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A GENERAL PROCEDURE FOR SIMULATION AND EVALUATION OF URBAN LAND-USE AND TRANSPORT POLICIES

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SOMMARIO

The paper focuses on simulation and evaluation of land-use and transport policies in an urban area. Activity and transport systems are simulated through a Land-Use Transport Interaction (LUTI) model, while a Data Envelopment Analysis (DEA) model allows evaluating alternative policies in relation to necessary resources.
Transport simulation models, generally, assume activity system as an exogenous input. At strategic scale, however, activity system cannot be considered constant. In order to overcome these limitations, LUTI models become necessary.
DEA was originally conceived to evaluate production efficiency in industrial systems. Later it has been applied in transport planning, where outputs were generally represented by services. In this context, DEA is used as an evaluation technique to compare different alternatives.
In the paper a general procedure, which integrates a LUTI model and a DEA model, to simulate and evaluate land-use and transport policies in the behalf of strategic transport planning, is proposed. The LUTI model provides the values of variables related to the activity and transport systems. These variables are inputs for indicators, which constitute the outputs that are processed, together with the inputs (resources), by DEA model in order to estimate a measure of relative efficiency.
A test application of the general procedure is performed in the urban area of Reggio Calabria (Italy). Preliminary results show potentialities connected to integration of a LUTI and DEA model.

1 INTRODUCTION

Transport planning, integrated with land-use planning, contributes to reach sustainable mobility. “The integration of land-use and transport planning can be instrumental in managing the demand for transport in Europe’s towns and cities. Spatial planning can facilitate walking, cycling and the use of public transport for the majority of travel purposes, thereby reducing the negative impacts on the environment of private vehicle use and provide social and economic benefits” (EEA, 2008).

Planning activities have to be strictly connected to technical, economic, financial and environmental evaluation (de Luca, 2000; Cascetta, 2006; Russo and Rindone, 2007).

The research deals with strategic transport planning at urban level. In particular, the paper focuses on simulation and evaluation of land-use and transport policies in an urban area, providing quantitative disaggregate measures. The application of quantitative methods is necessary to evaluate how and in which measure alternative scenarios pursue the goals defined. Evaluation has to be performed before the implementation of planned interventions (ex ante evaluation), during the execution of interventions (in itinere evaluation) and after the realization of interventions (ex post evaluation). The three phases have to be integrated inside the planning process. For each phase, it’s possible to refer to specific evaluation tools (Russo and Rindone, 2007).

In order to support ex ante evaluation, in literature are present:

- quantitative models to simulate transport system, in which it is generally assumed that activities system is not affected by modifications in transport system; however, in strategic transport planning, interactions between transport and activity systems can not be neglected;
- quantitative models and methods to evaluate, compare and rank alternative scenarios in terms of their effects and in relation to objectives and constraints of decision maker.

Concerning transport simulation models, the three main components are the supply model, the demand model and the assignment model. In literature a large variety of models belonging to each component has been developed, starting from the proposition of Wardrop’s principles (1952). Transport simulation models, generally, assume activity system as an exogenous input. At strategic scale, however, activity system cannot be considered constant. In order to overcome these limitations, so-called Land-Use Transport Interaction (LUTI) models have been developed in literature (de la Barra, 1989; Hensher et al., 2004; Cascetta, 2006; Russo and Musolino, 2007).

Concerning evaluation models and methods, a classification is proposed based on two criteria.

The first is related to the number of objectives to pursue. There are two classes of methods (Varipapa, 2002; Cascetta, 2006; Petrina and Virno, 2006; Ponti, 2006):

- mono objective (with single or multiple indicators), as financial or economic cost benefit analysis and value added analysis;
- multi objectives (with multiple indicators), as Multiple Criteria Decision Making (MCDM).

The second is related to the nature of objectives to pursue. There are (Fielding et al., 1985):

- methods to evaluate efficiency measured in terms of ratio between quantity of outputs obtained and quantity of input used inside a production process; in the context of urban sustainability, PROPOLIS project (Lautso K. et al., 2004) defines efficiency "as obtaining the maximum economic benefit for each unit of resources used (environmental efficiency) and the greatest human benefit from each unit of economic activity (welfare efficiency)";
- methods to evaluate effectiveness (satisfaction of demand) measured in terms of ratio between quantity of output demanded from users and quantity of inputs.

