A MODELLING FRAMEWORK FOR THE DESIGN OF SUSTAINABLE INTEGRATED TRANSIT SYSTEMS: THE CASE STUDY OF CAMPANIA REGION (ITALY)

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ABSTRACT

The paper proposes a general methodology, applicable to different geographical contexts, for the design of sustainable integrated transit systems (including the minimal transit services definition) through transit market share optimization. The difficulty of this approach is to define proper network design methodologies for an effective maximization of the market share of public transport, that is finding the optimal mix of possible actions (increase in service frequency, new stations, enhanced feeder bus lines and so on). For this aim, the modeling part of the DSS is firstly described and then the network design methodology (including all heuristics adopted for overcoming computationally unfeasible network design procedures) is proposed. Finally, the DSS is applied to some test sites within Campania region (Italy), from the crowded metropolitan area of Napoli to the scarce demand area of countryside towns, by adapting to the specific test site both actions and methodology.

Minimal transit service design, sustainable mobility, enhancing transit systems

1. INTRODUCTION

A key issue for the promotion of transit systems in urban and metropolitan areas is the definition, by local administrations and regional governments, of the amount of *minimal transit services* to be supplied. In a modern interpretation, they should be defined in order to achieve a sustainable mobility, rather than simply satisfying the basic needs of mobility of weak sectors of the population. In that respect, their design should be inspired by a principle of effectiveness, simply measurable as the transit modal share they are able to guarantee in a given context. Clearly, such market share in a given context is the result of complex interactions of various factor: the geographical and demographic structure of the territory, the combination of push and pull policies, the integration between services, tickets and fares of different operators, the amount and density of railway infrastructures and services, and so on. As a consequence, only part of those factors can be endogenously modified by the planners and, most of all, the definition of an adequate market share for a given context is extremely difficult, as well as the establishment of benchmarks on the basis of analogies with different contexts.

The basic idea of the paper is to implement a quantitative DSS, applicable to different geographical contexts, for the design of sustainable integrated transit systems (including minimal transit service definition), through optimal network design procedures based on transit market share optimization.

In more detail, since public transport is in a position of weakness with respect to the private car competitor, because of its inherent shortcomings (spatial and temporal discontinuity), a maximum value of the transit market share, that is an asymptotic benchmark, can be considered as pursuable in any given context as a function of the underlying "environmental" conditions (characteristics and amount of railway infrastructures, railway network density, presence of TDM policies and so on). This benchmark may be practically estimated by modelling an hypothetical scenario wherein the specific transit system under analysis, simulated together with the aforementioned environmental conditions, is stressed to its maximum efficiency, irrespectively of efficacy considerations, through undifferentiated increase of the number of railway stations and bus stops, doubling the frequency of all existing services and so on. Notably, the same modelling approach can be also applied to any combination of policies and action, each with a designed level of increase, leading to an ordered sequence by increasing transit market share (see for instance Figure 3) whose upper bound represents the aforementioned benchmark. As a result, this allows defining the best mix of policies/actions in terms both of efficiency and efficacy, that is the scenario wherein the most efficacy actions are chosen (in term of ratio between the provided increase in the transit market share and the investment needed) and the extent to which improve them is defined so that the benchmark is not too close i.e. the impact of the marginal investment is still remarkable.

The practical problem of modelling policies and identifying therefore the best solution is faced through specific network design procedures, or heuristic proxies, so as to make them applicable to large scale contexts, contrarily to most of the network design procedures available in the literature which require a significant computational effort and are, consequently, too much time demanding for this purpose.

The paper is structured as follows. Section 2 provides for a brief overview of the state of practice of urban/metropolitan transit systems in Italy and across Europe. Section 3 deals with the methodological proposal for effective design of sustainable integrated transit services in a study area. In order to provide for a practical case study, Section 4 proposes the application of the methodology to some homogeneous contexts within the territory of Campania region (Italy), from the crowded metropolitan area of Napoli to the scarce demand area of countryside towns. Finally, Section 5 draws some conclusions.

2. BACKGROUND AND MOTIVATION

A detailed picture of the current status and of the perspectives of transit systems in urban and regional contexts in Italy and in Europe has been reported by the authors in the final report of the research project underlying this study (Cascetta et al., 2009). From a broad perspective, public transport in Italy suffers a substantial weakness with respect to the corresponding European situation: for instance, an overview provided by Earchimede (2005) evidenced that the territorial coverage of transit systems in Italy is -8% with respect to the corresponding European average, the average commercial speed is -13%, the mean age of rolling stock +20% (9.2 years against 7.7 in Europe), the productivity of employees -14% and the revenue/costs ratio -41%.

However, a detailed analysis within the Italian territory showed a remarkable heterogeneity in public transport performances, from the satisfactory 46% of transit market share in Milano or the 42% of the Provinces of Genova and Campobasso to more than 2000 municipalities over about 8000 with a less than 5% market share. Therefore, a first analysis has been carried out in order to discover and model possible relationships between transport demand, transport supply and relevant territorial characteristics (e.g. population density, orography, altitude, shape). Indeed, such relationships would allow for quantifying the amount of infrastructures and services, in terms of vehicles·km, to be supplied in a given context for achieving a given transit market share.

In more detail, the methodological path initially defined was the following. All Italian contexts with presence of transit systems, disaggregated by administrative level (Regions, Provinces, Municipalities), have been firstly clustered in homogeneous groups with respect to the aforementioned relevant characteristics, through appropriate statistical procedures. Then, within each cluster, a regression between a demand indicator (e.g. transit market share) and a standard supply indicator (e.g. per capita amount of vehicles·km supplied) has been estimated. Finally, for each homogeneous cluster a benchmark value of the transit market share has been defined and through the estimated regression the corresponding increase in vehicles·km to be supplied calculated.

Unfortunately, this procedure failed in some points. Firstly, the definition of a benchmark was cumbersome and not satisfactory. Secondly, all estimated regressions, also those encompassing a significant number of explanatory variables related to the territorial and transport supply characteristics of the contexts within each cluster, showed very poor goodness of fit values. That is, the underlying factors affecting transit market shares are too much inherently complex for being accommodated through aggregated relationships dealing with the whole geographical context under analysis. For instance, the structure of the rail network, the effectiveness of the bus feeder services towards stations, the presence of integrated fare systems across operators and transit services, the contemporary adoption of push policies affecting private car use cannot be satisfactorily encompassed in aggregated relationship. Rather, the possibility of application of such aggregated regressions is effective only in providing for a very preliminary insight on the magnitude order of the investments needed for enhancing transit systems.

Instead, a quantitative methodology based on a disaggregate model of the whole transport system within the study area, appropriately coupled with heuristics for preliminary design of single and synergic push/pull policies for enhancing transit market share should be adopted. For this reason, a specific part of the research was devoted to this objective, leading to the proposal described in detail in the next Section.

3. THE DESIGN OF OF SUSTAINABLE INTEGRATED TRANSIT SYSTEMS

3.1 The proposed methodology

As stated in the introduction, the main objective of the paper is to define a methodology for the design of sustainable integrated transit systems, including the minimal transit services definition: this means establishing both the most effective set of push and/or pull policies (also denoted as "actions" in the following) and, consistently, the extent to which each single policy/action should be improved (how many more stations/bus stops and where, the amount of frequency increase of transit services, and so on). The kernel of the procedure is represented by a model for simulating the whole transport system (i.e. private car, bus and rail transit) in the study area. Such model should be implemented by following some recommendations.

With reference to the supply model, private transport may be implemented through common state-of-the-art approaches in the literature (e.g. Cascetta, 2009), while the transit supply model should possibly simulate jointly the road and the rail transit networks through a multimodal approach. Normally, due to the very large amount of rail and bus services in urban/metropolitan contexts, an aggregated dataset of regional transit services can be implemented by collecting service frequency for each hourly interval within the daily time horizon, i.e. allowing for a synchronic approach within each time interval.

With reference to the demand model, consistently, o-d matrices should be related to time intervals short enough to be compliant with the above mentioned synchronic intervals and to allow for an effective and reliable static assignment (e.g. considering 1-hour or 2-hours time horizons). Moreover, at least a mode choice model should be implemented, possibly with different specifications across homogeneous geographical clusters, e.g. intra-urban trips, trips to/from the main urban pole(s) within the study area, other intercity trips. Obviously, all policy variables related to the policies to be analyzed for enhancing transit market share should be explicitly introduced. The mode choice model should also possibly include as choice alternatives bus, rail and park & ride options.

On the basis of such detailed model for the overall transport system, the proposed methodology for the design of sustainable integrated transit systems is made up by the following five steps:

1. identification of all relevant push and pull actions for enhancing effectiveness and efficacy of transit systems within the specific context. The list of such actions, taken into account in this paper, deals with the following pull policies:

    a. increasing urban and extra-urban rail and bus transit services;

    b. realizing new rail infrastructures (lines and/or stations) with the related new services;

    c. establishing integrated fares among operators and transit systems;

d. enhancing reliability and regularity of transit systems and providing for pre-trip and en-route information;

e. increasing accessibility towards urban and suburban railways by means of more effective feeder bus services;

f. increasing performances of bus services through bus priority systems;

g. introduction of dial-a-ride services

and with the following push policies:

a. cordon pricing for entering city centres and other measures related to car usage taxation (e.g. parking fees);

b. limited traffic zones;

2. optimal design of the transit system under each action singularly, by means of specific heuristics in substitution of formal network design procedures, normally requiring an unfeasible computational effort. The proposition of such heuristics, based on intensive application of the transport system model mentioned above, is a key proposal of the paper: they are described in detail, for each of the listed push and pull actions, in Section 3.2;

3. definition of a priority list of the aforementioned actions on the basis of the outcomes of the preceding point. In more detail, the optimal design for any action is characterized by means of a cost-benefit analysis and of specific performance and impact indicators, i.e. actions are ordered per increasing cost/benefit ratio. This also means building proper methodologies for (parametric) determination of costs and for calculation of appropriate indicators for measuring benefits and impacts. Section 3.3 deals with these issues in detail;

4. definition of policy scenarios characterized by combinations of actions, in order to underline potential synergic effects. Combined scenarios can be built on the basis of the priority list defined in the preceding point and accordingly with analyst's experience. Each combined scenario is modelled as superposition of the actions provided in the single scenarios, with possible minor optimization adjustments, i.e. no further network design procedures are entirely performed. Again, a new priority list of combined scenarios is obtained through the same procedure described at point 2;

5. final definition of the optimal mix of actions through a comparison of the results obtained in the previous points, and taking into account the asymptotic efficiency of policies mentioned in Section 1.

