COMPARISON OF EFFECTS THROUGH DATA ENVELOPMENT ANALYSIS: A TEST ON A LIGHT RAIL TRANSIT

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ABSTRACT

An internal transport planning process is affected by the objectives to be pursued to implement strategies which respect constraints. Starting from analysis of the current situation, in the plan a set of strategies to adopt is identified such as to respect all constraints. Effects of alternative scenarios may be simulated and evaluated by applying a system of models. They are represented by means of performance measurement that may be compared with objectives and constraints before and after implementation of planned interventions.

In this paper evaluation methods to compare effects within the strategic urban transport planning process are focused. The economic efficiency criterion is adopted to measure the capacity of a Decision Making Unit (DMU) in creating a production process that combines production factors to obtain one or more products. Methods to measure efficiency in production can be classified into: parametric methods, based on the hypothesis that the production function is known; non-parametric methods, based on comparison among performances of production units to construct a frontier with non-requirement of an explicit a priori determination of relationships between output and inputs.

In this paper a non-parametric method, Data Envelopment Analysis (DEA), is adopted to compare effects of alternative planning scenarios in strategic urban dimensions. At each scenario is associated a DMU that creates a virtual production process in which input variables (e.g. resources needed to implement scenario interventions) are combined to obtain output variables. In this paper, outputs are assumed the effects generated after implementation of interventions (e.g. effects on mobility after implementation of infrastructures and services). Input and output variables of each scenario are processed in DEA to obtain an efficient frontier production. This frontier constitutes the term of reference to compare all alternative scenarios.

An application to verify applicability of DEA is presented.

Keywords: efficiency, DEA, comparison, transportation planning

1. INTRODUCTION

1.1 General problem

A transport plan has to be evaluated in terms of objectives which respect constraints. Starting from analysis of the current situation, in the plan a set of strategies to adopt is identified such as to respect all constraints. Strategies are translated into a set of interventions that represent alternative scenarios. Effects of these scenarios may be simulated and evaluated by applying a system of models. They are represented by means of indicators that may be compared with objectives and constraints before and after implementation of planned interventions. These indicators measure performances of infrastructures and services (*performance measurement*).
At the tactical and operative planning time scales, infrastructure characteristics can be considered constants. Thus evaluation concerns only service characteristics. At the strategic scale, evaluation concerns infrastructures and service characteristics.
Evaluation methods able to support comparison of effects within the strategic urban transport planning process may be grouped into monocriteria or multicriteria methods (Cascetta, 2006; Petrina and Virno, 2006; Ponti, 2006; Varipapa, 2002). Below, the strategic planning scale is considered. In particular, methods to measure performance in terms of efficiency are analysed.
In this paper a method is proposed to compare impacts of different transportation planning alternative scenarios in urban areas, with non-requirement of explicit a priori determination of relationships between inputs and outputs. The proposed method is a preliminary attempt to obtain a synthetic evaluation of effects obtained from ex ante evaluations, applying simulation models, and observed effects obtained from ex post evaluations, applying monitoring models. The effects of different transport interventions are compared in terms of efficiency.

1.2 State of the art

In the economics literature, efficiency is sometimes considered a characteristic of the production process that is a set of activities by which factors of production (or inputs) are combined to obtain one or more products (or outputs). A production process can be represented by which a production function that describes the *technical relationship between the inputs and output* of the process (Coelli et al., 1998). A frontier production function is *an extension of a production function and represents the maximum output attainable given a set of inputs* (Pesaran and Schmidt, 1999).
Adopting Farrell's (1957) definition, efficiency represents *success in producing as large as possible an output from a given set of inputs*. The European Commission defines efficiency *as the best relationship between resources employed and results achieved* (European Commission, 2004). In general, efficiency measures the capacity of a Decision Making Unit (DMU) to create a *production process* that combines production factors (input) to obtain products (outputs). In engineering, efficiency of a production process is achieved when it is

possible to obtain *the maximum amount of output that is physically achievable with current technology, given a fixed amount of inputs* (Diewert and Lawrence, 1999).
In the literature there are several methods to measure efficiency from calculation of specific indicators. A possible classification of such methods is based on knowledge of the production function:

- parametric methods, based on the assumption that the production function of fully efficient firms is known (Coelli et al., 1998); one method consists in Stochastic Frontier Analysis (SFA) (Aigner *et al.*, 1977; Meeusen and van de Broeck, 1977);
- non-parametric methods, based on the assumption that the production function of fully efficient firms is not known; in this case the efficiency of production units is compared to construct a frontier with non-requirement of an explicit a priori determination of relationships between output and inputs; possible methods are Data Envelopment Analysis (DEA) (Charnes et al., 1978); Free Disposal Hull (FDH) (Deprins, et al., 1984; Lovell and Eeckaut, 1993).

In the following DEA, a non-parametric method, is considered. DEA allows a frontier production function to be determined involving mathematical programming methods. The frontier consists of the best productive units observed and relative virtual units obtained from a linear combination among inputs and outputs of observed units.
DEA was introduced by Farrell's formulations of efficiency and denoted with the CCR model. This first formulation was based on the hypothesis of constant returns to scale (CRS). An extension of the CCR model, denoted with the acronym BCC, has been proposed by Banker et al. (1984), in which the CRS hypothesis is removed and variable returns to scale (decreasing or increasing) are admitted.
Generally, DEA defines the technical efficiency in terms of a minimum set of inputs needed to produce a given output known as an input-oriented model, or maximum output obtainable from a given set of inputs known as output-oriented model. The distance from the frontier is a measure of inefficiency of a DMU, that could be eliminated through a variation in quantity of inputs or outputs or both (Cooper et al., 2000).
DEA was originally conceived to evaluate production efficiency in industrial systems, where inputs are labour, energy and capital resources and outputs are goods or services. DEA has subsequently been extensively applied in many fields of economics and engineering (Tavaresa, 2002). Several DEA applications focus on transport systems, especially to evaluate performance of urban transport (Nozick et al., 1998; Odeck, 2006), container ports (Cullinane et al., 2006) and airports (Lupi and Danesi, 2007). In some papers DEA is applied within 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).
The paper, after this introduction, is divided into three sections. The first illustrates adoption of DEA to compare effects of alternative planning scenarios. The second reports the first results of an application of DEA to evaluate a railway system in an urban area in the south of Italy. The last concludes with considerations about strengths and weaknesses associated to adoption of DEA as an evaluation method in strategic transport planning.

2. COMPARISON WITH THE DEA METHOD

The proposed method based on DEA is applied in a transport system to compare impacts of an alternative scenario (j), constituted by a set of interventions to realise transport infrastructures and services. Effects of a single scenario are estimated in ex ante evaluations and measured in ex post evaluations.

2.1 Inputs and outputs

A generic scenario (j) is associated to a Decision Making Unit (DMU) that creates a production process represented by:

- *inputs*, expressed in terms of material and immaterial resources required to realise infrastructures and services (in general capital, labour, land and natural resources);
- *outputs*, expressed in terms of effects on mobility; these effects can be simulated or observed.

Comparisons are made with any hypothesis on the production function, or relationship among inputs and outputs. From these comparisons, synthetic evaluations can be formulated in relation to performance of infrastructures and services. *Inputs* and *outputs* of each scenario (j) are processed in DEA to obtain an efficient frontier production that constitutes a sort of benchmark for each scenario.
In analytical terms, each scenario (j) is represented by:

- a vector of inputs $\mathbf{i}_j$ with r dimensions, where r is the number of the inputs considered in the virtual production process; this vector corresponds to multi-input selected to represent a generic scenario,

$$\mathbf{i}_j : (i_{1j}, i_{2j}, \ldots, i_{rj})^T \qquad j = 1,\ldots, n$$

- a vector of outputs $\mathbf{o}_j$ with s dimensions, where s is the number of the outputs considered in the virtual production process; this vector corresponds to multi-output selected to represent a generic scenario,

$$\mathbf{o}_j : (o_{1j}, o_{2j}, \ldots, o_{sj})^T \qquad j = 1,\ldots, n$$

Each scenario is then represented by a point in R^{r+s} which, if belonging to the frontier, is efficient.