The work is carried out in the behalf of a research, which has the following general objectives: formalization of a LUTI model and description of all components and connections (Russo and Musolino, 2007); model specification and application in an urban area (Musolino, 2007), definition of land-use and transport policies; assessment of their long-term impacts in terms of sustainability indicators; evaluation and ranking by means of non parametric methods to evaluate relative efficiency (Data Envelopment Analysis, DEA).

In this paper a general procedure to simulate and evaluate land-use and transport policies, which integrates a LUTI model and a DEA model, is proposed. The general procedure is applied and validated in an urban area comparing several transport and land-use scenarios.

The paper is articulated in three sections. The first presents the state-of-the-art on LUTI models and DEA models. In the second the general procedure is proposed. The third illustrates the preliminary results of the application performed in the urban area of Reggio Calabria (Italy). At the end, final considerations are reported.

2 STATE-OF-THE-ART

This section presents the state-of-the-art on LUTI models and DEA models.

2.1 LUTI models

LUTI models present in literature may be grouped into three categories: micro-economic, spatial interaction and accounting models.

Micro-economic models focus their analysis on consumers (households and firms) and producers (landowners and employers). Their behaviour is driven by market mechanisms, in which consumers maximise their utilities subject to budget constrains and producers maximise their benefits, generating an equilibrium pattern of land rent. The pioneering work of Von Thünen (1826) explained the effect of transport cost on activity locations and land prices. Wingo (1961) and Alonso (1964) adapted Von Thünen model for the urban case by adding consumers budget constraints. Further developments were present in Mills (1969) and Muth (1968). After the proposition of random utility theory (Domencich and McFadden, 1975), several models proposed an able to bring into agreement land, labour and goods markets with residential location and travel demand modelling (Anas and Duann, 1984, Anas and Kim, 1997, Anas and Liu, 2007).

Spatial interaction models provide an aggregate perspective, since both space and activities are grouped into discrete categories. Lowry (1964) proposed a gravity-based urban land-use model, which allows to estimate the distribution of population, employment and land-use. A general theoretical framework for gravity models is the entropy-maximizing method introduced by Wilson (1967, 1970). Lowry model was further developed by Putman (1973).

Accounting models rely on Multi-Regional Input-Output (MRIO) framework. MRIO was originally developed to represent national economies, subdivided into sectors and zones (regions). At national scale, the attention is focused on production location and on travel (freight and passenger) demand estimation, neglecting the land-use aspect. The basic concept was in Keynes theory (Keynes, 1936), who introduced the principle of effective demand, whereby production is determined by consumption. In the sphere of Keynes theory, Leontief (1941) firstly proposed an IO model to simulate inter-dependencies between economic sectors through fixed technical coefficients. Further modelling developments able to reproduce a spatial representation of economy were later proposed (Isard, 1951; Moses, 1955; Leontief and Strout, 1963; Leontief and Costa, 1987) introducing constant trade coefficients to locate production across zones. After the proposition of random utility theory (Domencich and McFadden, 1975), Cascetta et al. (1996) estimated trade coefficients, elastic to production prices and transport costs, through a discrete location model. Several papers were presented in which economy and freight travel demand at national scale are simulated (Cascetta et al., 1996; Russo and Conigliaro, 1997; Russo, 2001; Marzano and Papola, 2004; Kochelman et al., 2005). At urban scale, several LUTI models, which integrate IO approach and random utility theory, were proposed in literature (de la Barra, 1989; Echenique and Hunt, 1993; Simmonds and Still, 1998). A detailed state-of-the-art of MRIO approach is presented in Russo and Musolino (2007).

2.2 DEA models

Data Envelopment Analysis (DEA) was introduced in literature by Charnes et al. (1978), starting from Farrel's (1957) formulations of efficiency.

Generally, efficiency is evaluated by means of parametric and non parametric methods that consider simultaneously different inputs and outputs. These methods allow to build production functions (e.g. stochastic frontiers) or production frontiers that represent the structure of a virtual production process characterized by optimal combinations of outputs (inputs) given a set of inputs (outputs).

Efficiency of a Decision Making Unit (DMU) can be calculated through (Vittadini and Minotti, 2006):

- parametric methods based on a specified function that represents relationship between input and output of a productive unit; these methods allow to estimate parameters of a production function; an approach is represented by Stochastic Frontier Analysis (SFA) that assumes a parametric distribution of production function; common production functions in literature are Cobb-Douglas and trans-logarithmic ones;
- non parametric methods based on comparison among performances of productive units; these methods allow to define an efficient production frontier, which is composed by the most productive DMUs; an approach is represented by Data Envelopment Analysis (DEA) where production frontier is not defined and inefficiency of each DMU is given by the minimum distance from the frontier.