3.2 Heuristics for the design of transit policies

The following sections deal with the methodology and the heuristics proposed for the optimal design of each of the push/pull actions listed in the preceding Section.

3.2.1 Increasing urban and extra-urban rail and bus transit services

The identification of which urban/extra-urban rail and bus services should be improved is the challenging aspect of this policy action from a design perspective. Indeed, once identified the services to be increased, the supply model can be updated consistently and a run of the mode choice model performed in order to calculate the new modal market shares and the corresponding network flows and indicators (Section 3.3).
In spite of the large amount of network design procedures proposed to date in the literature, there are no effective procedures when dealing with large study areas and dense networks. In substitution, an heuristic procedure can be performed instead, in order to analyze the elasticity of transport demand to improvements of the transit system performances, through the following steps:

1. assignment of the current transit o-d matrix to the current supply model for calculation of current flows onboard existing rail and bus services;

2. assignment of the current transit o-d matrix to an hypothetical supply model characterized by doubled frequencies for all rail and bus services (i.e. undifferentiated increase), for calculation of corresponding onboard flows;

3. definition of a list of rail and bus services in decreasing order of increase of onboard flows between the current and the hypothetical undifferentiated scenarios;

4. definition of an acceptance threshold for cutoff of the list defined in the preceding point, i.e. identification of the effective lines characterized by an onboard flow increase higher than the acceptance threshold;

5. definition of the project scenario with doubled frequency only for rail and bus services identified in the preceding point, calculation of the new modal market shares through the mode choice model and corresponding assignment for calculation of performances and indicators.

Obviously, the procedure can be repeated for different acceptance thresholds and for different percentage increase of line frequencies (i.e. instead of simply doubling current frequencies). It is also worth underlining that the proposed heuristic easily allows for the exact calculation of the amount of vehicle·km needed for increasing the frequencies of the considered set of lines, and, therefore, of the corresponding costs.

3.2.2 Realizing new rail infrastructures (lines and/or stations)

Modelling effects of new railway infrastructures (lines and/or station) is a classical application of transport model systems. Indeed, the topological and analytical supply models can be simply updated so as to include the new infrastructures with the related services, then the new supply performances can be calculated, in turn the mode choice model can be run in

order to predict new market shares and finally an assignment for calculation of onboard flows can be performed.
As in the previous Section, the key point is in the design of the new railway infrastructures to be taken into account, an issue widely addressed in the literature and in the practice, even if with remarkable computational issues in applying theoretically appealing network design procedures. For this aim, heuristic procedures may be applied as well, e.g. defining new infrastructural patterns on the basis of o-d desire lines. Preliminary reference can be also given to all planning documents and programs for public transport infrastructures already available within the study area.
In the current paper, a map of accessibility of the zones within the study area to the current railway stations has been matched with population density and other territorial/demographic maps, in order to identify all areas worth to be better served through new stations. Then, keeping the current structure of rail networks, new station locations have been indentified in order to solve the previously identified accessibility gaps.

3.2.3 Integrated fare systems

The presence of integrated fare systems impacts on transport costs for transit and park & ride alternatives, and can be easily modelled through consolidated procedures available in the literature (e.g. Cascetta, 2009).
Notably, for the applications reported in the case studies in Section 4, an integrated fare system covering the whole territory of Campania region is already in operation (*UnicoCampania* system, see Cascetta and Pagliara, 2008). Therefore, in order to measure the efficacy of such policy action in a context where it has already been implemented, a back-casting simulation may be performed, by calculating the number of transfers between transit modes NT_{od} within the shortest time hyperpath (i.e. made up by NT_{od}+1 transit services), and assigning to the hyperpath a total cost equal to the sum of the costs of each leg.

3.2.4 Enhancing reliability/regularity of transit systems

Modelling and evaluation of the impacts of new technologies for pre-trip and en-route information and, in general, for enhancing reliability and regularity of transit systems is a complex topic, with doubtful transferability to other geographical contexts. From a broad perspective, the introduction of advanced technologies may be thought to lead to both a better perception of the transit service performances, in terms of real-time timetable, and a contemporary increase of its level of service.
The former effect can be turn into a model by introducing a lower waiting time attribute in the utility specification of the transit alternative in the mode choice model (Section 3.1), that is reducing the reliability parameter for the calculation of the waiting time from the frequency of the transit system (Cascetta, 2009). Contemporarily, the higher perception of the quality and of the level of service of the transit system may be modelled through a reduction of the coefficient of the waiting time attribute, i.e. reducing the disutility associated to the waiting time itself, whose value lies normally in between 2 and 3 times the coefficient of onboard

time.
Therefore, since both effects are modelled by acting on a coefficient and on an attribute multiplying each other, a simplified assumption of reduction of just one of the two can be introduced, for instance assuming a parametric reduction of the waiting time coefficient. In that respect, some preliminary analyses suggest a percentage reduction of 10% to be realistic, especially in extra-urban contexts where frequencies are not so high as in the cities.

3.2.5 Increasing accessibility to railways through effective feeder bus services

The policy of increasing accessibility to railways through effective feeder bus services is substantially analogous to the policy of increasing rail and bus services (Section 3.2.1). For this aim, the same methodology described in Section 3.2.1 can be also applied, that is:

1. assignment of the current transit o-d matrix to an hypothetical scenario characterized by an undifferentiated increase in accessibility towards all subway and suburban railway stations;

2. classification of access station and railway lines by decreasing flow increase order;

3. definition of an acceptance threshold for cutoff of the list defined in the preceding point, i.e. identification of the effective lines and stations characterized by an onboard flow/access flow increase higher than the acceptance threshold;

4. definition of the project scenario with increased accessibility only for lines and stations identified in the preceding point, calculation of the new modal market shares through the mode choice model and corresponding assignment for calculation of performances and indicators.

The proposed methodology allows also for direct calculation of the exact amount of vehicle·km of feeder bus services needed for achieving the desired increase in accessibility.

3.2.6 Bus priority systems

Bus priority systems are characterized by appropriate intelligent transport systems and technologies (e.g. traffic lights with transit prioritization) or by structural interventions (e.g. reserved bus lanes) aimed at increasing the commercial speed of bus transit services. From a practical standpoint, therefore, it is sufficient to modify the performances of the bus lines subject to prioritization into the supply model and then perform a run of the whole model system for calculation of onboard flows and market shares.
As for policies described in Sections 3.2.1 and 3.2.5, the design phase is faced through a double-step heuristic, that is an assignment of the current o-d matrix to an undifferentiated scenario of bus prioritization is firstly performed, in order to identify the lines with the highest increase, and then a new model run is carried out with prioritization only for those lines. Notably, the undifferentiated scenario is built by taking into account only bus services running on road infrastructures whose width allows for the implementation of a reserved lane.

3.2.7 Dial-a-ride services

Modelling and design of dial-a-ride services is a topic widely addressed in the literature, with a number of theoretical and operational approaches with complexity variable in function of the characteristics of the service under analysis. It should be also noted that, in most of European Countries, all significant dial-a-ride experiences are built with the aim of serving specific demand segments (e.g. sparse demand in sprawled suburbs, night services and so on) rather than providing for a substantial improvement of the performances and of the market penetration of transit services. This normally leads also to higher fares than the ordinary transit services in the same study area.

The present study, on the contrary, is characterized by a different vision of dial-a-ride systems, whose target is thought to increase further accessibility towards railway stations to/from sprawled suburbs, in substitution of economically unsustainable ordinary transit services. That is, the idea is to replace the amount of ordinary transit vehicles·km with the corresponding amount of dial-a-ride vehicles·km with the same budget. Consistently, the dial-a-ride service may be limited to sprawled suburbs not far from railway stations and characterized by a strong relationship with a main urban pole in the study area.

Therefore, the methodological framework for modelling dial-a-ride services, within the approach followed throughout the paper, is the following:

1. definition of the area to be served within the study area, then definition of the ordinary transit services to be replaced by dial-a-ride services and calculation of the amount of dial-a-ride vehicles·km feasible with the budget made available from the elimination of ordinary transit services;

2. Monte-carlo assignment, starting from observed distributions in the study area, of a desired starting time for each trip of each temporal o-d matrix referred to the operational horizon of the dial-a-ride service;

3. Design of the dial-a-ride service through state of the practice methods and algorithms (e.g. Catta et al., 2004);

4. Calculation of demand served by the dial-a-ride service through a mode choice model including early/late penalties (difference between the desired starting time and the offered starting time);

5. Assignment for calculation of performance indicators.

3.2.8 Cordon pricing

The simulation of cordon pricing policies is again a consolidated topic in the related literature. For the objectives of the current study, the area interested by the pricing policy should be exogenously defined, together with all links with toll payment systems. Furthermore, all drivers are assumed to pay the same fare, independently of the entry/exit time and of vehicle type. In such hypotheses, the supply model can be easily updated by introducing cordon pricing fares on the above mentioned toll links, and then a run of the whole model system performed. Finally, the revenue of the cordon pricing system can be directly calculated by knowing flows on entering/exiting toll links.

