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Data Envelopment Analysis (D.E.A.) for urban road system performance assessment

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Abstract

Improving the efficiency of transport networks by enhancing road system performance, lays the foundations for the positive change process within a city, achieving good accessibility to the area and optimizing vehicle flows, both in terms of cost, management and attenuation of environmental impacts. The performance of an urban road system can be defined according to different thematic areas such as traffic flow, accessibility, maintenance and safety, for which the scientific literature proposes different measurement indicators. However variations in performance are influenced by interventions which differ from one another, such as infrastructure, management, regulation or legislation, etc.. Therefore sometimes it is not easy to understand which areas to act on and what type of action to pursue to improve road network performance. Of particular interest are the tools based on the use of synthetic macro-indicators that are representative of the individual thematic areas and are able to describe the behavior of the entire network as a function of its characteristic elements. These instruments are of major significance when they assess performance not so much in absolute terms but in relative terms, i.e. in relation to other urban areas comparable to the one being examined. Therefore the objective of the proposed paper is to compare performances of different urban networks, using a non-parametric linear programming technique such as Data Envelopment Analysis (DEA), Farrel (1957), in order to provide technical support to the policy maker in the choice of actions to be implemented to make urban road systems efficient. This work is the conclusive study of road system performance analysis using DEA.
The study forms part of a research project supported by grant, PRIN-2009 prot. 2009EP3S42_003, in which the University di Cagliari is a partner with a research team comprising the authors of this paper, and which addresses performance assessment of road networks, Fancello, Uccheddu and Fadda (2013a),(2013b).

Keywords: efficiency transport networks; Data Envelopment Analysis; road system performance.

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1. Introduction

DEA is a typical benchmarking analysis, commonly used in econometrics to estimate the efficiency of production units and for years it has found wide application in areas such as health, education, finance, local public transport, ICT and macroeconomics of sector studies.

The applications of DEA to transportation issues concern all the major transport modes. The efficiency of container port terminal operators has been studied by Marchese et al, (2000), a comparison of different terminals has been performed by Cullinane, Song, Teng-Fei Wang (2004); Rolle and Hayuth (1993) defined a theoretical ratio of port efficiency, Budria-Martinez (1999) analyzed the efficiency of ports in relation to the evolution of the efficiency of a single port, Tongzon (2001) studied the factors affecting efficiency performance of a port, focusing particular attention on the number of cranes and berths for container ships and waiting times. DEA has also been used for airport analysis: for example, measuring the efficiency of Italian airports following privatization of the sector has been analyzed by Curi, Gitto, Mancuso (2008) and the study by Adler, Berechman (2001), who measure airport quality from the airlines viewpoint using DEA.

In the 1990s DEA started to be used to study local public transport in combination with other analytical techniques (Stochastic Frontier Analysis or Free Disposal Hull), in order to compare results. DEA is often used not only to assess the efficiency of companies but also the regulatory impact on the local public transport sector, Piacenza, (2006), or for other specific evaluations of particular policies, Gagnepain and Ivaldi, (2002). Levaggi (1994) adopted parametric and non-parametric approaches for analyzing the efficiency of urban transport in Italy, while Buzzo, Erbetta, Petraglia and Piacenza (2007), analyze regulatory and environmental effects on public transit efficiency using a mixed DEA-SFA approach. Hermans , Brijs, Wets, Vanhoof (2009) propose a computational model based on DEA, created on the model output, for identifying the positive and negative aspects of road safety in each country analyzed, while Shen, Hermans, Brijs, Wets, Vanhoof (2012) use DEA as a performance measurement technique that provides an overall perspective on a country's road safety, and further assess whether the road safety outcomes registered in a country correspond to the numbers that can be expected based on the level of exposure to risk. In doing so, three model extensions are considered: the DEA based road safety model (DEA-RS), the cross-efficiency method, and the categorical DEA model. Finally, regarding the application of DEA to urban transport management, Fancello, Uccheddu and Fadda (2013a, 2013b) adopted this approach for comparing urban road systems in different cities, assessing the network performance using a number of indicators.