DEA allows to build an efficient frontier from available (observed or simulated) inputs and outputs related to each DMU, through an optimisation model. The distance from frontier is a measure of inefficiency of a DMU, that could be eliminated through a variation in quantity of inputs (or outputs) (Cooper et al., 2000).

DEA may present two specifications:

- input oriented, in which inputs are minimized in order to satisfy the given output levels; inefficiency, in this case, is measured in terms of inputs variation;
- output oriented, in which outputs are maximized in order to satisfy the given input levels; inefficiency, in this case, is measured in terms of outputs variation.

A first specification of DEA, denoted with the acronym CCR, has been introduced by Charnes et al. (1978). CCR is based on hypothesis of Constant Return of Scale (CRS) (Cooper et al., 2000). An extension of CCR, denoted with the acronym BCC, has been proposed by Banker et al. (1984), in which CRS hypothesis is removed and variable return to scale (decreasing or increasing) is admitted.

DEA was originally conceived to evaluate production efficiency in industrial systems, where inputs are represented by labour, energy and capital resources and output are represented by goods or services. Later, DEA has been extensively applied in many fields of economy and

engineering (Tavaresa, 2002). Several DEA applications are focused on transport systems, where outputs are represented, directly or indirectly, through travel demand. Nozick et al. (1998) applied DEA to evaluate efficiency of Travel Demand Management (TDM) measures. Efficiency is estimated considering transit accessibility and scarcity of off-site parking as inputs and passengers-per-vehicle as output. Cullinane et al. (2006) evaluated efficiency of different container ports comparing the results provided by DEA and SFA methods; efficiency of each container port is estimated considering human resources (labour), available spaces (land) and equipment as input and container throughput as output. Odeck (2006) estimated efficiency of bus operators in Norway through five inputs (fuel consumption, equipment, effective driving hours, total number of seats, total number of staff employed) and two outputs (seat-kilometers, passenger-kilometers). Lupi and Danesi (2007) applied DEA to estimate global performances of Italian airports; efficiency of each airport is estimated through three inputs (area of airport, parking area, length of runway) and three outputs (total number of commercial aircraft, total annual number of arriving and departing passenger and goods).

In some papers DEA is applied inside an evaluation process in order to rank different alternative scenarios (Cook and Green, 2000; Tsamboulas and Mikroudis, 2000; Bernroider and Stix, 2006; Lahdelma and Salminen, 2006).

3 GENERAL PROCEDURE

A general procedure to simulate and evaluate land-use and transport policies in the behalf of transport planning activity is presented in this section. It is articulated in two main connected parts (Figure 1). In the first part, starting from the analysis of current situation and the formulation of objectives and constraints, it's defined a set of strategies adoptable by means of alternative scenarios to overcome critical state of current situation. Alternative scenarios require inputs, **I**, which may be financial, economic, territorial resources. Inputs are translated into some decision variables, which feed the LUTI model. The decision variables are:

$\mathbf{Y^e}$, exogenous activity demand vector;

Δ, link-path incidence matrix, which represents the transport network topology;

$\boldsymbol{c}(\mathbf{f})$, link cost functions vector.

In the second part, LUTI and DEA models are sequentially applied:

a. LUTI model provides the values of variables related to the activity system (productions vector, **X**; prices vector, **p**) and to the transport system (demand vector, **d**, link flows vector **f**, transport utilities vector, **V**); variables are combined for the estimation of indicators;

b. indicators constitute the output vector (**O**) that is processed, together with the inputs (**I**), by DEA model in order to estimate a measure of relative efficiency, in terms of distance from efficient frontier.

The estimated level of relative efficiency is compared to efficient frontier (objectives) and it is verified against constrains. If the scenario belongs to the efficient frontier (the objectives are pursued) and the constrains are not violated, the procedure ends; otherwise, there is a feedback to the definition of alternative scenarios.

In the following sub-sections, the two models integrated in the general procedure are presented.