3.2.9 Limited traffic zones

The adoption of limited traffic zones (LTZ) is a very common policy for traffic management in urban areas, which should be properly supported through adequate compensative measures for balancing the decrease of car accessibility. Similarly with the cordon pricing policy, the simulation of the introduction of limited traffic zones is carried out firstly through exogenous definition of LTZ boundaries and corresponding entering/exiting links. Consistently, all o-d trips made by users not living in d, with $d \in LTZ$, are associated with a park & ride facility p_{LTZ} at LTZ boundaries, and the car alternative is replaced by the sequence of the car alternative for the o- p_{LTZ} leg and of the transit (or walking) alternative for the p_{LTZ}-d leg. The vice versa applies for the o-d trips with $o \in LTZ$. Notably, with this approach the utility specification of the car alternative in the mode choice model encompasses transit and pedestrian attributes, for which the corresponding coefficients estimated for the corresponding mode choice alternatives can be applied.

3.3 Performance and impact indicators and cost estimation

In accordance with the methodology set up in Section 3.1, all policies and actions modelled through the heuristics described in Section 3.2 should be compared among each other by means of appropriate performance and impact indicators, and a preliminary cost estimate for their implementation should be performed as well in order to carry out a preliminary cost/benefit analysis. The following subsections deal respectively with all indicators and cost estimates adopted in the study.

3.3.1 Performance indicators

Performance indicators aim at quantifying the effect of push and pull policies on transport system users. The current study adopts the following indicators:

1. variation of modal split and total demand attracted by transit (rail and bus) systems;
2. variation of total and per-capita generalized transport cost across all modes;
3. variation of total and per-capita generalized transport cost for transit modes;
4. variation of territorial accessibility;
5. variation of the average trip duration by car;
6. variation of the overall amount of vehicle·kms by car.

The variation of modal split and total demand attracted by transit (rail and bus) systems can be easily quantified through indicators based on the availability of the o-d matrices

corresponding respectively to the current and the project scenarios.
The variation of the total and per-capita generalized transport cost can be expressed through the variation of the expected maximum perceived utility (Cascetta, 2009), given by the logsum of mode choice under the modeling assumptions set up in Section 3.1. In more detail, given an o-d pair *od* and a trip purpose *s* (i.e. commuting, other work purposes, study, other), the mode choice logsum for that *od* pair and trip purpose can be expressed as:

$$Y_{od,s} = \ln \sum_m \exp\left(V^m_{od,s}\right) \tag{1}$$

Consequently, the logsum variation for that *od* pair and trip purpose between the project and the current scenario can be expressed as:

$$\Delta Y_{od,s} = Y_{od,s,proj} - Y_{od,s,curr} \tag{2}$$

and, an equivalent measure in term of generalized cost variation (€) can be computed by dividing the logsum variation (2) by the cost coefficient for trip purpose β_{cs} (1/€):

$$\Delta C_{od,s} = \frac{\Delta Y_{od,s}}{\beta_{cs}} \tag{2b}$$

Then, the total generalized cost variation can be computed by summing up across trip purposes and o-d pairs for a given scenario:

$$\Delta C = \sum_{od} \sum_s d_{od,s} \Delta C_{od,s} \tag{3}$$

where $d_{od,s}$ is the demand on the o-d pair for the trip purpose *s.*

Obviously, a per-capita variation ΔCPC can be also determined through the relationship:

$$\Delta CPC = \frac{\Delta C}{\sum_{od} \sum_s d_{od,s}} \tag{4}$$

Notably, since the logsum indicator (1) increase by definition for an enhancement of any utility included in the sum, indicators (3) and (4) provide always for a reduction of the generalized cost across all modes, for all policies determining an enhancement of the performances of the transit modes.
On the contrary, the same indicators cannot be applied only for the calculation of the variation of the total and per-capita generalized transport cost for transit modes, i.e. only for transit users. That is, if a policy determines a reduction of the generalized cost for transit modes, the main effect is to provide, in turn, for an increase of the demand using those modes. Therefore, the total generalized cost for transit modes may increase in the project scenario because of the compensation between the reduction in costs and the increase in demand. For this reason, a specific indicator expressing the generalized cost variation $\Delta C^{od}_{tc,s}$ on transit system *tc* for trip purpose *s* and for the o-d pair *od* has been defined through the following formula:

$$\Delta C^{tc}_{od,s} = \frac{1}{\beta_{cs}}\left[d^{tc}_{od,s}{}^{curr} \Delta V^{tc}_{od,s} + \left(d^{tc}_{od,s}{}^{proj} - d^{tc}_{od,s}{}^{curr} \right) \frac{\Delta V^{tc}_{od,s}}{2} \right] \tag{5}$$

Wherein $\Delta V^{od}_{tc,s}$ is the variation of systematic utility of transit mode between project and current scenarios for trip purpose *s* and for the o-d pair *od*, $d^{tc}_{od,s}{}^{curr}$ and $d^{tc}_{od,s}{}^{proj}$ the values of demand on transit mode for trip purpose *s* and for the o-d pair *od* in the current and project scenarios respectively, and β_{cs} the cost coefficient for trip purpose *s*. Expression (5) mimics the approximation made in transport oriented cost-benefit analyses of approximating the demand-utility curve with a straight relationship (Cascetta, 2009), that is current transit users are assigned with the overall variation of systematic utilities, while new transit users are assigned with half of such variation. Similarly with relationships (3) and (4), an overall and a per capita indicators can be defined as follows:

$$\Delta C^{tc} = \sum_{od} \sum_{s} \Delta C^{tc}_{od,s} \tag{6}$$

$$\Delta CPC^{tc} = \frac{\Delta C^{tc}}{\sum_{od} \sum_{s} d^{tc}_{od,s}{}^{prog}} \tag{7}$$

The variation of territorial accessibility is another significant indicator taken into account in the study. In general, following the theory of accessibility, each zone can be associated with indicators measuring active and passive accessibility, respectively expressing easiness in reaching and in being reached to/from other zones of the study area. In that respect, each zone can be weighted through specific variables as proxy of their importance, for instance the population for passive accessibility and the number of local units and employees for the active accessibility for the commuting purpose. In more detail, the active weighted accessibility AWA_o of zone *o* is calculated as:

$$AWA_o = \sum_d \left[Emp_d \cdot \left(\frac{\sum_s C_{od,s} d_{od,s}}{\sum_s d_{od,s}} \right) \right] = \sum_d \left[Emp_d \cdot \left(\frac{\sum_s \left(-\ln \sum_m \exp - \left(V^m_{od,s} / \beta_{cs} \right) \right) \cdot d_{od,s}}{\sum_s d_{od,s}} \right) \right] \tag{8}$$

where Emp_d is the number of employed in zone *d*, $C_{od,s}$, as in (2b), is equal to the ratio between $Y_{od,s}$ and $\beta_{c,s}$ and the other variables have already been defined. Analogously, the passive weighted accessibility PWA_d of zone *d* is calculated as:

$$PWA_d = \sum_o \left[Pop_o \cdot \left(\frac{\sum_s C_{od,s} d_{od,s}}{\sum_s d_{od,s}} \right) \right] = \sum_o \left[Pop_o \cdot \left(\frac{\sum_s \left(-\ln \sum_m \exp - \left(V^m_{od,s} / \beta_{cs} \right) \right) \cdot d_{od,s}}{\sum_s d_{od,s}} \right) \right] \tag{9}$$

where Pop_o is the population of zone *o* and the other variables have already been defined. The preceding indicators allows for designing accessibility maps for the project and current scenarios respectively, for a geographically disaggregated characterization of the impacts of the related policies towards increase and/or decrease in territorial accessibility. This is particularly relevant for all policies affecting only specific transit lines and corridors.

Finally, in order to measure also the magnitude of impacts only on private transport modes (i.e. car users), two indicators can be considered, expressing respectively the variation of the average trip duration by car ΔAT^{car} and the variation of the overall amount of vehicle·kms by car ΔVKM^{car}. They are respectively defined as:

$$\Delta AT^{car} = AT^{car}{}_{proj} - AT^{car}{}_{curr} = \frac{\sum_l t_{l,car}^{proj} f_{l,car}^{proj}}{d_{carTOT}^{proj}} - \frac{\sum_l t_{l,car}^{curr} f_{l,car}^{curr}}{d_{carTOT}^{curr}} \tag{10}$$

$$\Delta VKM^{car} = VKM^{car}{}_{proj} - VKM^{car}{}_{curr} = \sum_l len_l \left(f_{l,car}^{proj} - f_{l,car}^{curr} \right) \tag{11}$$

where $t_{l,car}^{proj}$ and $t_{l,car}^{curr}$ are the car travel times along link l in the project and current scenarios respectively, $f_{l,car}^{proj}$ and $f_{l,car}^{curr}$ the corresponding project and current link flows respectively, d_{carTOT}^{proj} and d_{carTOT}^{curr} the overall car demand in the project and current scenarios and len_l the length of link l expressed in kms.

3.3.2 Impact indicators

Impact indicators aim at quantifying the effect of push and pull policies on all inhabitants within the study area. The current study adopts as impact indicators the variation of average energetic consumption for single trip by car, and the variation of car pollutant emissions.
In more detail, the variation of average energetic consumption ΔAEC_{car} for single trip by car is given by the formula:

$$\Delta AEC_{car} = AEC_{car}{}^{proj} - AEC_{car}{}^{curr} = \left(\frac{\sum_l len_l f_{l,car}^{proj}}{d_{carTOT}^{proj}} - \frac{\sum_l len_l f_{l,car}^{curr}}{d_{carTOT}^{curr}} \right) k_{fuel} P_{fuel} \tag{12}$$

where k_{fuel} is the specific fuel consumption, assumed equal to 0.1 litres/km, P_{fuel} the fuel cost, assumed equal to 1.2 €/litre and the other symbols have already been defined.
The variation of car pollutant emission can be easily calculated by means of models already available in the literature, normally requiring as input link flows and other traffic flow variables (e.g. speeds) provided by the model system described in Section 3.1. In more detail, this study refers to the model applied in Cascetta et al. (2009).