All scenarios can be represented contemporaneously with:

- a matrix **I** with n x r dimensions, where n is the number of alternative scenarios and r is the number of inputs considered in the virtual production process

$$\mathbf{I} = \begin{pmatrix} \mathbf{i}_1 \\ \ldots \\ \mathbf{i}_n \end{pmatrix} = \begin{pmatrix} i_{11} & \ldots & i_{1r} \\ \ldots & \ldots & \ldots \\ i_{n1} & \ldots & i_{nr} \end{pmatrix}$$

- a matrix **O** with n x s dimensions, where n is the number of alternative scenarios and s is the number of outputs considered in the virtual production process

$$\mathbf{O} = \begin{pmatrix} \mathbf{o}_1 \\ \dots \\ \mathbf{o}_n \end{pmatrix} = \begin{pmatrix} o_{11} & \dots & o_{1s} \\ \dots & \dots & \dots \\ o_{n1} & \dots & o_{ns} \end{pmatrix}$$

2.2 Analytic formulation

The efficiency measure for each scenario is the ratio between the virtual output, obtained from the weighted outputs, and the virtual inputs, obtained from weighted input. The efficient frontier is obtained by adopting the input-oriented CCR model. The dual form of input-oriented efficiency measurement problem can be written as a series of n linear programming envelopment problems:

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

subject to:
$O_j / I_j \leq 1$ (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 representative of j^{th} scenario;
$I_j = \mathbf{v_j}^T \mathbf{i_j}$,	virtual input representative of j^{th} scenario;
θ_j,	efficiency measure of representative of j^{th} scenario (if $\theta_j = 1$, the j^{th} scenario is efficient, otherwise it is inefficient);
$\mathbf{o_j}$,	vector of outputs of j^{th} scenario;
$\mathbf{i_j}$,	vector of inputs of j^{th} scenario;
$\mathbf{u_j} : (u_{1j}, \dots, u_{sj})^T$,	vector of unknown weights assigned to outputs of j^{th} scenario;
$\mathbf{v_j} : (v_{1j}, \dots, v_{mj})^T$,	vectors of unknown weights assigned to inputs of j^{th} scenario.

In the DEA formulation, inputs and output are known and the weights are unknown variables. This formulation, for each j^{th} scenario, finds the set of weights, u_{sj} and v_{mj}, that maximize the efficiency, θ_j.

The problems (1) may be expressed in the following linear form:

maximize $\theta'_j = O_j$ (j = 1, ..., n) (2)
$\mathbf{u_j}, \mathbf{v_j}$

subject to:
$I_j = 1$

$O_j / I_j \leq 1$ (j = 1, ..., n)
$\mathbf{u_j} \geq 0$
$\mathbf{v_j} \geq 0$

θ'_j values indicate whether the j[th] scenario is efficient.
The efficient frontier is obtained from envelopment of points representing efficient alternative scenarios. Points not belonging to the frontier represent non-efficient scenarios. In this case, among the simulated scenarios, there is at least one that is efficient. For these points the distance from the frontier may be calculated.

3. TEST APPLICATION

A test application of DEA was conducted to compare a proposed intervention in the city of Reggio Calabria (Italy). The city has about 180,000 inhabitants and an area of 236.02 km^2. The intervention is called the Sustainable Mobility System (SMS) (Russo et al. 2008). Intervention consists in a Light Rail Transit (LTR), with stops every 400-500 metres. Vehicle guidance is fully automated and the control system is centralized.
The study area is divided into 35 zones with homogeneous socio-economic characteristics. The central district is divided into 24 zones, the northern district into six, the southern district into two and the hill district into three zones. Figure 1 shows the study area, the districts and zone boundaries, and the area where the SMS will operate.
Figure 2 shows the SMS area inside the central district, with pole locations and a schematic representation of bus, railway and SMS itineraries. The system is designed to serve a central district with residential and retail activities, educational and public services clustered into three poles (university, regional government and health, municipal government); and three suburban districts (northern, southern, hill) with manufacturing activities and scattered residences.