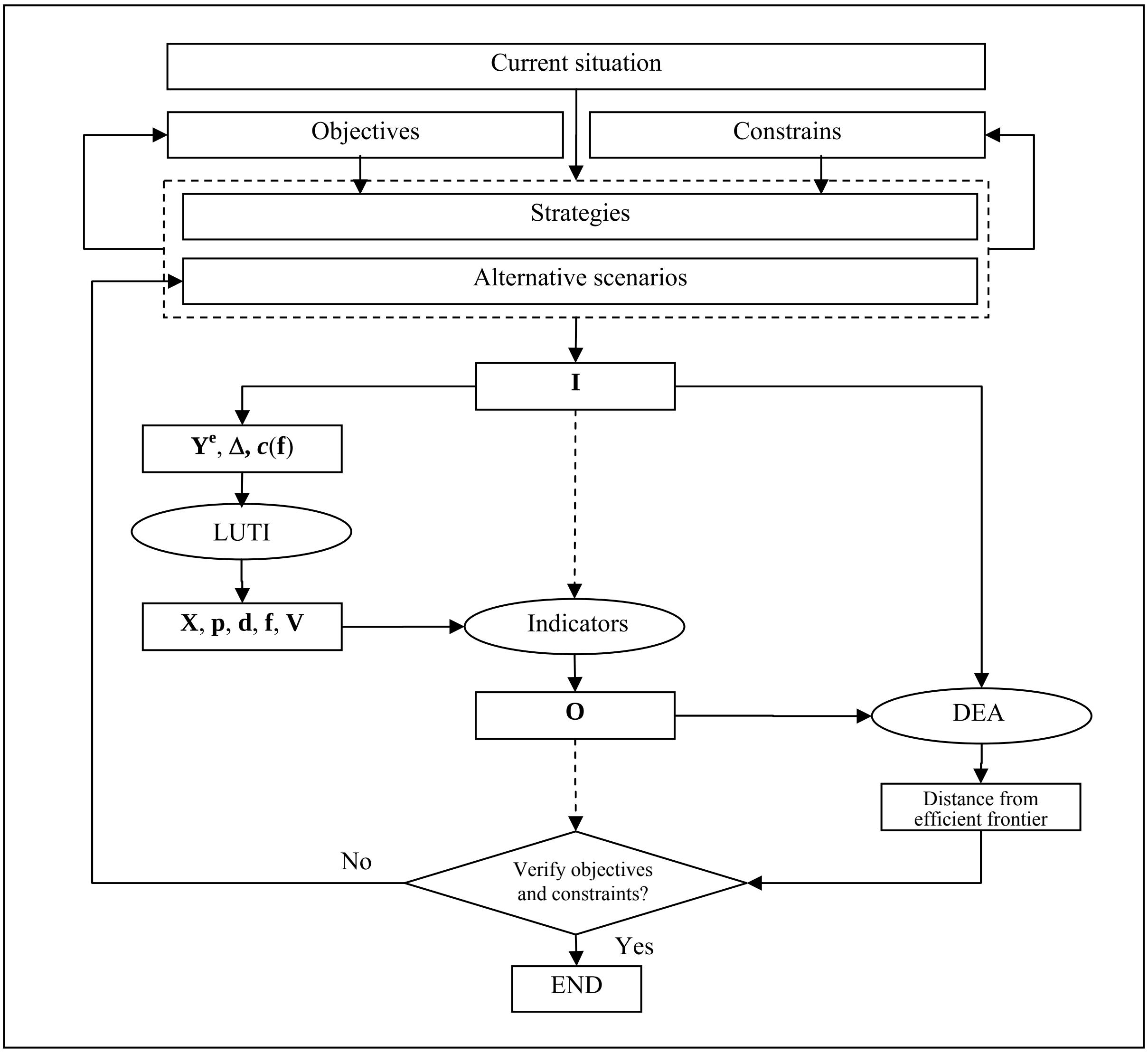

Figure 1. General procedure proposed.

3.1 LUTI model

The LUTI model has two interacting modelling components: the transport model and the activity model. The former solves the internal circular dependence among transport demand (vector **d**), link flows (vector **f**) and link costs (vector **c**), which is represented in the assignment model (eq. 3). According to the transport model, path costs depend on link flows due to congestion (eq. 2.a). The latter solves the internal circular dependence among activity demand (vector **Y**), activity flows (vector **F**) and prices (vector **p**), which is represented in the activity generation-location interaction model (eq. 6). According to the activity model, prices depend on activity flows due to limited production capacities. Moreover, the transport model and the activity model are mutually interacting: the former provide transport utilities (vector **V**) to activity location model (eq. 5) in the latter; the latter provide activity flows (matrix **F**) which affect transport demand in the former. Exogenous physical or regulatory constrains gives rise to rents, which reflect the congestion in the transport and activity markets and provide the mechanisms to bring the demand in line with the available supply (market clearing).