3.3.3 Cost and revenue estimation

The final step of the methodology deals with a parametric analysis of the costs for the implementation of the policies listed in Section 3.2. For this aim, a benchmark analysis carried out on average implementation costs in various Italian regions (Cascetta et al., 2009) led to the values reported in the following Table 1.

Table 1 – Parametric estimation of costs for implementation of policies listed in Section 3.2.

Policy measure	Context	
	urban / suburban	extraurban
new rail infrastructures	150 M€/km subway; 50 M€/km railway; 10 M€/station	
ITS and user information	0.3 €/veic km	
fare integration	3.000 €/vehicle	2.000 €/vehicle
increase in transit services and enhanced bus feeder services to rail	2 €/veic km bus 10 €/veic km rail	3 €/veic km bus 10 €/veic km rail
cordon pricing	300.000 €/toll gate	-
LTZ	300.000 €/toll gate	-
bus priority	400.000 €/km	-

In more detail, for new rail infrastructures policies, a cost per km has been defined accordingly with the type of railway and station, while for enhanced services policies a cost per vehicle·km has been estimated. Furthermore, the cost for ITS and user information has been associated to the vehicle·km, the cost of fare integration to each single equipped vehicle, with scale economies for large scale implementations. Finally, costs related to cordon pricing and LTZ are associated with the number of toll gates, while costs for bus priority systems are related to the length of reserved lanes introduced.
In order to compare revenues and costs, a life horizon has been defined for each implemented policy and the related implementation and operational costs have been split across years up to the life horizon. With reference to revenues, in a social point of view, direct revenues have been summed up with the yearly estimate of the reduction of cost for transit users given by (5).

4. THE CASE STUDY OF CAMPANIA REGION

As mentioned in Section 1, some applications of the proposed methodology to different test sites are proposed. The motivation underlying such implementation of the methodology proposed in Section 3 was related to the preparation of the Pre-Feasibility Study for the enhancement of the Regional Metro System (SMR) of Campania (Ente Autonomo Volturno, 2008). Indeed, Campania region is a very interesting study area from this standpoint, because of the very large update of an extended railway network since year 2000 and an integrated fare system covering all the region (Cascetta and Pagliara, 2008). In more detail, different *test sites* have been defined within the regional territory, according to different socio-economic, territorial and transport characteristics, and the proposed methodology has been applied into each of them in order to analyze the impact of different policies and calculate the amount of minimal services needed for achieving sustainable mobility in each test site.
The current section proposes firstly a brief explanation of the characteristics of the test sites (Section 4.2) and then a detailed analysis of the application of the proposed methodology with the related results (Section 4.3).

4.2 Brief description of the test sites

Campania region (Figure 1), whose main city is Napoli, has a population of 5.811.390

inhabitants (2007 figure), corresponding to approximately 10% of Italian population, making it the second populated region after Lombardia (the region of Milan). Within Campania, the county of Napoli encompasses more than 50% of the regional population in just the 9% of its territory, and is the most densely populated in Italy.
An aggregate analysis of the ISTAT census of systematic mobility (i.e. for work and study purposes) between Italian municipalities carried out in 2001, with integration from other studies (Cascetta et al., 2005), leads to the o-d matrix at county level for one-way commuting and non systematic trips reported respectively in the following Tables 2 and 3.

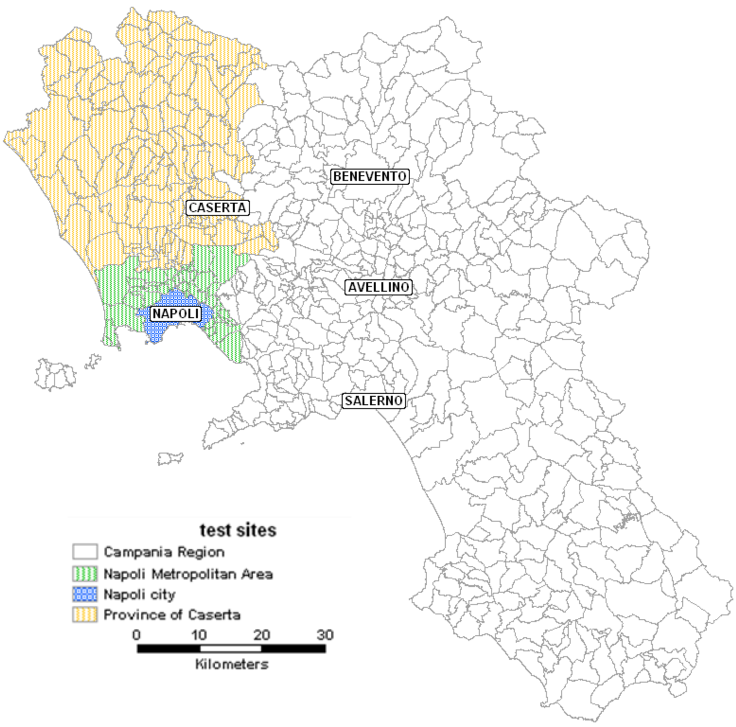

Figure 1 – Campania Region and test sites

Table 2 – One-way daily systematic trips at county level (source: ISTAT 2001 and Cascetta et al. 2005).

Systematic	Caserta	Benevento	Napoli	Avellino	Salerno	Total	% intracounty
Caserta	289463	1917	25484	232	600	317696	**91%**
Benevento	2452	107773	2909	1834	370	115338	**93%**
Napoli	21822	725	1129441	2627	12769	1167384	**97%**
Avellino	666	3620	8876	156044	5182	174388	**89%**
Salerno	908	124	17855	2180	418773	439840	**95%**
Total	315311	114159	1184565	162917	437694	2214646	
% intracounty	**92%**	**94%**	**95%**	**96%**	**96%**		

Table 3 – One-way daily non systematic trips at county level (source: ISTAT 2001 and Cascetta et al. 2005).

Non systematic	Caserta	Benevento	Napoli	Avellino	Salerno	Total	% intracounty
Caserta	450576	2241	84377	1342	976	539511	**84%**
Benevento	6461	95449	11390	3863	549	117712	**81%**
Napoli	52879	280	2344073	11376	15530	2424139	**97%**
Avellino	2310	3790	21361	207951	5993	241404	**86%**
Salerno	5495	268	50020	5281	555857	616922	**90%**
Total	517721	102028	2511221	229813	578905	3939688	
% intracounty	**87%**	**94%**	**93%**	**90%**	**96%**		

The main result is that the county of Napoli counts for about 54% of generated and attracted commuting trips, followed by Salerno and Caserta with 20% and 14% respectively, and finally by Benevento and Avellino with 7% and 5%. On average, the ratio of commuting trips per inhabitant is almost constant across all counties, with a 0.40 trips/inhabitant figure. It is also worth mentioning the predominance of the intra-county trips, which count for more than 90% of the total. Within them, approximately the 70% for each county is represented by intra-municipality trips. Similar considerations can be also drawn for non systematic trips.
Aggregate figures from the same data source lead to the mode market shares for systematic trips reported in the following Table 4.

Table 4 – One-way daily systematic trips between municipalities by transport mode within Campania Region (source: ISTAT 2001. Car/motorcycle refers both to drivers and passengers).

transport mode	systematic trips					
	total		intra-municipality		inter-municipality	
rail	88.101	4%	19.159	1%	68.942	9%
bus	344.361	16%	182.577	13%	161.784	21%
by feet	637.692	29%	615.809	43%	21.883	3%
car/motorcycle	1.144.498	52%	625.025	43%	519.473	67%
total	**2.214.652**		**1.442.570**		**772.082**	

Transit systems had a remarkably low market share, with approximately 30% for inter-municipality trips (21% bus and 9% rail). Previous studies (Regione Campania, 2002) evidenced that in 1991 the same market share was about 43% (25.5% bus and 17.5% rail) with an already remarkable reduction with respect to 1981 values. That is, in year 2001 the transit system of Campania touched its lowest point, with a substantial contraction of rail users and a slight reduction of bus users. However, since the launch of the SMR project in 2001, a substantial change has been observed. Data from ACAM (Regional Agency for Sustainable Mobility) based on surveys carried out in 2008 point out a 40% increase of rail users with respect to 2001, with a maximum of 75% increase in commuting trips to/from Napoli. Further evidence of this tendency is reported in Cascetta et al. (2005), who pointed out a decrease from 47.9% to 42.5% of car trips to/from Napoli and a contemporary increase of transit systems from 52.1% to 57.5%, A complete picture of the market shares for the year 2008 is reported in the following Table 5.
Finally, the following Figure 2 draws the bus and rail networks respectively as in 2008, with

indication of the corresponding daily services stopping at each municipality. These pictures represent an aggregate of the database of transit services described in Section 3.1.

Within the territory of Campania, five different test sites have been chosen (see Figure 1) for application of the methodology described in Section 3: city of Napoli; metropolitan area of Napoli; Campania region excluded the metropolitan area of Napoli; county of Caserta; city of Giugliano in Campania.

The choice of the city and of the metropolitan area of Napoli as test sites comes from their inherent characteristics of current satisfactory public transport infrastructure supply not always properly supported by adequate services, a consolidated integrated fare system and parking fees in almost all territory. The test site of the county of Caserta is significantly different, with a lower population density, sprawled urban areas, a good rail infrastructure but poor rail and bus services. Finally, Giugliano in Campania has been chosen because of the very low load factor of the current bus services in spite of two railway stations within the city with good connections with Napoli.