The aim of DEA is to calculate an efficiency frontier measured as relative performance of different units called DMU (Decision Making Unit) in terms of distance per unit to the ideal frontier, constructed using observed input and output data. The efficiency frontier is a set of points that shows the efficient combination of input and output that can be obtained in the systems examined, Cooper, Lewin and Seiford (1994). In their original study, Charnes, Cooper, and Rhodes (1978) described DEA as a "mathematical programming model applied to observational data that provides a new way of obtaining empirical estimates of relations, such as the production functions and/or efficient production possibility surfaces, that are cornerstones of modern economics". The efficiency score in the presence of multiple input and output factors is defined as:

Efficiency = weighted sum of outputs/weighted sum of inputs.

Assuming that there are n DMU$_s$, each with m inputs and s outputs, the relative efficiency score (1), (2) of a test DMU$_p$ is obtained by solving the following model proposed by Charnes et al. (1978):

$$\text{Max} \quad \frac{\sum_{k=1}^{s} v_k \, y_{kp}}{\sum_{j=1}^{m} u_j \, x_{jp}} \tag{1}$$

Subject to
$$\frac{\sum\limits_{k=1}^{s} v_k \, y_{kj}}{\sum\limits_{j=1}^{m} u_j \, x_{ji}}$$

(2)

$v_k, u_j \geq 0 \quad \forall k,$

Where
k = 1 to s;
j = 1 to m;
i = 1 to n;
y_{ki} = amount of output k produced by DMU i;
x_{ji} = amount of output j produced by DMU i;
v_k = weight given to output k;
u_j = weight given to output j.

Each DMU selects input and output weights that maximize its efficiency score. In general, a DMU is considered to be efficient if it obtains a score of 1 while a score of less than 1 implies that it is inefficient. Relative efficiency in DEA has the advantage of avoiding the need to assign a priori measures of relative importance to any input or output, Cooper, Seiford and Zhu, (2004). This approach is called the CCR model: it calculates the efficiency ratio for the DMUs based on their inputs and outputs and, after comparison of the results, the DMU's efficiency is defined. Using linear programming, we determine the optimal weights, which maximize the efficiency ratio for each DMU: the optimal weights usually vary from one DMU to another. The CCR model is built on the assumption of constant returns to scale: this means that inputs and output are linked in a strictly proportional manner (if all inputs are doubled, outputs are expected to double, too). The Banker-Charnes-Cooper (BCC) model (1984) is an extension of the CCR model and allows for the fact that the productivity at the most productive scale size may not be attainable for other scale sizes at which a given DMU is operating. Therefore, the BCC model estimates the pure technical efficiency of a DMU at a given scale of operation. The only difference between the CCR and BCC models is the convexity condition of the BCC model, which means that the frontiers of the BCC model have piecewise linear and concave characteristics, which lead to variable returns-to-scale.

Charnes, Cooper, Lewin, Seiford (1994) describe several advantages of the DEA approach:

- it uses individual observations and not their average and it produces an aggregate measure of efficiency for each DMU, using known variables as inputs and outputs;
- it uses a multiplicity of inputs and outputs, whereas the units of measurement can differ from one another;
- it evaluates the efficiency of homogeneous DMUs and it calculates which inputs and outputs of inefficient DMU need to be changed to attain efficiency;
- it yields Pareto efficient solutions.
  On the contrary, DEA does present some drawbacks:
- the efficiency of each DMU depends on the efficiency of the other DMUs and it is impossible to prove that all DMU are inefficient;
- to consider only one value for each input and output, produces measurement errors or approximations;
- If one DMU has a slightly higher production than another it is considered efficient and therefore able to change the production frontier.

The objective of this paper is to compare performances of different urban networks, using a non-parametric linear programming technique such as Data Envelopment Analysis (DEA), Farrel (1957), in order to provide

technical support to the policy maker in the choice of actions to be implemented to make urban roads systems efficient. In this investigation, concerning the use of DEA for studying the efficiency of road systems, the DMUs are the road networks in different urban contexts. Inputs and outputs are selected from among the main characteristics of road system indicators: traffic flow, accessibility and safety. For comparing the performance of different road networks by means of linear programming, the following requirements need to be met: Homogeneity: the road network must use the same type of inputs to produce the same type of results, Independence: the flows relating to different networks should be completely independent, Autonomy: each network has the ability to decide how to use their inputs to produce their results.

