indexes applied on different domains and it is not immediate a comparison of these dishomogeneous indexes. Moreover, a linguistic evaluation of the reliability index could represent a more coarser grained and intuitive estimation of the reliability. Here we provide a fuzzy approach to evaluate a specific linguistic expression for the reliability index. Our approach can be used for any index. The concept of linguistic expression was introduced by Zadeh in 1975 (e.g., [15]); a linguistic expression is a basic concept in approximate reasoning in order to form fuzzy rules. We use the theory of evaluated linguistic expression developed by Novak [11, 12]. A single linguistic expression can be formed by the following form:

<Evaluating expression> = <Linguistic hedge> atomic expression

Following [11], we use these linguistic hedges: Ex (extremely), Si (significantly), Ve (very), empty hedge, ML (more or less), Ro (roughly), QR (quite roughly), VR (very roughly) with one of the expressions: Sm (small), Me (medium), Bi (big). It is important to note that the empty hedge is a linguistic hedge. In this mode a linguistic expression can be formed by an atomic evaluation expression. The set of atomic expression is given by "small", "medium", "big". Each linguistic hedge is modelled by using a continuous function ν_{abc} with three parameters a, b, c, with a < b < c, defined as

$$\nu_{abc} = \begin{cases} 0 & \text{if } x < a \\ \dfrac{(x-a)^2}{(b-a)(c-a)} & \text{if } a \le x \le b \\ 1 - \dfrac{(c-x)^2}{(c-b)(c-a)} & \text{if } b < x < c \\ 1 & \text{if } x \ge c \end{cases} \tag{4}$$

The fuzzy sets of a linguistic hedge with one atomic expression are assigned as
<linguistic hedge> small = ν(LH(x)), <linguistic hedge> medium = ν(MH(x)),
<linguistic hedge> big = ν(RH(x)), where

$$LH(x) = \begin{cases} \dfrac{0.5 - x}{0.5} & \text{if } 0 \le x \le 0.5 \\ 0 & \text{if } 1 \ge x > 0.5 \end{cases}$$

$$MH(x) = \begin{cases} \dfrac{x}{0.5} & \text{if } 0 \le x \le 0.5 \\ \dfrac{1-x}{0.5} & \text{if } 1 \ge x > 0.5 \end{cases}$$

$$RH(x) = \begin{cases} 0 & \text{if } 0 \le x \le 0.5 \\ \dfrac{x - 0.5}{0.5} & \text{if } 1 \ge x > 0.5 \end{cases}$$

In Fig. 12 we show the three linear functions LH, MH, RH.

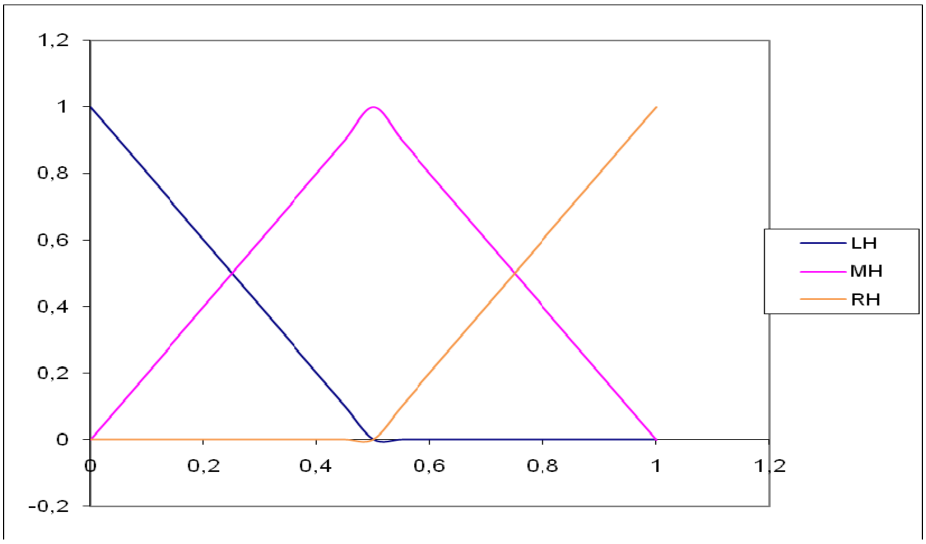

Fig. 12. The functions LH, MH, RH

In order to obtain their extensional meaning we can use the simple linear transformation x=(s-a)/(b-a), where s∈[a,b], if the interval [a,b] is a domain of an index. In our case the domain of the mobility index is [0,1] and we no need to use the above linear transformation. In the general case, we can obtain a linguistic expression for the reliability index using the functions (4). In Fig. 13 we show, as example, the fuzzy sets “VR small”, “VR medium”, “VR big” determined by setting a = b = c = 0.5. In Fig.14 we show the fuzzy sets “Ex small”, “Ex medium”, “Ex big” determined by setting a =0.03, b= 0.5, c = 0.96. We assign to the index reliability the linguistic expression of the fuzzy set for which the membership degree of the index value given by (3) is higher; if we obtain the same membership degree for two or more fuzzy sets, then it is assigned the linguistic expression of the lowest fuzzy set in accordance to the partial ordering of the evaluating expression defined in [11, 12]. Within the set of the evaluating linguistic expressions we define a partial ordering “≤” as “Ex <exp>” ≤ “Si <exp>” ≤ “Ve <exp> ” ≤ “empty hedge <exp>” ≤ “ML <exp>” ≤ “Ro <exp>” ≤ “QR <exp>” ≤ “VR <exp>”, where <exp> is one of the expressions: “small”, “medium”, “big”. As previously mentioned, if we obtain the same membership degree for two or more fuzzy sets, we assign the linguistic expression of the lowest fuzzy set to the reliability index according to the above ordering. For example, if we have x=1 for two fuzzy sets “Ex big” and “VR big”, we assign the linguistic expression “Ex big” to the reliability index because “Ex big” ≤ “VR big” in the above ordering.