<u>Transport model</u>

The transport model (Musolino, 2007; Russo and Musolino, 2007) is composed by:

- a demand model, elastic to costs on the emission and mode dimensions, with a stochastic path choice model

$$\mathbf{h} = \boldsymbol{P}\,(\Delta^{T}\,\boldsymbol{c}\,(\mathbf{f}))\,\boldsymbol{d}\,(\mathbf{F}, \mathbf{V}) \tag{1}$$

with

h, path flows vector;

P, probability path choice functions matrix;

Δ, link-path incidence matrix;

c, link cost functions vector;

f, link flows vector;

d, demand functions vector;

F, activity flows vector;

V=***V***(g), transport utilities vector;

- a congested network model

$$\mathbf{g} = \Delta^{T}\,\boldsymbol{c}\,(\mathbf{f}) \tag{2.a}$$

$$\mathbf{f} = \Delta\,\mathbf{h} \tag{2.b}$$

with **g**, path costs vector;

- an assignment model

$$\mathbf{f}^* = \Delta\, \boldsymbol{P}\, (\Delta^{T}\, \boldsymbol{c}\, (\mathbf{f}^*))\, \boldsymbol{d}\, (\mathbf{F}, \mathbf{V}) \quad (3)$$

$$\mathbf{f}^* \in S_{\mathbf{f}}$$

with

f*, link flows vector at equilibrium;

$S_{\mathbf{f}}$, set of feasible link flows;

<u>Activity model</u>

The activity model is composed by:

- an activity generation model with technical coefficients depending on prices

$$\mathbf{Y} = \boldsymbol{A}(\mathbf{p})\, \mathbf{Y} + \mathbf{Y}^{\mathbf{e}} \quad (4)$$

with

Y, activity demand vector;

A(**p**), technical coefficients functions matrix;

p=***p***(**F**), sector prices vector, which depends on activity flows through the production vector **X**;

X, production vector;

$\mathbf{Y}^{\mathbf{e}}$, exogenous activity demand vector;

- an activity location model for estimation of trade coefficient matrix, **T**, which depends on prices and transport utilities

$$\mathbf{T} = \boldsymbol{T}\, (\mathbf{p}, \mathbf{V}) \quad (5)$$

with

T the trade coefficient functions matrix;

- an activity generation-location interaction model:

$$\mathbf{F}^* = \boldsymbol{T}\, (\boldsymbol{p}(\mathbf{F}^*), \mathbf{V})\, \boldsymbol{A}(\boldsymbol{p}(\mathbf{F}^*))\, \boldsymbol{Dg}(\mathbf{Y}) + \boldsymbol{T}(\boldsymbol{p}(\mathbf{F}^*), \mathbf{V})\, \boldsymbol{Dg}\, (\mathbf{Y}^{\mathbf{e}}) \quad (6)$$

with

F*, activity flow matrix at equilibrium;

Dg(**Y**), matrix obtained by arranging the elements of vector Y along the main diagonal.

Finally, production vector, **X**, is obtained from:

$$\mathbf{X} = \mathbf{1}^T \mathbf{F} \quad (7)$$

3.2 DEA model

The model considered in the proposed procedure is based on CCR hypothesis. The model is formalised to obtain, for each DMU_j, values of weights (v_m and u_s) that maximise efficiency, subject to specific constrains. It is expressed by means of the following optimization problem (one for each DMU_j):

$$\underset{\mathbf{u_j},\, \mathbf{v_j}}{\text{maximize}}\ \theta_j = O_j / I_j \quad (j = 1, ..., n) \quad (8)$$

subject to:

$O_j / I_j \leq 1 \qquad (j = 1, ..., n)$

$\mathbf{u_j} \geq 0$

$\mathbf{v_j} \geq 0$

where

$O_j = \mathbf{u_j}^T\ \mathbf{O_j}$, virtual output of DMU_j;

$I_j = \mathbf{v_j}^T\ \mathbf{I_j}$, virtual input of DMU_j;

θ_j, value of efficiency measure of DMU_j (if $\theta_j = 1$, DMU_j is efficient otherwise is inefficient);

$\mathbf{O_j} = [O_{1j}, \ldots, O_{sj}]^T$, vector of outputs of DMU_j;

$\mathbf{I_j} = [O_{1j}, \ldots, O_{mj}]^T$, vector of outputs of DMU_j;

$\mathbf{u_j} = [u_1, \ldots, u_s]^T$, vector of unknown weights assigned to outputs;

$\mathbf{v_j} = [v_1, \ldots, v_m]^T$, vectors of unknown weights assigned to inputs.