The analysis will have an input-oriented approach where, starting from fixed outputs, the optimal value will be defined, in percentage terms, as the amount of input that the road system can cope with to become efficient. The concept of "performance" of an urban transport network will be explored, highlighting what has emerged from analysis of the state-of-the-art literature, with specific reference to synthetic indicators calculation representing different issues. The inputs will be identified by examining the needs that emerged from the analysis of population mobility and accessibility, while the outputs will be defined according to traffic flow, environmental quality and safety. The application, simply illustrative, concerns the urban road networks in eight different cities (Benevento, Caltanissetta, Crotone, Matera, Savona, Viareggio, Vigevano and Viterbo) selected according to the following criteria: population between 60,000 and 65,000 and perimeter of the urban area between 15 km and 20 km. DEA analysis allowed to calculate, for each urban system, a value of relative efficiency on the basis of which the eight networks have been ranked, distinguishing efficient from inefficient ones. The efficiency of each network is only meaningful within the context examined, in relation to the model chosen and to the sample units considered. One only needs to introduce a new network or to change the model characteristics, from input to output oriented for example, to obtain different efficient networks or different efficiency values, Zhao, Triantis, Murray-Tuite and Edera (2011). With the DEA analysis, a value of relative efficiency is calculated for each urban system that makes it possible to rank the networks examined, discriminating between efficient and inefficient ones.

2. Definition of DEA parameters

Two analyses have been conducted in parallel: the first assuming constant returns to scale using the CRS method Charnes, Cooper and Rhodes, (1978); the second assuming variable returns to scale using the VRS method, Banker, Charnes and Cooper (1984). Both analyses are input-oriented: the level of relative efficiency is therefore the maximum proportion of the inputs that an efficient network must guarantee, to achieve at least the current level output. This means that the movement required to attain the output level is attributed to the input. We also evaluated some cases in which cities with efficient networks are adopted as peers for some of the inefficient ones (ie, efficient and dominant cities evaluated as best practice, whose input values can be used as reference by the inefficient cities dominated by them). The inputs and outputs chosen to measure the level of performance of road systems are given in Table 1 and are grouped according to the four macro-areas of investigation: traffic flow, accessibility, safety, public transport. Since the DEA shows, within the inefficient networks, the input values that should be adopted in order to achieve efficiency, the inputs are represented by values that need to be minimized (by contrast the output values should be maximized). Therefore, for this kind of analysis, referring to some of the indicators chosen, the required reciprocal value is calculated, so as to maintain consistency among the values of the calculated production functions.

Table 1. Macro-areas, Input and Output

Macro-areas/Input-Output	Input	Output
Traffic flow	(Number of vehicles registered in the metropolitan area)/(length metropolitan area network – m.a.n.)	Level Of Service
Accessibility	n° of major attractors within 300 m from the town hall	(Rate of average time needed to reach the town hall)/(n° of main accesses)

Safety	spent by the Administration)/(length m.a.n .)	(Rate of n° of fatal accidents)/(length m.a.n.)
Local Public Transport	(Number of public buses)/(length m.a.n.)	(Rate of n° passengers transported in a year from bus system)/(length m.a.n.)

The inputs and outputs shown in Table 1, each assigned an identification code, are described in detail below:

- **I_1 (number of vehicles registered in the metropolitan area)/(length metropolitan area network):** although generic, this indicator is able to show the occupation level of the road network. Flow density indicators are easy to retrieve from website databases, that are updated annually by Italian town councils or the Public Car Registry;

- **O_1 Level Of Service, LOS:** it is an indicator of quality level and network congestion. For the purposes of the present analysis we used the standard value V/C specified in H.C.M. (Highway Capacity Manual); its value increases with increasing congestion and diminishing network quality. As it was not possible to calculate the average value of the LOS for all networks it was decided to use an identical value of 0.55 (which indicates a LOS between B and C, representative of the different traffic conditions in medium-sized cities such as those studied) for all the networks examined. This indicator has been used in the analysis by calculating the reciprocal value (1/LOS), so as to minimize the effect;

- **I_2 number of major attractors within 300 m from the town hall:** this is an indicator of the degree of accessibility of schools, public offices, places of entertainment and culture from a given point, symbolically identified as the town hall. The larger the number of attractors, the greater the degree of network accessibility, with a consequent increase in the level of user satisfaction. The data have been calculated with GIS and used in the analysis by calculating the reciprocal value (1/number attractors);