Table 5 – Market shares for all trip purposes at county level (source: ACAM 2008).

Origin		Destination							
		OUTSIDE REGION	NAPOLI (CITY)	AVELLINO	BENEVENTO	CASERTA	NAPOLI	SALERNO	total
car	OUTSIDE REGION	-	38%	86%	94%	72%	83%	73%	74%
	NAPOLI (CITY)	52%	-	40%	49%	68%	61%	53%	60%
	AVELLINO	80%	38%	90%	85%	100%	76%	82%	86%
	BENEVENTO	95%	54%	83%	92%	86%	100%	100%	90%
	CASERTA	74%	70%	100%	87%	92%	94%	70%	90%
	NAPOLI	64%	60%	79%	100%	94%	87%	81%	79%
	SALERNO	66%	52%	83%	100%	74%	81%	81%	80%
	total	**71%**	**60%**	**86%**	**90%**	**90%**	**79%**	**80%**	**80%**
bus	OUTSIDE REGION	-	11%	7%	6%	7%	0%	5%	6%
	NAPOLI (CITY)	20%	-	36%	22%	9%	10%	26%	11%
	AVELLINO	0%	42%	10%	11%	0%	14%	18%	12%
	BENEVENTO	5%	24%	12%	8%	7%	0%	0%	8%
	CASERTA	7%	9%	0%	7%	6%	4%	14%	6%
	NAPOLI	0%	10%	11%	0%	4%	6%	8%	7%
	SALERNO	5%	26%	17%	0%	12%	9%	16%	16%
	total	**6%**	**11%**	**12%**	**8%**	**6%**	**7%**	**16%**	**10%**
rail	OUTSIDE REGION	-	40%	7%	0%	20%	14%	22%	19%
	NAPOLI (CITY)	28%	-	24%	30%	23%	29%	20%	28%
	AVELLINO	20%	20%	0%	4%	0%	10%	0%	2%
	BENEVENTO	0%	23%	6%	0%	7%	0%	0%	2%
	CASERTA	18%	21%	0%	7%	2%	2%	16%	4%
	NAPOLI	21%	29%	10%	0%	3%	7%	11%	14%
	SALERNO	19%	22%	0%	0%	14%	10%	3%	4%
	total	**18%**	**28%**	**2%**	**2%**	**4%**	**13%**	**4%**	**10%**
	other transit systems	**5%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**
	overall total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

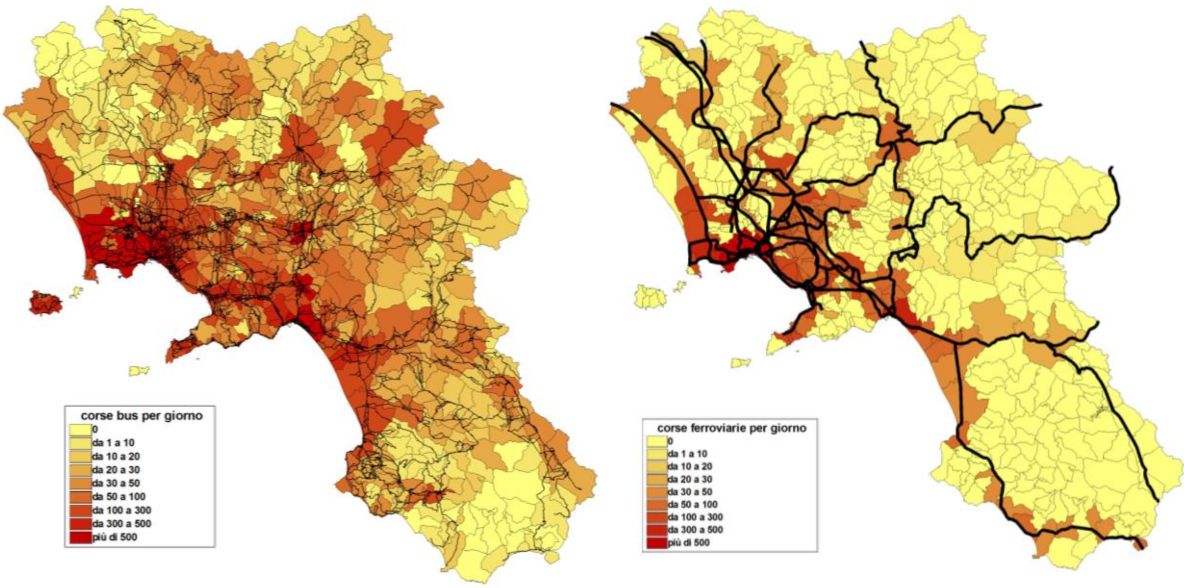

Figure 2 – Daily bus (left) and rail (right) services per municipality in 2008

4.3 Applications and results

4.3.1 Single scenarios

Depending on the above mentioned characteristics of each test site, a first analysis has been carried out by simulating some scenarios for each test site, accordingly with the correspondence table reported in Table 6. Furthermore, all scenarios have been simulated by assuming contemporary presence of fare integration, except obviously for the integration scenario itself. In addition, the policy of increasing current bus and rail services has been simulated by considering four different demand increase thresholds as cutoff for the inclusion of the increased services into the scenario (see Section 3.2.1): that is, given a certain threshold in demand increase (e.g. plus *x*% passengers onboard), only services providing for an increase larger than *x%* have been considered for final inclusion into the scenario.

Table 6 – Correspondence between policy actions and test sites for simulation.

Policy action	Test site				
	Campania region	Napoli metropolitan area	Napoli city	county of Caserta	Giugliano in Campania
enhanced transit services	●	●	●	●	
new railway infrastructures	●	●	●	●	
fare integration	●	●	●	●	
ITS and user information	●	●	●	●	
enhanced feeder bus to rail	●	●	●	●	
bus priority			●		
cordon pricing		●	●		
LTZ		●	●		
dial a ride					●

A detailed and disaggregated presentation of the results of each simulation goes beyond the scopes of the present paper, the reader may refer to the final report of the study (Cascetta et al., 2009).

In order to draw and discuss the main outcomes of the analysis, a synoptic synthesis of the main impacts through proposition of the indicators described in Section 3.3.1 and Section 3.3.2 is reported in the following Tables 7 to 10. Furthermore, a synthesis of the implementation costs is reported, accordingly with the methodology reported in Section 3.3.3, in the following Table 11. In more detail, values reported in Tables 7 to 10 are referred to the morning peak hour (7:00-9:30) of the average working day, while, in Table 11, the total generalized cost variation for transit users presented in Tables 7 to 10 – referred to year - is presented as an yearly direct benefit (last column) to be compared with the yearly investment cost (third to last column).

Table 7 – Results of the policy scenarios modelling for the test site Campania Region.

Test site CAMPANIA REGION	Generalized cost [€]		generalized cost for transit users [€]		market share (morning peak hour)				average trip duration by car [min]	overall vehicle kms by car	specific fuel consumption by trip [€]
	total	per capita	total	per capita	% car	% transit	% park & ride	% feet			
base	**988350**	**1.882**	**421690**	**5.127**	**65.57%**	**15.66%**	**0.91%**	**17.86%**	**14.133**	**3734878**	**1.692**
					344320	**82242**	**4767**	**93780**			
new railway infrastructures	979940	1.866	245070	3.075	64.96%	16.39%	1.01%	17.64%	14.062	3744104	1.686
	-8410	*-0.016*	*-176620*	*-2.052*	*-0.61%*	*0.73%*	*0.11%*	*-0.22%*	*-0.070*	*9227*	*-0.006*
ITS and user information	984860	1.876	412153	5.015	65.12%	16.19%	0.92%	17.77%	14.101	3751046	1.688
	-3490	*-0.007*	*-9537*	*-0.112*	*-0.46%*	*0.53%*	*0.02%*	*-0.09%*	*-0.031*	*16168*	*0.001*
fare integration *(backcasting)*	1007500	1.919	465798	5.763	67.59%	13.22%	0.96%	18.23%	14.280	3971827	1.721
	19150	*0.036*	*44108*	*0.635*	*2.02%*	*-2.44%*	*0.06%*	*0.37%*	*0.148*	*236949*	*0.034*
enhanced transit services F1	968630	1.845	374484	4.681	62.58%	20.28%	1.00%	16.13%	14.465	3707124	1.732
	-19720	*-0.038*	*-47206*	*-0.446*	*-2.99%*	*4.62%*	*0.10%*	*-1.73%*	*0.333*	*-27754*	*0.011*
enhanced transit services F2	966070	1.840	367824	4.630	62.28%	20.64%	0.99%	16.09%	14.443	3682666	1.729
	-22280	*-0.042*	*-53866*	*-0.497*	*-3.29%*	*4.97%*	*0.08%*	*-1.77%*	*0.311*	*-52212*	*-0.003*
enhanced transit services F3	963450	1.835	361174	4.578	61.98%	20.99%	0.98%	16.05%	14.414	3656782	1.726
	-24900	*-0.047*	*-60516*	*-0.549*	*-3.60%*	*5.32%*	*0.08%*	*-1.81%*	*0.281*	*-78096*	*0.034*
enhanced transit services F4	935880	1.782	307590	4.208	59.81%	23.63%	0.97%	15.60%	14.377	3507120	1.720
	-52470	*-0.100*	*-114100*	*-0.920*	*-5.76%*	*7.96%*	*0.06%*	*-2.26%*	*0.244*	*-227757*	*-0.006*
enhanced feeder bus to rail	965900	1.839	366356	4.554	63.62%	18.39%	0.86%	17.13%	14.215	3686250	1.699
	-22450	*-0.043*	*-55334*	*-0.573*	*-1.95%*	*2.73%*	*-0.05%*	*-0.72%*	*0.083*	*-48628*	*-0.021*

Table 8 – Results of the policy scenarios modelling for the test site Metropolitan Area of Napoli.