In DEA formulation, inputs and output are parameters, while weights are the decision variables. The model provides the set of weights, u_s and v_m, that maximize efficiency, θ_j, of DMU_j.

The model (8) may be expressed in the following linear form:

$$\underset{\mathbf{u_j},\, \mathbf{v_j}}{\text{maximize}}\ \theta'_j = O_j \qquad (j = 1, ..., n) \quad (9)$$

subject to:

$I_j = 1$

$O_j / I_j \leq 1 \qquad (j = 1, ..., n)$

$\mathbf{u_j} \geq 0$

$\mathbf{v_j} \geq 0$

θ_j values indicate if DMU_j is efficient and they allow to rank DMUs.

4 TEST APPLICATION

An application is performed in the urban area of Reggio Calabria (Italy), a town of about 180.000 inhabitants which has an extension of 236,02 Km^2. The application is performed according to the sequential steps defined in the second part of the general procedure. Some land-use and transport scenarios are simulated through LUTI model. Their impacts are assessed through a proposed indicator, defined as a proxy of the social component of sustainability. DEA model is applied in order to evaluate relative efficiency of alternative scenarios.

4.1 Study area: current situation and alternative scenarios

The study area includes the municipality of Reggio Calabria. It consists of a central district with residential and retail activities, educational and public services clustered into three poles (university, regional government and health, municipal government); and of three suburban districts (northern, southern, hill) with manufacturing activities and scattered residences.

The study area is divided into 35 zones with homogeneous socio-economic characteristics. Central district is divided into 24 zones, northern into 6, southern into 2 and hilly into 3 zones. Figure 2 shows the study area, the districts and zones delimitation.

The activity system inside the study area was segmented into 8 sectors to match available census residential and employment location data (ISTAT, 2001): manufacturing, service and office, retail, school education, university education, low-income population, high-income population, available floorspace.

Inter-dependencies between activity sectors are simulated through Leontief-type technical coefficients defined in a simplified Social Accounting Matrix (SAM). Coefficients connected to employment in each sectors are fixed, while those connected to floorspace consumption per sector are price elastic.

Travel demand, segmented into 6 transport categories (low-income work, high-income work, services, purchase, school, university), is associated to activity sectors which generate activity flows, according to the transport category vs. activity sector correspondence matrix.

The current transit system comprises urban and regional bus services; regional rail services, connected with bus services through the bus terminus beside the main rail station in the central district; and inter-regional maritime services. The transit system has no direct connections among the three poles or between the latter and the rail stations, harbour and bus terminal. Trips are mainly undertaken by private mode (car), while transit services have a negligible role.

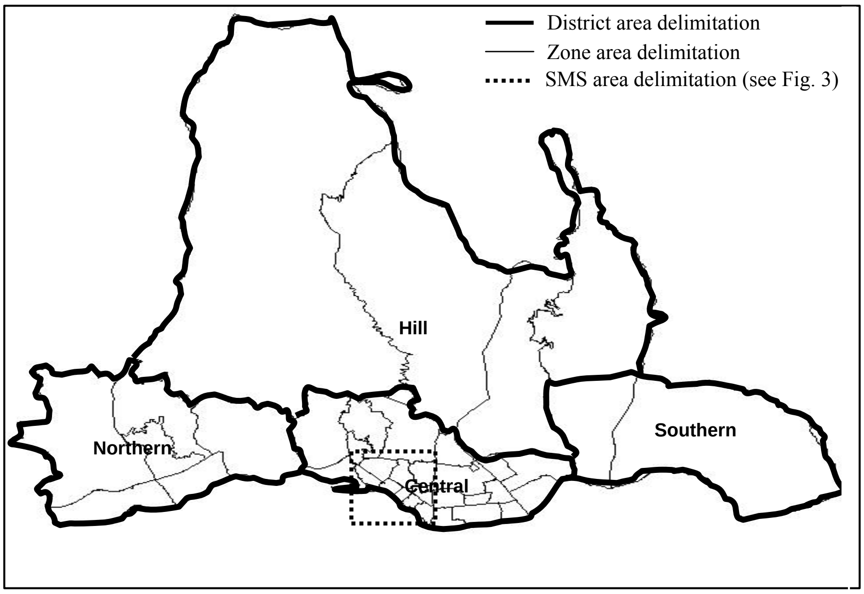

Figure 2. The study area: districts, zones and SMS area delimitations.