- **O_2 Average time needed to reach the town hall:** this indicator of the degree of network accessibility is calculated using GIS with which the main accesses of the urban road network have been identified. We calculated the journey time along the shortest path from every access point to the town hall. These were then added together and divided by the number of accesses obtained in the network. The lower the value obtained, the greater the level of network user satisfaction. This indicator was therefore used in the analysis by calculating the reciprocal value (1 / (Σtimes / Σaccesses));

- **I_3 (spent by the Administration)/(length metropo litan area network):** this is an indicator of road safety; the higher its value, supposedly better the safety through road maintenance and upgrading. Missing data from the on-line survey have been recovered through direct calls to the competent authorities. This indicator was used to calculate the reciprocal value (1 / (spen t / km network));

- **O_3 (Number of fatal accidents)/(length metropolitan area network):** this is an indicator of road safety; the higher its value, supposedly greater the inefficiencies and the more dangerous the road system; consequently this indicator was used to calculate the reciprocal value (1 / (number of fatalities / km network));

- **I_4 (Number of public buses)/(length metropolitan area network):** this is an indicator of the degree of efficiency of local public transport services; an indicator of the flow density of local public transport. The higher its value, supposedly greater is the degree of satisfaction of the users who benefit from a fast and capillary service.

- **O_4 (Number of bus passengers transported per year)/(length metropolitan area network):** this is an indicator of the degree of satisfaction of public transport users. Although it was easy to retrieve for the provincial capitals, for others it was necessary to contact the bus company.

The application of DEA, moreover, requires a minimum number of networks to be able to properly discriminate between the efficiency results. It is necessary to carefully evaluate the trade-off between the DMU and inputs/outputs sets. In fact, a large amount of input and output data allows one to better characterize the production process, but, increasing the variables data requires more observation data. Too many input/output data, for a small DMU's set, can generate a great deal of DMU efficiency data, often unusable for benchmarking analysis. A practical rule suggests that a good level of usability of results can be obtained when DMUs are at least equal to twice the product of output and input: 2*(I*O). Tables 2 and 3 show the elementary data and the

values of the calculated inputs and outputs.

From the elementary data shown in Table 2, we observe that:

- Vehicles Registered: this indicator is significant only if it refers to the metropolitan area. Note, for example, that Viterbo has a very large number of vehicles for a very short length of metropolitan area roads, indicative of a high level of congestion ;
- Major Attractors: the city with the greatest number of attractors is Savona, Viterbo and Caltanissetta have the lowest. The elementary data are significant for the degree of accessibility of the city centers (in our case);
- Average Time and Main Access: The lower the value obtained, the higher the level of network user satisfaction. As we can observe, Viareggio and Caltanissetta have higher values;
- Euro spent: this value has been obtained through direct contacts with the competent authorities and is also very approximate. The information concerns road safety, the amount invested by local authorities for road maintenance and upgrading;
- Fatal accidents: higher values are indicative of greater inefficiencies and a more dangerous road system. The cities with the lowest numbers of fatal accidents are Benevento and Matera;
- Public buses and passengers per 1000 inhabitants are indicators of service efficiency and the degree of satisfaction of public transport users: Savona turned out to have the highest values of both indicators;
- LOS: this is an indicator of traffic flow, we decided to use an identical value for all the networks examined as it proved impossible, with the available data, to calculate an average LOS value for each city. We decided however to include this indicator, as it is important to have an indicator of quality level and network congestion.

Table 2. Elementary Data

Cities	Metropolitan area [Km]	Vehicles registered [n°]	Major attractors [n°]	Average time [t]	Main access. [n°]
Benevento	180	48.569	9	33.70	5
Caltanissetta	140	51.211	5	21.40	6
Crotone	280	43.032	11	54.10	5
Matera	185	47.585	10	34.00	5
Savona	165	52.981	13	31.70	4
Viareggio	225	54.634	7	27.10	4
Vigevano	175	47.525	10	41.40	6
Viterbo	195	62.049	6	34.40	6
Cities	Euro spent [ ]	Fatal accidents [n°]	Public b uses[n°]	Pax per 1000 inhab.[n°]	LOS
Benevento	3.085.000	2.70	154	37.80	0.55
Caltanissetta	500.000	9.70	74	9.70	0.55
Crotone	3.450.000	9.00	207	11.40	0.55
Matera	1.250.000	2.70	211	24.40	0.55
Savona	1.300.000	5.30	221	72.20	0.55
Viareggio	1.983.000	8.70	16	19.02	0.55
Vigevano	670.000	5.00	9	5.07	0.55
Viterbo	2.159.000	7.30	135	42.20	0.55