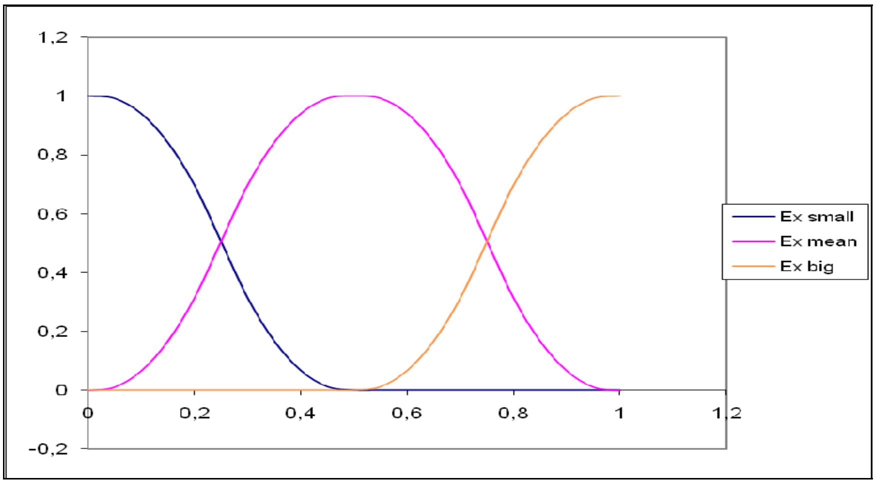

Fig. 13. VR small, VR medium and VR big (a=b=c=0.5)

The expert has suggested the values reported in Table 2 for the parameters a, b, c. By using (3), we obtain the value 0.87 for the final mobility reliability index corresponding to the linguistic expression "Ve big".

7 Conclusions

The research designed and implemented a database via a GIS. Not only this GIS could be updated, but it can also convert the huge quantity of information within each indicator in one complex index. It can give immediately the trend towards sustainable mobility. The database is useful to compare either a zone of the district in different times or different areas of the district at the same time. We strongly believe that this is a really powerful tool to support decisions: it can help assessing the plan in its realization process and defining feedback actions as well. A similar experience has been done by the District of Milan, where the list of indices was also used to define alternative plans and to assess the best options during the planning process [12]. The District of Naples has not adopted this procedure and uses indices only to evaluate the performance of the plan. The process of building indices can help transparency in planning procedures and social learning through the appraisal process, if citizenship and stakeholders were involved. The combined use of participatory techniques and multiple criteria analysis takes conflicting interest into account and is the only way to solve them in a common vision. The method implemented in this research should be also applied to planning process and should involve most of the society.

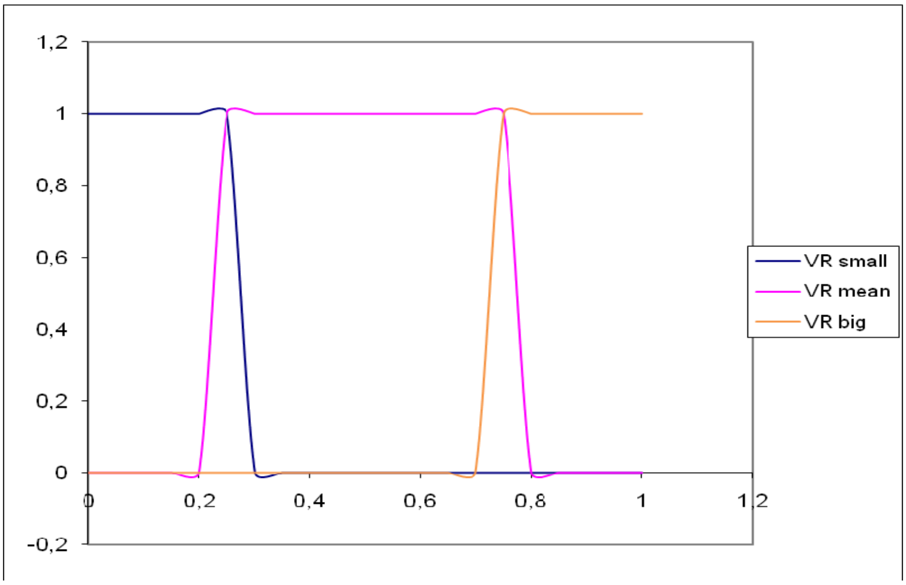

Fig. 14. Ex small, Ex medium and Ex big (a=0.03, b=0.5, c=0.96)

Linguistic expression	**a**	**b**	**c**
Ex <exp>	0.03	0.50	0.96
Si <exp>	0.10	0.50	0.85
Ve <exp>	0.25	0.50	0.75
Empty hedge <exp>	0.30	0.50	0.70
ML <exp>	0.35	0.50	0.65
Ro <exp>	0.40	0.50	0.60
QR <exp>	0.45	0.50	0.55
VR <exp>	0.50	0.50	0.50

Table 2. Parameter used for creating the fuzzy sets associated to the linguistic expressions

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