Test site NAPOLI METROPOLITAN AREA	Generalized cost [€]		generalized cost for transit users [€]		market share (morning peak hour)				average trip duration by car [min]	overall vehicle kms by car	specific fuel consumption by trip [€]
	total	per capita	total	per capita	% car	% transit	% park & ride	% feet			
base	**1061900**	**2.942**	**495190**	**5.527**	**50.72%**	**24.82%**	**1.86%**	**22.60%**	**34.492**	**2027007**	**0.876**
					183060	**89590**	**6726**	**81567**			
new railway infrastructures	1058800	2.933	491601	5.487	50.54%	25.04%	1.91%	22.50%	34.482	2018701	0.872
	-3100	*-0.009*	*-3589*	*-0.040*	*-0.17%*	*0.22%*	*0.05%*	*-0.10%*	*-0.010*	*-8306*	*-0.004*
ITS and user information	1055900	2.925	486458	5.432	50.29%	25.40%	1.87%	22.43%	34.412	2002913	0.866
	-6000	*-0.017*	*-8732*	*-0.095*	*-0.43%*	*0.58%*	*0.01%*	*-0.16%*	*-0.080*	*-24094*	*-0.010*
fare integration *(backcasting)*	1102100	3.053	556341	6.358	53.63%	20.40%	2.03%	23.94%	34.621	2044618	0.884
	40200	*0.111*	*61151*	*0.831*	*2.91%*	*-4.42%*	*0.17%*	*1.34%*	*0.129*	*17611*	*0.008*
enhanced transit services F1	1026800	2.845	448234	5.059	48.48%	27.80%	1.94%	21.79%	34.077	1910643	0.826
	-35100	*-0.097*	*-46956*	*-0.468*	*-2.24%*	*2.98%*	*0.07%*	*-0.81%*	*-0.415*	*-116364*	*-0.050*
enhanced transit services F2	1025400	2.841	444336	5.041	47.91%	28.99%	1.95%	21.15%	34.387	1895762	0.819
	-36500	*-0.101*	*-50854*	*-0.486*	*-2.81%*	*4.17%*	*0.09%*	*-1.44%*	*-0.105*	*-131245*	*-0.057*
enhanced transit services F3	1022500	2.833	440842	5.011	47.74%	29.18%	1.99%	21.10%	34.364	1888230	0.816
	-39400	*-0.109*	*-54348*	*-0.516*	*-2.98%*	*4.36%*	*0.12%*	*-1.50%*	*-0.128*	*-138777*	*-0.060*
enhanced transit services F4	1014900	2.812	429853	4.922	47.22%	29.91%	1.97%	20.91%	34.250	1860414	0.804
	-47000	*-0.130*	*-65337*	*-0.605*	*-3.50%*	*5.09%*	*0.10%*	*-1.69%*	*-0.242*	*-166593*	*-0.072*
enhanced feeder bus to rail	985770	2.731	417053	4.778	47.89%	28.96%	1.77%	21.39%	33.200	1832898	0.792
	-76130	*-0.211*	*-78137*	*-0.749*	*-2.83%*	*4.14%*	*-0.10%*	*-1.21%*	*-1.292*	*-194109*	*-0.084*
cordon pricing 2 €	1191100	3.300	495190	5.527	46.15%	27.56%	2.14%	24.15%	33.656	1750921	0.757
	129200	*0.358*	*0*	*0.000*	*-4.57%*	*2.74%*	*0.28%*	*1.55%*	*-0.836*	*-276086*	*-0.119*
cordon pricing 5 €	1288400	3.570	495190	5.527	40.33%	31.05%	2.53%	26.09%	32.486	1411747	0.610
	226500	*0.628*	*0*	*0.000*	*-10.39%*	*6.23%*	*0.66%*	*3.50%*	*-2.006*	*-615260*	*-0.266*

Table 9 – Results of the policy scenarios modelling for the test site City of Napoli.

Test site NAPOLI CITY	Generalized cost [€]		generalized cost for transit users [€]		market share (morning peak hour)				average trip duration by car [min]	overall vehicle kms by car	specific fuel consumption by trip [€]
	total	per capita	total	per capita	% car	% transit	% park & ride	% feet			
base	**345160**	**2.142**	**182230**	**4.115**	**44.21%**	**27.49%**	**1.81%**	**26.49%**	**33.141**	**482603**	**0.467**
					71237	**44285**	**2912**	**42688**			
new railway infrastructures	342190	2.124	179063	4.045	43.93%	27.93%	1.84%	26.30%	33.087	500246	0.484
	-2970	*-0.018*	*-3167*	*-0.070*	*-0.28%*	*0.44%*	*0.03%*	*-0.19%*	*-0.054*	*17643*	*0.017*
ITS and user information	342930	2.128	179103	4.046	43.98%	28.04%	1.82%	26.15%	33.048	500790	0.485
	-2230	*-0.014*	*-3127*	*-0.069*	*-0.23%*	*0.55%*	*0.02%*	*-0.34%*	*-0.093*	*18187*	*0.018*
fare integration *(backcasting)*	361560	2.244	207897	4.806	46.96%	23.06%	1.97%	28.02%	33.918	558062	0.540
	16400	*0.102*	*25667*	*0.691*	*2.75%*	*-4.43%*	*0.16%*	*1.52%*	*0.778*	*75459*	*0.073*
enhanced transit services F1	334870	2.078	168927	3.835	42.87%	29.49%	1.90%	25.75%	32.820	484456	0.469
	-10290	*-0.064*	*-13303*	*-0.280*	*-1.35%*	*2.00%*	*0.09%*	*-0.75%*	*-0.321*	*1853*	*0.002*
enhanced transit services F2	331990	2.061	165372	3.769	42.41%	30.26%	1.91%	25.43%	32.876	479163	0.464
	-13170	*-0.082*	*-16858*	*-0.346*	*-1.80%*	*2.77%*	*0.10%*	*-1.07%*	*-0.265*	*-3440*	*-0.003*
enhanced transit services F3	331830	2.060	165152	3.765	42.38%	30.29%	1.92%	25.41%	32.865	478433	0.463
	-13330	*-0.083*	*-17078*	*-0.350*	*-1.84%*	*2.80%*	*0.12%*	*-1.09%*	*-0.276*	*-4170*	*-0.004*
enhanced transit services F4	331750	2.059	165001	3.762	42.36%	30.32%	1.91%	25.41%	32.863	478667	0.463
	-13410	*-0.083*	*-17229*	*-0.353*	*-1.85%*	*2.83%*	*0.11%*	*-1.09%*	*-0.278*	*-3936*	*-0.004*
enhanced feeder bus to rail	318140	1.975	149701	3.494	41.11%	32.46%	1.77%	24.65%	32.610	457956	0.443
	-27020	*-0.168*	*-32529*	*-0.621*	*-3.11%*	*4.98%*	*-0.03%*	*-1.84%*	*-0.531*	*-24647*	*-0.024*
cordon pricing 2 €	367120	2.279	182230	4.115	41.33%	28.91%	1.91%	27.86%	33.046	476571	0.461
	21960	*0.136*	*0*	*0.000*	*-2.89%*	*1.43%*	*0.10%*	*1.36%*	*-0.095*	*-6032*	*-0.006*
cordon pricing 5 €	376910	2.339	182230	4.115	38.51%	30.33%	2.01%	29.16%	32.978	447652	0.433
	31750	*0.197*	*0*	*0.000*	*-5.71%*	*2.84%*	*0.20%*	*2.67%*	*-0.163*	*-34950*	*-0.034*
LTZ	374230	2.323	182230	4.115	39.16%	29.91%	1.96%	28.98%	33.623	465407	0.451
	29070	*0.180*	*0*	*0.000*	*-5.06%*	*2.42%*	*0.15%*	*2.48%*	*0.482*	*-17196*	*-0.017*
bus priority	335700	2.084	171035	3.879	43.06%	29.38%	1.84%	25.72%	32.950	487423	0.472
	-9460	*-0.059*	*-11195*	*-0.236*	*-1.15%*	*1.90%*	*0.03%*	*-0.77%*	*-0.190*	*4820*	*0.005*

Table 10 – Results of the policy scenarios modelling for the test site County of Caserta.

Test site COUNTY OF CASERTA	Generalized cost [€]		generalized cost for transit users [€]		market share (morning peak hour)				average trip duration by car [min]	overall vehicle kms by car	specific fuel consumption by trip [€]
	total	per capita	total	per capita	% car	% transit	% park & ride	% feet			
base	**157730**	**1.180**	**73197**	**4.932**	**66.60%**	**10.53%**	**0.69%**	**22.17%**	**0.203**	**389278**	**0.454**
					89036	**14079**	**927**	**29636**			
new railway infrastructures	157390	1.177	71657	4.832	66.21%	10.86%	0.88%	22.05%	0.206	391791	0.457
	-340	*-0.003*	*-1541*	*-0.100*	*-0.40%*	*0.33%*	*0.19%*	*-0.12%*	*0.003*	*2513*	*0.003*
ITS and user information	157460	1.178	71443	4.819	66.27%	10.93%	0.71%	22.09%	0.205	390391	0.456
	-270	*-0.002*	*-1754*	*-0.113*	*-0.33%*	*0.40%*	*0.01%*	*-0.08%*	*0.002*	*1113*	*0.001*
fare integration *(backcasting)*	159610	1.194	79983	5.464	67.75%	9.11%	0.71%	22.43%	0.208	404226	0.472
	1880	*0.014*	*6786*	*0.532*	*1.15%*	*-1.43%*	*0.02%*	*0.26%*	*0.005*	*14948*	*0.017*
enhanced transit services F1	151330	1.132	44545	3.571	62.54%	15.75%	0.82%	20.89%	0.213	381955	0.446
	-6400	*-0.048*	*-28652*	*-1.361*	*-4.06%*	*5.21%*	*0.13%*	*-1.28%*	*0.010*	*-7323*	*-0.009*
enhanced feeder bus to rail	156710	1.172	57781	4.134	64.55%	13.54%	0.66%	21.25%	0.207	382694	0.447
	-1020	*-0.008*	*-15416*	*-0.798*	*-2.06%*	*3.01%*	*-0.03%*	*-0.92%*	*0.003*	*-6584*	*-0.008*

Table 11 – Yearly cost/revenue data for the test sites results from Table 7 to Table 10.