Table 3. Original Input and Output values

Cities	I_1	I_2	I_3	I_4	O_1	O_2	O_3	O_4
Benevento	269.83	0.11	0.00006	1.17	1.82	0.15	66.67	13.027.35
Caltanissetta	365.79	0.20	0.00028	1.89	1.82	0.28	14.43	4.175.64
Crotone	153.69	0.09	0.00008	1.35	1.82	0.09	31.11	2.516.06
Matera	257.22	0.10	0.00015	0.88	1.82	0.15	68.52	8.021.40
Savona	321.10	0.08	0.00013	0.75	1.82	0.13	31.13	27.371.68
Viareggio	242.82	0.14	0.00011	14.06	1.82	0.15	25.86	5.452.65
Vigevano	271.57	0.10	0.00026	19.44	1.82	0.14	35.00	1.845.48
Viterbo	318.20	0.17	0.00009	1.44	1.82	0.17	26.71	13.763.04

To observe the responses of different urban networks 48 tests have been performed divided into two groups, as shown in Table 4:

- 1 Input = 2 Outputs: for a total of 24 tests, one for each of the four proposed inputs; these tests allow to understand which input is sensitive to which outputs;
- 2 Inputs = 1 Output: for a total of another 24 tests, one for each of the four proposed outputs; these tests

evaluate which output generates the best effects in the network.

Table 4. Test

Group	TEST	I_1	I_2	I_3	I_4	O_1	O_2	O_3	O_4	Group	TEST	I_1	I_2	I_3	I_4	O_1	O_2	O_3	O_4
1	1	x				x	x			2	25	x	x			x			
1	2	x				x		x		2	26	x		x		x			
1	3	x				x			x	2	27	x			x	x			
1	4	x					x	x		2	28		x	x		x			
1	5	x					x		x	2	29		x		x	x			
1	6	x						x	x	2	30			x	x	x			
1	7		x			x	x			2	31	x	x				x		
1	8		x			x		x		2	32	x		x			x		
1	9		x			x			x	2	33	x			x		x		
1	10		x				x	x		2	34		x	x			x		
1	11		x				x		x	2	35		x		x		x		
1	12		x					x	x	2	36			x	x		x		
1	13			x		x	x			2	37	x	x					x	
1	14			x		x		x		2	38	x		x				x	
1	15			x		x			x	2	39	x			x			x	
1	16			x			x	x		2	40		x	x				x	
1	17			x			x		x	2	41		x		x			x	
1	18			x				x	x	2	42			x	x			x	
1	19				x	x	x			2	43	x	x						x
1	20				x	x		x		2	44	x		x					x
1	21				x	x			x	2	45	x			x				x
1	22				x		x	x		2	46		x	x					x
1	23				x		x		x	2	47		x		x				x
1	24				x			x	x	2	48			x	x				x

The 48 tests have been conducted with both the CRS and VRS methods. The test results were analyzed in different ways: comparing the efficiency results of the two test groups and in terms of macro-areas.

3. Results

Table 5 shows the results obtained for the CRS and VRS tests respectively, for the first and second groups:

Table 5. Results CRS and VRS tests Groups 1 and 2

CRS TEST	Benev.	Caltanis.	Crot.	Mat.	Sav.	Viar.	Vig.	Vit.	VRS TEST	Benev.	Caltanis.	Crot.	Mat.	Sav.	Viar.	Vig.	Vit
1	0.80	1	1	0.84	0.60	0.89	0.78	0.77	1	0.80	1	1	0.84	0.60	0.89	0.78	0.77
2	0.93	0.42	1	1	0.48	0.63	0.61	0.48	2	0.93	0.42	1	1	0.48	0.63	0.61	0.48
3	0.83	0.45	1	0.74	1	0.71	0.57	0.72	3	0.83	0.45	1	0.74	1	0.71	0.57	0.72
4	0.95	1	0.97	1	0.59	0.87	0.80	0.77	4	0.95	1	1	1	0.61	0.89	0.82	0.78
5	0.96	1	0.83	0.89	1	0.88	0.70	0.93	5	1	1	1	0.94	1	0.94	0.78	0.95
6	1	0.19	0.76	1	1	0.45	0.48	0.59	6	1	0.45	1	1	1	0.71	0.61	0.72
7	0.81	0.85	0.85	0.90	1	0.63	0.88	0.64	7	0.85	1	0.85	0.94	1	0.66	0.92	0.69
8	0.89	0.38	0.85	1	1	0.54	0.79	0.46	8	0.89	0.38	0.85	1	1	0.54	0.79	0.46
9	0.69	0.38	0.85	0.77	1	0.54	0.77	0.46	9	0.69	0.38	0.85	0.77	1	0.54	0.77	0.46
10	0.90	0.85	0.65	1	1	0.63	0.88	0.64	10	0.91	1	0.85	1	1	0.66	0.93	0.69
11	0.81	0.85	0.62	0.90	1	0.63	0.88	0.64	11	0.85	1	0.85	0.94	1	0.66	0.92	0.69
12	0.94	0.12	0.50	1	1	0.29	0.51	0.32	12	1	0.38	0.85	1	1	0.54	0.79	0.46
13	1	0.39	0.72	0.39	0.46	0.51	0.22	0.76	13	1	1	0.72	0.39	0.46	0.51	0.22	1
14	1	0.21	0.72	0.41	0.46	0.51	0.22	0.65	14	1	0.21	0.72	1	0.46	0.51	0.22	0.65
15	1	0.21	0.72	0.39	0.97	0.51	0.22	0.68	15	1	0.21	0.72	0.39	1	0.51	0.22	0.68
16	1	0.39	0.45	0.39	0.97	0.51	0.22	0.76	16	1	1	0.72	0.39	1	0.51	0.22	1
17	1	0.39	0.45	0.39	0.97	0.51	0.22	0.76	17	1	1	0.72	0.39	1	0.51	0.22	1
18	1	0.07	0.34	0.41	0.97	0.22	0.12	0.68	18	1	0.21	0.72	1	1	0.51	0.22	0.68
19	0.75	0.88	0.55	0.99	1	0.06	0.04	0.71	19	0.76	1	0.55	1	1	0.06	0.04	0.75
20	0.74	0.39	0.55	1	1	0.05	0.04	0.52	20	0.74	0.39	0.55	1	1	0.05	0.04	0.52
21	0.64	0.39	0.55	0.85	1	0.05	0.04	0.52	21	0.64	0.39	0.55	0.85	1	0.05	0.04	0.52
22	0.76	0.88	0.41	1	1	0.06	0.04	0.71	22	0.76	1	0.55	1	1	0.06	0.04	0.75
23	0.75	0.88	0.40	0.99	1	0.06	0.04	0.71	23	0.77	1	0.55	1	1	0.06	0.04	0.76
24	0.80	0.12	0.29	1	1	0.03	0.02	0.34	24	1	0.39	0.55	1	1	0.05	0.04	0.52
25	0.78	0.45	1	0.85	1	0.64	0.85	0.54	25	0.78	0.45	1	0.85	1	0.64	0.85	0.54
26	1	0.42	1	0.60	0.59	0.69	0.57	0.73	26	1	0.42	1	0.60	0.59	0.69	0.57	0.73
27	0.85	0.58	1	1	1	0.63	0.57	0.71	27	0.85	0.58	1	1	1	0.63	0.57	0.71
28	1	0.41	1	0.80	1	0.67	0.77	0.66	28	1	0.41	1	0.80	1	0.67	0.77	0.66
29	0.69	0.39	0.85	0.85	1	0.54	0.77	0.52	29	0.69	0.39	0.85	0.85	1	0.54	0.77	0.52
30	1	0.42	0.82	0.85	1	0.51	0.22	0.76	30	1	0.42	0.82	0.85	1	0.51	0.22	0.76
31	0.91	1	0.78	1	1	0.79	0.97	0.74	31	0.94	1	1	1	1	0.89	0.98	0.80
32	1	1	0.89	0.83	0.63	0.94	0.70	0.95	32	1	1	1	0.86	0.66	0.97	0.78	1