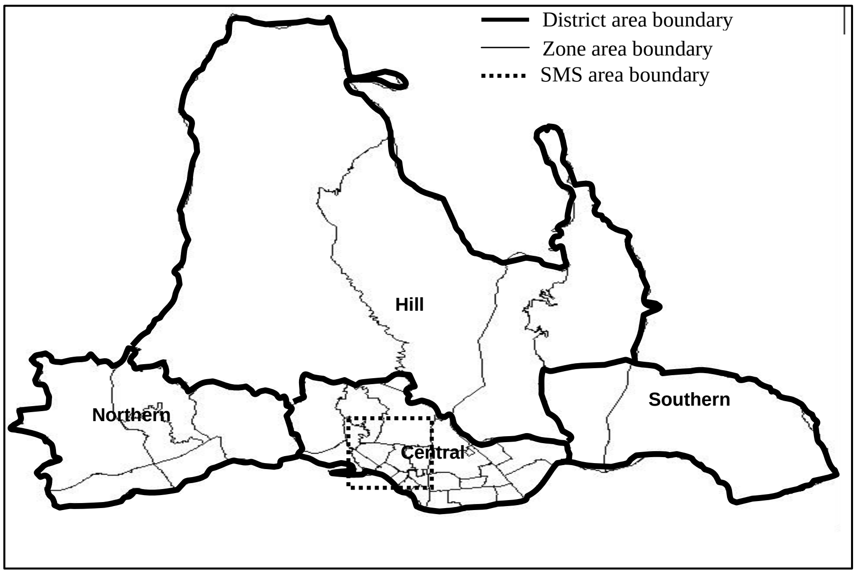

Figure 1. The study area: district and zone boundaries

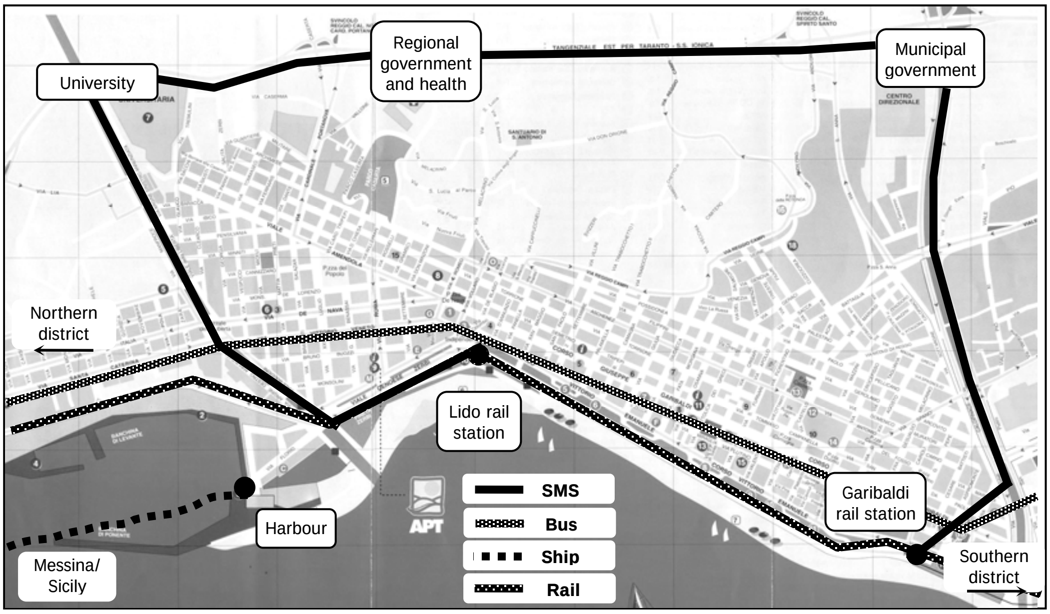

Figure 2. SMS area inside the central district: pole location, bus, rail and SMS itineraries

Effects of the SMS intervention are simulated by applying system of models proposed in Cascetta, 2006; models are calibrated for the city of Reggio Calabria how described in Russo et al., 2008; effects deriving from land use and transport interactions are simulated in Musolino and Rindone, 2009.