CAMPANIA REGION	new services	New infrastructures				total cost	direct revenue	Δ transit cost
	vehicles km/year	km rail	new stations	LTZ/CP gates	km res. lanes	[M€]	[M€/year]	[M€/year]
new railway infrastructures	-	172	45	-	-	1421.00	-	-27.39
ITS and user information	-	-	-	-	-	25.00	-	-14.31
fare integration	-	-	-	-	-	10.00	-	-66.16
enhanced transit services F1	13,941,495	-	-	-	-	65.53	-	-70.81
enhanced transit services F2	18,719,547	-	-	-	-	87.98	-	-80.83
enhanced transit services F3	29,878,999	-	-	-	-	140.43	-	-90.78
enhanced transit services F4	40,179,024	-	-	-	-	188.84	-	-171.13
enhanced feeder bus to rail	2,310,480	-	-	-	-	12.94	-	-83.00

METROPOLITAN AREA NAPOLI	new services	New infrastructures				total cost	direct revenue	Δ transit cost
	vehicles km/year	km rail	new stations	LTZ/CP gates	km res. lanes	[M€]	[M€/year]	[M€/year]
new railway infrastructures	-	62	45	-		541.00	-	-5.38
ITS and user information	-	-	-	-		15.00	-	-13.07
fare integration	-	-	-	-		5.00	-	-91.72
enhanced transit services F1	16,382,438	-	-	-		77.00	-	-70.44
enhanced transit services F2	19,908,325	-	-	-		93.57	-	-76.28
enhanced transit services F3	24,964,424	-	-	-		117.33	-	-81.52
enhanced transit services F4	28,629,990	-	-	-		134.56	-	-98.01
enhanced feeder bus to rail	6,688,800	-	-			34.11		-117.47
cordon pricing 2 €	-	-	-	121		36.30	118.87	0.00
cordon pricing 5 €	-	-	-	121		36.30	185.13	0.00

NAPOLI CITY	new services	New infrastructures				total cost	direct revenue	Δ transit cost
	vehicles km/year	km rail	new stations	LTZ/CP gates	km res. lanes	[M€]	[M€/year]	[M€/year]
new railway infrastructures	-	23	30	-	-	214.00	-	-7.33
ITS and user information	-	-	-	-	-	10.00	-	-4.69
fare integration	-	-	-	-	-	3.00	-	-38.50
enhanced transit services F1	7,444,979	-	-	-	-	34.99	-	-19.96
enhanced transit services F2	11,242,843	-	-	-	-	52.84	-	-25.29
enhanced transit services F3	14,275,181	-	-	-	-	67.09	-	-25.62
enhanced transit services F4	17,467,724	-	-	-	-	82.10	-	-25.84
enhanced feeder bus to rail	2,279,160	-	-	-	-	10.48	-	-48.79
cordon pricing 2 €	-	-	-	69	-	20.70	21.31	0.00
cordon pricing 5 €	-	-	-	69	-	20.70	43.65	0.00
LTZ	-	-	-	69	-	20.70	-	0.00
bus priority	-	-	-	-	62.5	18.00	-	-16.79

COUNTY OF CASERTA	new services	New infrastructures				total cost	direct revenue	Δ transit cost
	vehicles km/year	km rail	new stations	LTZ/CP gates	km res. lanes	[M€]	[M€/year]	[M€/year]
new railway infrastructures	-	49	20	-	-	415.20	-	-2.31
ITS and user information	-	-	-	-	-	15.00	-	-2.63
fare integration	-	-	-	-	-	5.00	-	-10.17
enhanced transit services F1	8,267,178	-	-	-	-	38.86	-	-42.97
enhanced feeder bus to rail	3,969,360	-	-	-	-	22.23	-	-49.98

A first significant result deals with the key role played by fare integration policies, which is the primary objective to be pursued by public bodies towards a sustainable mobility. Indeed, it is characterized by high efficacy in modal split equilibration (+4.43% for transit in test sites Napoli and Napoli metropolitan area) and in transit cost reduction (-66.1 M€ for Campania region and -91.7 M€ for the metropolitan area of Napoli), in spite of low required investments falling between 3 and 10 M€ for the considered test sites. However, a number of political and practical difficulties arise when considering the implementation of fare integration policies.
A second remarkable outcome deals with the policies related to enhancing bus feeder services towards railway stations, which provide for a significant modal split equilibration (+4% for transit in the metropolitan area of Napoli, +5% in the city of Napoli and +11% in the county of Caserta) and transit cost reduction (-48 M€ for the city of Napoli, -83 M€ for the county of Caserta, - 50 M€ for Campania region and -117 M€ in the metropolitan area of Napoli), with again very few investments (from 10 M€ of Napoli city to 34 M€ of the metropolitan area of Napoli). Furthermore, this action offers always a benefit/cost ratio

(yearly generalized transit cost variation/yearly investment costs) higher than one.
In general, results show that investments towards enhancement of current bus and rail services are worth to be implemented, however with lower positive effects on modal split and transit cost reduction with respect to fare integration and enhanced feeder services policies. In more detail, the highest results come from the Campania region test site, where the largest service increase scenario (F4) leads to a +8% in transit market share and a -171 M€ total cost for transit systems, while in the same test site the enhanced bus feeder services policy leads to a +2.73% for transit market share and a -83 M€ transit yearly cost. However, the two scenarios have a substantially different implementation cost, the former requiring almost 189 M€ for supplying about 40 more million bus and rail vehicles·km and the latter just 13 M€ corresponding to about 6 million bus vehicles·km. That is, the synergy between bus and rail towards more effective feeder services seems to play a more significant role than the pure enhancement of the existing services.
Notably, infrastructural investments towards new railway lines and stations are observed to offer a limited increase of transit system efficacy in spite of the significant implementation costs. However, this result is partly due to the already mentioned high railway infrastructuration of Campania region.
Finally, the dial-a-ride test site, not reported here for the sake of brevity, evidenced the feasibility and the effectiveness of substituting ordinary transit bus services with dial-a-ride services as effective feeder to/from railway station in sparse urban areas.

4.3.2 Synergic scenarios and identification of minimal sustainable services

Starting from the outcomes of the single scenarios proposed in Section 4.3.1, and taking into account their corresponding prioritization in terms of impacts on modal split and on other relevant indicators, all feasible combinations of push and pull policies have been also simulated, for the sake of brevity, for the Napoli city and for the County of Caserta test sites. For each test site, a comprehensive diagram of the transit market share achieved with each single and synergic scenario has been drawn, with two objectives. The first is to identify the possible presence of the asymptote mentioned in the introduction, that is a value of transit market share extremely difficult to overcome even if with very large investments. The second is to identify a reasonable market share threshold (obviously lower with respect to the asymptotic value) which can be regarded as sustainable, that is over which the marginal increase in transit market share can be reached only through unsustainable marginal investments.
For the test site Napoli city, all pull actions and only the cordon pricing push policy have been taken into account, because of the similitude with the LTZ policy. The following Table 12 and Figure 3 report respectively the modal shares of all single and synergic scenarios, and the ordered diagram of increasing overall transit (i.e. bus, rail, park & ride) market share by type of policy.
Firstly, the limited increase of transit market share should be noted, as a consequence of the already mentioned satisfactory base situation, and in addition the increase offered by synergic scenarios is less than linear. For instance, bus priority systems, which singularly provide for almost +2% transit market share, lead to an insignificant increase when coupled with increasing services scenarios (e.g. compare simulation no. 3 and 4, or 5 and 7, or 9 and

10 in Table 12). Similarly, the increase in services scenario (e.g. with threshold F3) leads singularly to an almost +3% increase in transit market share (Table 9) and only to a +0.42% increase if coupled with enhanced feeder services and cordon pricing (simulation no. 5 and 9 respectively in Table 12). Furthermore, the relationship drawn in Figure 3 underlines a sustainability threshold for the transit market share equal to 36%, easily achievable through best push and pull policies, i.e. combining enhancing feeder bus services towards rail and cordon pricing (simulation no. 5). Notably, the 36% threshold can be hardly overcome with very significant further investments. This means that it is not feasible to overcome this threshold and, in addition, there is a confirmation that in a context with a dense railway network, such as in the city of Napoli, enhancing bus feeder services is the highest priority for enhancing transit market share. By considering scenario 5 as the best mix of action, the “minimal service” identification derive as a result, that is the current amount of vehicles·km increased of the amount of needed enhanced feeder services.