33	0.82	1	0.78	1	1	0.79	0.70	0.79	33	0.91	1	1	1	1	0.89	0.78	0.85
34	1	0.89	0.71	0.92	1	0.73	0.88	0.78	34	1	1	1	0.95	1	0.74	0.92	1
35	0.81	0.88	0.62	0.99	1	0.63	0.88	0.71	35	0.85	1	0.85	1	1	0.66	0.92	0.75
36	1	0.92	0.52	0.99	1	0.51	0.22	0.92	36	1	1	0.82	1	1	0.51	0.22	1
37	0.93	0.15	0.76	1	0.59	0.40	0.51	0.32	37	0.93	0.45	1	1	1	0.64	0.86	0.54
38	1	0.15	0.77	1	0.38	0.41	0.48	0.33	38	1	0.42	1	1	0.59	0.69	0.61	0.73
39	0.93	0.15	0.76	1	0.53	0.40	0.48	0.32	39	0.93	0.58	1	1	1	0.63	0.61	0.71
40	1	0.11	0.54	1	0.59	0.29	0.51	0.27	40	1	0.11	0.54	1	0.59	0.29	0.51	0.27
41	0.88	0.11	0.50	1	0.59	0.26	0.51	0.24	41	0.89	0.39	0.85	1	1	0.54	0.79	0.52
42	1	0.10	0.39	1	0.53	0.20	0.12	0.31	42	1	0.42	0.82	1	1	0.51	0.22	0.76
43	0.57	0.13	0.19	0.37	1	0.26	0.08	0.51	43	0.83	0.45	1	0.85	1	0.71	0.85	0.72
44	1	0.13	0.19	0.37	1	0.26	0.08	0.69	44	1	0.45	1	0.74	1	0.73	0.57	0.82
45	0.57	0.13	0.19	0.37	1	0.26	0.08	0.51	45	0.88	0.58	1	1	1	0.71	0.57	0.73
46	1	0.07	0.14	0.25	1	0.22	0.05	0.68	46	1	0.41	1	0.80	1	0.67	0.77	0.68
47	0.33	0.06	0.08	0.25	1	0.11	0.05	0.26	47	0.69	0.39	0.85	0.85	1	0.54	0.77	0.52
48	1	0.07	0.14	0.25	1	0.22	0.03	0.69	48	1	0.42	0.82	0.85	1	0.51	0.22	0.76

In this study the focus was not placed on investigating the behavior of each city in relation to each test, but rather on evaluating the behavior of cities in relation to the test group. It is important to examine how many times each city is efficient and with respect to which input and output the city is inefficient. In particular, as this study aims to provide a support tool for policy decision makers, the focus is on the relation between efficient cities and macro-areas.

From the results of the CRS test for the first group we can observe that:

- In the input of the second macro-area (I_2), related to accessibility, the best city is Savona in six tests (from 7 to 12), also Matera in tests 8, 10 and 12;
- In the input of the third macro-area (I_3), related to safety, the best city is Benevento in all six tests (from 13 to 18);
- In the input of the fourth macro-area (I_4), related to public transportation network, the best city is Savona in six tests (from 19 to 24) also Matera in tests 20, 22 and 24.

This is an important result because it is consistent with the results published in Fancello, Uccheddu and Fadda (2013c), where, one input and one output have been used; Savona is the best city for the macro-areas related to accessibility and public transportation network.

The results of the CRS test for the second group we can observe that:

- In the output of the third macro-area (O_3), related to safety, the best city is Matera in six tests (from 37 to 42), also Benevento in tests 38, 40 and 42;
- In the output of the fourth macro-area (O_4), related to public transportation network, the best city is Savona in six tests (from 43 to48) also Benevento in tests 44, 46 and 48.