The intervention is compared with other urban railway systems realised in other Italian cities: Rome, Milan, Naples and Genoa. For these cities, use is made of observed data and information obtained from an official source (ISFORT, 2008). Each agency, that governs urban transport railway system in the cities selected, is considered a different Decision Making Unit.

In order to apply a DEA model, in the form presented in section 2.2, each urban transport railway system is expressed in terms of (see Table I):

- two *inputs* corresponding to reserved railway infrastructure extension expressed in terms of kilometers (km), (**i**$_1$) and urban rail systems services in terms of vehicle*kilometres/year (vehic.*km/year), (**i**$_2$);
- one *output*, annual demand expressed in terms of passengers/year (pax/year), **o**$_1$.

From application, it's possible to obtain a score efficiency (θ_j) for each DMU_j.

Table I. Inputs, outputs and CCR efficiency for each scenario

DMU_j	Infrastructure extension (km) (i_1)	Urban rail services (10^6vehic.*km/year) (i_2)	Demand (10^6 pax/year) (o_1)	Score Efficiency θ
Rome	36.6	31.5	331	1.00
Milan	74.1	54.4	328	0.57
Naples	13.4	4.2	28	0.63
Genoa	5.5	1	8	0.76
Reggio Calabria (SMS)	8.7	0.16	1.7	1.00

Results allows to compare railway systems selected in terms of relative efficiency, respect to the efficient frontier. We can note that railways systems in the cities of Rome and Reggio Calabria belong to the frontier. Railways systems in the other cities (Milan, Naples and Genoa) are inefficient. In particular, score efficiency of Milan is lower than Genoa and Naples (Table I). The results of the application provide a synthetic comparison among performances of different railway systems selected. From this analysis it's emerges that SMS intervention, expressed in terms of inputs and outputs selected, is comparable in terms of efficiency at urban railway system in Rome. Nevertheless, these preliminary results depend on the choice set of input and output variables selected to represent compared interventions. The case considered is simplified because two input and one output variables are selected. To obtain improved results about SMS intervention it's necessary:

- to consider other inputs (for instance, more details about characteristics of infrastructures and services) and other outputs (for instance, more details about effects on sustainability in terms of social, economic and environment outcomes);
- to increase the number of DMU selected, considering an homogeneous set of urban railways system to improve comparisons.

4. FINAL CONSIDERATIONS

In literature, several methods to compare economic production processes are based on efficiency criterion. A possible classification of these methods is based on knowledge of the production function: parametric methods, based on the assumption that the production function of fully efficient firms is not known; non parametric methods, based on the assumption that the production function of fully efficient firms is known.
Generally these methods was applied in economics to compare performances of different firms. Comparisons concerns firm's output in terms of services produced.
In this paper, an evaluation method for transport planning is proposed. The method is based on the assumption that each transport planning scenario is represented by means of a production process fed by a set of inputs that are combined to obtain a set of one or more outputs. Performances of this process are measured in terms of efficiency.
A non-parametric method to compare different scenarios is proposed. In particular, principal aim of this paper is to verify applicability of DEA method to compare a planned intervention in an urban transport system respect to real systems. Application is conducted in order to test the potential of DEA in urban transport planning. in particular DEA method is extended to compare effects of urban railway infrastructures and services.
Preliminary results of application give some first indication about comparison among analysed intervention respect to the set of urban railway systems selected. Possible extensions of this work are connected to the choice of other inputs and output sets or connected to the choice of urban railway systems selected for comparisons.

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