Table 12 – Market shares for all modes in single and synergic policy scenarios for the Napoli city test site.

simulation no	policy package	market shares				
		car/moto	transit (bus and rail)	park & ride	feet	transit + park & ride
0	base	44.21%	27.49%	1.81%	26.49%	**29.30%**
1	bus priority	43.06%	29.38%	1.84%	25.72%	**31.22%**
2	enhanced services F4	42.38%	30.29%	1.92%	25.41%	**32.21%**
3	enhanced feeder services	41.15%	32.50%	1.67%	24.68%	**34.17%**
4	enhanced feeder services + bus priority	41.06%	32.45%	1.81%	24.68%	**34.26%**
5	cordon pricing 2€ + enhanced feeder services	38.36%	33.87%	1.86%	25.91%	**35.73%**
6	cordon pricing 2€ + enhanced feeder services + enhanced services F1	38.37%	34.07%	1.75%	25.81%	**35.82%**
7	cordon pricing 2€ + enhanced feeder services + bus priority	38.27%	34.01%	1.90%	25.82%	**35.91%**
8	cordon pricing 2€ + enhanced feeder services + enhanced services F2	38.13%	34.22%	1.87%	25.79%	**36.09%**
9	cordon pricing 2€ + enhanced feeder services + enhanced services F3	38.08%	34.28%	1.87%	25.77%	**36.15%**
10	cordon pricing 2€ + enhanced feeder services + enhanced services F3 + bus priority	38.02%	34.30%	1.89%	25.79%	**36.19%**

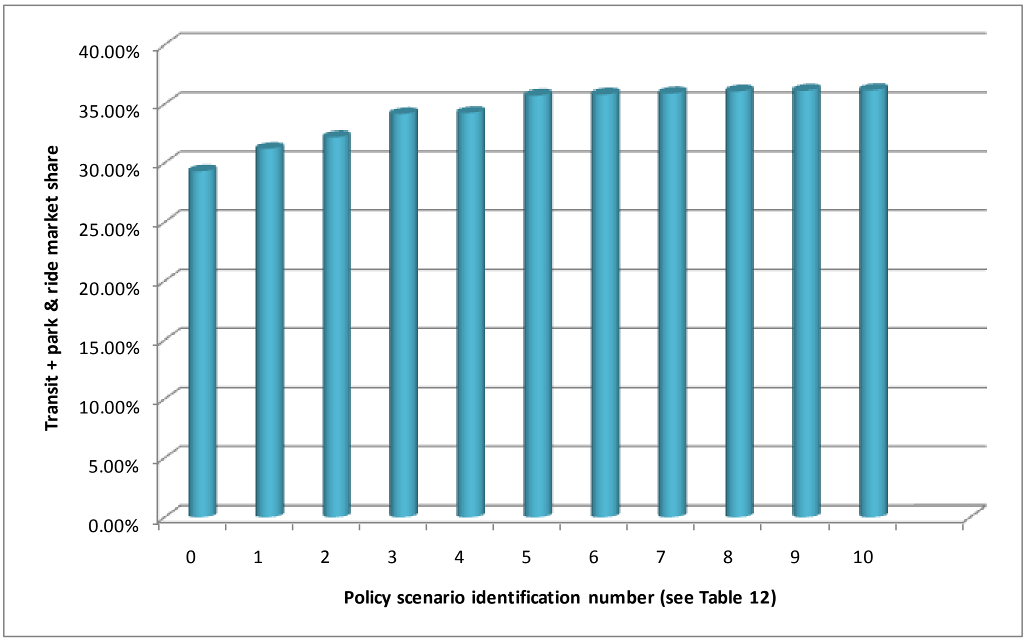

Figure 3 – Transit (bus, rail, park & ride) market share by type of policy (single and synergic)

For the test site County of Caserta, the number of single actions implemented are definitely lower and a unique synergic scenario has been simulated, by considering contemporarily enhanced bus feeder services and increase of current bus and rail services. For this test site, the same kind of results presented in the preceding Table 12 and Figure 3 are reported in the following Table 13 and Figure 4 respectively.

Table 13 – Market shares for all modes in single and synergic policy scenarios for the County of Caserta test site.

simulation no	policy package	market shares				
		car/moto	transit (bus and rail)	park & ride	feet	transit + park & ride
0	base	66.60%	10.53%	0.69%	22.17%	**11.22%**
1	enhanced services F1	62.54%	15.75%	0.82%	20.89%	**16.57%**
2	enhanced feeder services	58.92%	21.61%	0.77%	18.71%	**22.38%**
3	enhanced feeder services + enhanced services F1	48.81%	34.22%	0.64%	16.33%	**34.86%**

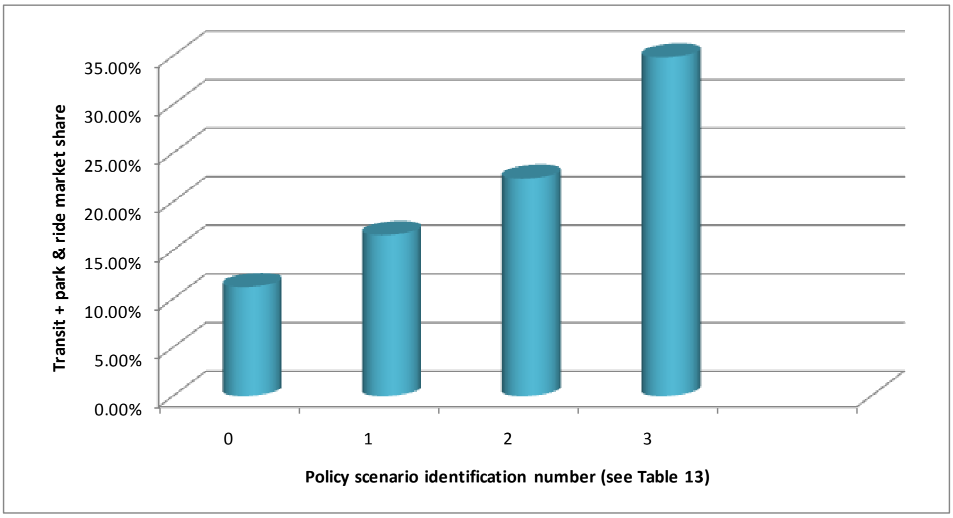

Figure 4 – Transit (bus, rail, park & ride) market share by type of policy (single and synergic)

In this case, the transit market share starting point is much lower (about 10%) and, therefore, the heuristic described in Section 3 for the identification of the services to be increased leads to very different percentage increases of transit services. For instance, in the synergic scenario there is an increase in vehicles·km of about 8 million of improved services and 4 million of enhanced bus feeder services, leading to a 12 million vehicles·km increase representing a doubling of the current baseline figure.
In this context, single scenarios already provide for remarkable transit market shares increase (e.g. +5.3% for increase in services and +11% for enhanced bus feeder services, see Table 10), and their combination shows a significantly more than linear effect leading to a +23.5% with respect to the baseline.
Consequently, the asymptotic value - too far from the starting point - is not identifiable with the few scenarios implemented but some conclusion can anyway be drawn. The most important is that a very good market share - very similar to the threshold identified for the Napoli city test site (Figure 3) - can be potentially reached also at a county level, in spite of the difference in the urban and transport structure. The main reason probably lies in the remarkable presence of railway lines and stations also in the county of Caserta, which is probably a necessary condition to be achieved for the enhancement of the transit system at any geographical level.

5. CONCLUSIONS

The main objective of the paper has been to provide for a methodology aiming at designing sustainable policies for the enhancement of the transit systems in urban and regional contexts.
Firstly, a detailed review of the state of practice of transit systems in Italy and across Europe has been carried out (see Cascetta et al. 2009 for details), through identification of all relevant characteristics for each analyzed context together with the corresponding balance between transit vehicles km supplied and transit market share. A substantial heterogeneity has been observed in that respect, leading to the impossibility of defining a benchmark value of vehicles km to be supplied for obtaining a sustainable transit system, even if in

homogeneous clusters, and also to the impossibility of establishing relationships between vehicles km supplied, other territorial/transport variables and the corresponding transit market share. Notably, such relationship would have allowed for a direct quantification of the amount of minimal services to be supplied for achieving a given modal split.
Therefore, a disaggregated quantitative methodology has been proposed for analyzing the impact of policies and for the design of the amount of sustainable minimal services to be supplied. The methodology is based on a system of models for the simulation of the whole transport system in the study area, and on some heuristics for effective design of policies to be analyzed. A detailed explanation of the methodology, as well as its application to five different test sites identified within the territory of Campania Region, has been proposed.
The main outcome of the analysis deals with the remarkable importance of implementing fare integration policies across operators and across transit modes, because of its very high ratio between benefits in terms of transit market share and implementation costs. Obviously, a higher impact can be observed when fare integration is pursued in contexts where a remarkable amount of integrated bus and rail services is already in operation. Furthermore, the policies of enhancing bus feeder services towards rail stations seems to provide for higher benefits rather than improving the existing services, as a further indication of the importance of achieving a synergy across transit modes. Finally, investments in new infrastructures do not seem to be by themselves a panacea for increasing transit market share: notably, this conclusion may be affected by the already satisfactory infrastructural level within the analyzed test sites.
Furthermore, through the comparison of the effects of single and synergic policy scenarios, the amount of minimal services to be supplied for sustainable mobility has been quantified for the test sites of Napoli city and of the County of Caserta. In more detail, within the former a clear asymptotic trend in modal split enhancement has been observed with respect to policy scenarios, leading to the conclusion that the 35% is a target value for sustainable transit mobility to be achieved through enhanced bus feeder services and cordon pricing strategies. Within the latter test site, instead, even if a very similar target transit market share can be potentially achieved, the corresponding policies to be put in force would require approximately doubling the current amount of supplied vehicles·km.
In conclusion, the main outcome of the study is that thorough attention should be paid in transferring results and policy packages across different contexts for enhancing transit market share, as a consequence of the remarkable number of peculiarities and specificities affecting the performances of transit systems in a given study area. On the contrary, the proposed methodology can be easily applied to other contexts, provided that a reliable transport system simulation model is available with the characteristics defined in Section 3.1.

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