The VRS test, for the first and second groups, yielded the same results as the CRS test for the best performing cities (Savona, Benevento and Matera). However the other cities also attain efficiency (value equal to 1). In tests 37 to 42 (related to safety and where we use one output) Crotone and Savona also attain efficiency, but the number of fatalities is high (9 and 5.30 fatalities per year respectively). In the CRS test for the same analysis only Benevento and Matera proved to be efficient in terms of safety. Importantly the results for the first and second groups, for the third macro-area, are more significant for the present study because in Fancello, Uccheddu and Fadda (2013d), where we use DEA with 4 Inputs and 1 Output, the question arises: "can a city with a number of fatalities per year equal to 9 be considered to perform better than another with half that number of fatalities, but with less competitive input data? Consequently it may be necessary to reduce the number of inputs, or conversely increase the number of outputs". In this paper the answer is that reducing the number of inputs and outputs and utilizing the CRS model yields realistic and correct results.

4. DEA conclusions

The objective of the proposed paper is to provide technical support to the policy maker in the choice of actions to be implemented to improve the efficiency of urban road systems.

The cities with the most efficient road networks are Savona, Matera and Benevento. Figure 1 shows the

efficiency score for each city for the two different tests (with efficiency value equal to 1). Note however, that:

- In the CRS tests, Viareggio Viterbo Vigevano never attained efficiency;
- in the VRS tests, Benevento and Crotone both came first with the same score, while Viareggio and Vigevano never attained efficiency;
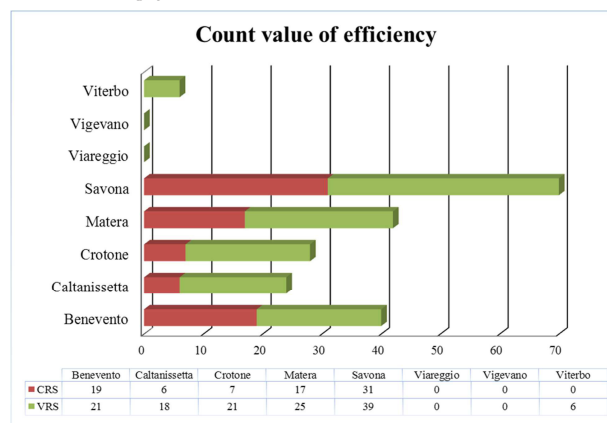- In both the CRS and VRS tests the best city proved to be Savona.

Count value of efficiency

	Benevento	Caltanissetta	Crotone	Matera	Savona	Viareggio	Vigevano	Viterbo
CRS	19	6	7	17	31	0	0	0
VRS	21	18	21	25	39	0	0	6

Fig. 1 Efficiency score

The CRS test proved to be more restrictive than the VRS test Cooper, Seiford and Tone (2006). However, the same three cities had the highest scores in both the CRS and VRS tests. We notice that using the DEA, the CRS method is more appropriate for analyzing the performance of road networks. Despite being more restrictive in the case at hand it proved to be the better approach.

The degree of efficiency achieved by each network is meaningful only in the context in which it has been measured, and then only in relation to the specific model and sample units considered. Simply introducing a new road network or changing the model characteristics (from input to output-oriented) or inputs, will produce different efficient networks or different efficiency values, Banker, Charnes and Cooper (1984).

The results show that the DEA technique is well suited for analyzing and comparing road networks. The main issue is not so much the technique as the calculation of the indicators, which should be chosen according to their utility and on the basis of their ability to retrieve the data necessary for processing them.

This study conducted here shows that:

- The CRS model is more restrictive than the VRS model, but is able to provide correct results that are representative of the real performance of the cities examined;
- If a city has a network with highly competitive values compared to the other cities, the values obtained in the present analysis are consistent with the results of an earlier study in Fancello, Uccheddu and Fadda (2013c).

In DEA analysis it is imperative to use a large number of road networks, as large numbers of inputs and outputs combined with a small number of DMUs yields results that do not reflect real performance and in some cases are actually incorrect. It is good practice to have a number of DMUs to be calibrated significantly greater than the number of observed data. A practical rule suggests that a good level of usability of results can be obtained when DMUs are at least equal to twice the product of output and input: 2*(I*O). This rule has been observed in all the tests conducted and we used both the smallest number of DMUs and a number greater than the smallest. In the latter case the results are more representative of real performance and only the cities with a highly competitive values prove to be efficient.

One of the limitations of this study is that the same LOS has been assigned to each city. Future research will focus on developing a method for calculating the average LOS for each city.

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