Several combined land-use/transport scenarios are defined which include facility interventions on transit system and different land-use development configurations.

The single interventions on transit system concern frequency doubling of bus and/or railway transit lines currently operating inside the study area and the execution of a new transit system denoted with the acronym SMS (Sustainable Mobility System) (LAST, 2004). SMS is a funicular travelling in a reserved right-of-way with stops every 400-500 metres. Vehicle guidance is fully automated and the control system is centralized. Figure 3 shows the SMS area inside the central district: pole locations and a schematic representation of bus, rail and SMS itineraries are depicted.

In the following the single transport interventions are synthesized:

- SMS system (SMS, Sustainable Mobility System);
- frequency doubling of bus and railway lines (DF, Double Frequencies);
- frequency doubling of railway lines (DF_{rail}, Double Frequencies of rail services).

The land-use development configurations concern the identification and different location of available land inside study area for the settlement of new residential and economic activities:

- available land in central district (LCZ, Land Central Zone);
- available land in southern district (LSZ, Land Southern Zone);
- available land in all suburban districts (LS, Land Suburbs).

Moreover, a Do-Nothing (DN) scenario has been defined with the current transport and activity system. Combined land-use transport scenarios are presented in Table 1.

The defined scenarios require resources to implement interventions. Financial resources are estimated considering annual costs of construction, maintenance and management needed for each intervention.

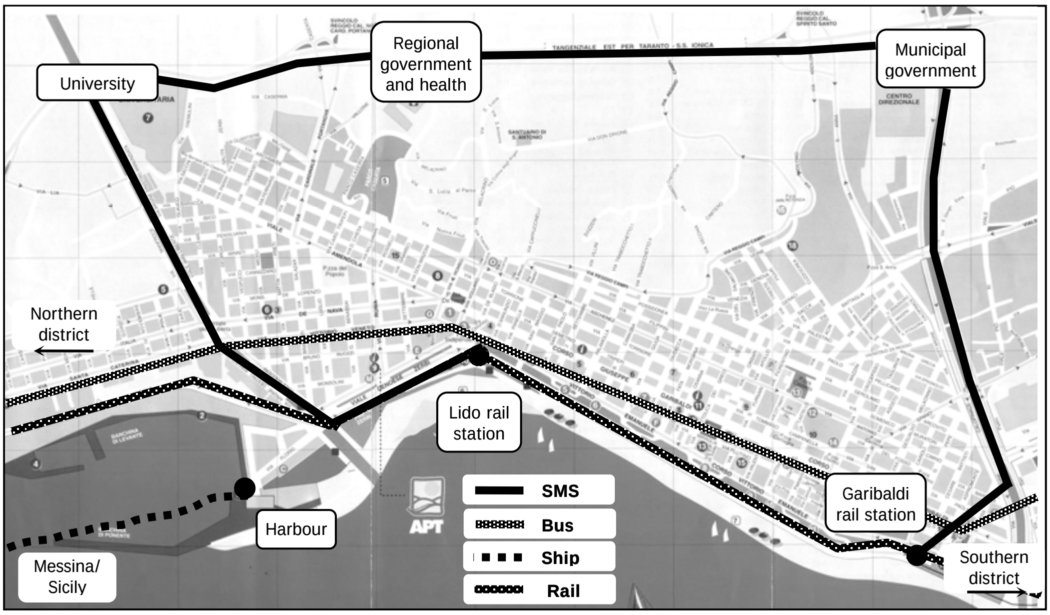

Figure 3. SMS area inside central district: poles location, bus, rail and SMS itineraries.

Table 1. Combined land-use transport scenarios

Scenario (DMU_j)	Code
Do-Nothing	DN
Available land in central district + SMS system	LCZ+SMS
Available land in southern district + SMS system	LCZ+SMS
Available land in all suburban districts + SMS system	LS+SMS
Available land in all suburban districts + SMS system + frequency doubling of bus and railway lines	LS+SMS+DF
Available land in southern district + frequency doubling of railway lines	LS+SMS+DF_{rail}

4.2 Preliminary results

LUTI model allows to estimate variables related to the activity system and to the transport system (Musolino, 2007). Combining the estimated variables, several indicators may be obtained.

In order to validate the proposed general procedure, one indicator has been identified, formalized and estimated in the application, which constitutes the output to be processed, together with the inputs (resources), by DEA model.

The proposed indicator is represented by accessibility, A, that could be considered as a proxy of social component of sustainability. Accessibility indicator requires disaggregate estimations per zone of variables related to activity system (residential and employment locations) and to transport system (transport utilities). It is obtained as:

$$A = \sum_c (\sum_o A^{a,c}_o + \sum_d A^{p,c}_d) \quad (10)$$

where

$A^{a,c}_o$ is active accessibility related to zone o and to trip purpose c:

$$A^{a,c}_o = \sum_d Add^c_d \exp(V^c_{od}) \quad \forall c \quad (11)$$

with

d, destination zone;

c, trip purpose (work, service, retail);

Add^c_d, employers related to sector connected to trip purpose c in zone d;

$A^{p,c}_d$ is passive accessibility related to zone d and to trip purpose c:

$$A^{p,c}_d = \sum_o Res^c_o \exp(V^c_{od}) \quad \forall c \quad (12)$$

with

o, origin zone;

Res^c_o, residents in zone o connected to trip purpose c.

Transport utility, V_{od}^c, related to OD couple od and to trip purpose c has been estimated by means of transport system of models as:

$$V^c_{od} = \theta \ln(\sum_m \exp(V^c_{od,m}/\theta)) \quad \forall c \quad (13)$$

with

$V_{od,m}^c$, transport utility related to OD couple od, transport mode m and to trip purpose c;

θ , dispersion parameter of logit model.

In order to apply DEA model, each scenario is expressed in terms of:

- two inputs,
  - o financial resources per year to implement transport interventions (construction and management costs), I_1;
  - o financial resources per year to implement land-use development (construction costs), I_2;
- one output, accessibility variation related to current situation, O_1.

Values of inputs and outputs for each scenario are reported in Table 2.

The specification of model (9) for the application is the following:

$$\underset{u_{1j}, v_{1j}, v_{2j}}{\text{maximize}}\ \theta_j = u_{1j}\, O_{1j} \qquad (j = 1, ..., 5) \qquad (14)$$

subject to:

$v_{1j}\, I_{1j} + v_{2j}\, I_{2j} = 1$ (j = 1,…, 5)

$((u_{1j}\, O_{1j}) / (v_{1j}\, I_{1j} + v_{2j}\, I_{2j})) \leq 1$ (j = 1,…, 5)

$u_{1j} \geq 0$

$v_{1j} \geq 0$

$v_{2j} \geq 0$

where

u_{1j}, value of unknown weights assigned to outputs 1 for each DMU_j;

v_{1j}, value of unknown weight assigned to input 1 for each DMU_j;

v_{2j}, value of unknown weight assigned to input 2 for each DMU_j.

Table 2. Inputs and outputs for each scenario

Scenario (DMU_j)	INPUT		OUTPUT
	Financial resources for transport (Meuro/year)	Financial resources for land-use (Meuro/year)	Accessibility variation (util x 10^3/day)
	I_1	I_2	O_1
LCZ+SMS	16,9	4,7	3,59
LSZ+SMS	10,2	4,7	0,41
LS+SMS	10,8	4,7	1,25
LS+SMS+DF	10,8	8,3	4,36
LSZ+ DF_{rail}	10,2	1,4	0,53

5 FINAL CONSIDERATIONS

The paper focuses on simulation and evaluation land-use and transport policies in an urban area. Activity and transport systems are simulated through a Land-Use Transport Interaction (LUTI) model, while a Data Envelopment Analysis (DEA) model allows to evaluate alternative policies in relation to necessary inputs.

At strategic scale activity system cannot be considered constant; so LUTI models become necessary to take into account interactions between transport and activity systems. DEA has been applied in transport planning, where outputs were generally represented by services. In this context, DEA is used as an evaluation technique to compare different alternatives.

In the paper a general procedure, which integrates a LUTI model and a DEA model, is proposed. The integration consists in assuming estimated variables with LUTI model as outputs of DEA model. On the other hand, inputs are required both in LUTI (for estimation of

decisional variables) and in DEA. Inputs and outputs are processed by DEA model in order to evaluate impacts defined in the behalf of strategic transport planning.

A test application is performed in the urban area of Reggio Calabria (Italy). Preliminary results show potentialities connected to integration of a LUTI and DEA model.

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