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Eleftherios Siskos[1], Michail Malafekas[2], Dimitris Askounis[1], John Psarras[1]

[1] Decision Support Systems Laboratory, School of Electrical & Computer Engineering, National Technical University of Athens, Greece
{lsiskos, askous, john}@epu.ntua.gr

[2] Decision Support Systems Laboratory, School of Electrical & Computer Engineering, National Technical University of Athens, Greece
mmalafekas@gmail.com

Abstract. E-government benchmarking is being conducted by various organizations but its assessment is based on a limited number of indicators and does not highlight the multidimensional nature of the electronically provided services. This paper outlines a multicriteria evaluation system based on four points of view: (1) infrastructures, (2) investments, (3) e-processes, and (4) users' attitude in order to evaluate European Union countries. In this paper, twenty one European Union countries are evaluated and ranked over their e-government progress. Their ranking is obtained through an additive value model which is assessed by an ordinal regression method and the use of the decision support system MIIDAS. In order to obtain robust evaluations, given the incomplete determination of inter-criteria model parameters, the extreme ranking analysis method, based on powerful mathematical programming techniques, has been applied to estimate each country's best and worst possible ranking position.

Keywords: E-government, Multicriteria analysis, Robustness, Benchmarking, Ordinal regression, Extreme ranking analysis.

1 Introduction

E-government benchmarks are used to assess the progress made by an individual country over a period of time and compare its growth against other countries. A focused assessment of e-government and other initiatives such as e-commerce, e-education, e-health, and e-science is essential if a country is to make substantial progress (Ojo et al., 2007). Benchmarks can have a significant practical impact, both political and potentially economic and can influence the development of e-government services (Bannister, 2007). The results of benchmarking and ranking studies, particularly global projects conducted by international organizations, attract considerable interest from a variety of observers, including governments (ITU, 2009).

Indices and indicators used in benchmarks are generally quantitative in nature, and collectively form a framework for assessment and ranking. Rorissa et al. (2011) classified the frameworks to those based on measurable characteristics of the entities; those that use one or more subjective measures; and the rest few that employ a combination of both. They also state that frameworks based on grounded and broadly applicable measures tend to attract fewer criticisms. On the other hand, the frameworks based on subjective measures are liable to controversies and complaints, especially from those countries or institutions who consider their characterization as inaccurate. Therefore, rankings should be supported by well understood and clarified frameworks and indices as well as transparent computational procedures to maximize their acceptability by the governments and the scientific community. Two among others well-known e-government benchmarks still being conducted are those of the United Nations and the European Commission (see United Nations, 2012 and European Commission, 2010 for more details).

Recently, Siskos et al. (2012) proposed a multicriteria evaluation system based on four points of view: (1) infrastructures, (2) investments, (3) e-processes, and (4) users' attitude from which eight criteria are modeled (see below) to evaluate twenty one European Union countries for which the related data are available. Their ranking is obtained through an additive value model which is assessed by an ordinal regression method. The whole approach consists of helping decision makers (DM), experts or potential evaluators in determining their own country evaluations, based on their own value systems and their own ways of preferring, in order to propose alternative evaluation solutions in contrast to standard published benchmarks.

The aim of this paper is to extend this decision support methodology to take into account the incomplete determination of inter-criteria model parameters and to obtain a robust evaluation of the countries. These targets were achieved with the aid of the extreme ranking analysis (Kadzinski et al., 2012) that estimates each country's best and worst possible rank. This method is based on powerful mathematical programming techniques.

The paper is organized as follows: In section 2 the consistent family of criteria is briefly outlined. Section 3 presents the assessment of the multicriteria evaluation model for a single specific decision maker-evaluator while section 4 presents the extreme ranking analysis method and the obtained results. Finally section 5 concludes the paper.

2 Multicriteria Benchmarking Modeling

In order to achieve an overall assessment of global e-government, a consistent family of criteria was built according to the classical modeling methodology of Roy (1985), in the following way:

Infrastructure criteria

g_1: Access to the web. This criterion expresses the percentage of households and businesses that have access to the web by any means.
g_2: Broadband internet connection. It shows the percentage of each country's households and businesses with a fixed broadband internet connection.

Investments criterion

g_3: Percentage of gross domestic product (GDP) spent on information & communications technology (ICT) and research & development (R&D). ICT and R&D expenditure data were retrieved from Eurostat and the International Monetary Fund (IMF), respectively.

E-processes criteria

g_4: Online sophistication: It shows each country's maturity on online service delivery. The data composing this criterion stem from the European Commission's 9th Benchmark Measurement published in 2010 (Digitizing Public Services in Europe: Putting ambition into action).

g_5: E-participation. It expresses the interaction achieved between governments and citizens in a manner of information sharing, e-consultation and e-decision making. The source of the e-participation criterion is the United Nation's survey on e-government published in 2012.

Users' attitude criteria

g_6: Citizens' online interaction with authorities. This criterion indicates the percentage of citizens that are already using the web to interact with the authorities.

g_7. Businesses' online interaction with authorities. It indicates the percentage of businesses that are using the web to interact with the authorities.

g_8: Users' experience. This criterion expresses citizens' experience over the 20 e-services and the national portal. The data composing this criterion stem from the European Commission's 9th Benchmark Measurement.

Table 1. Criteria evaluation scales and sources.

Criterion	Index	Worst level	Best level	Source
g_1	% population	0	100	Eurostat
g_2	% population	0	100	Eurostat
g_3	% GDP	0	5	Eurostat and IMF
g_4	%	0	100	European Commission
g_5	index [0-1]	0	1	United Nations
g_6	% citizens	0	100	Eurostat
g_7	% businesses	0	100	Eurostat
g_8	% index	0	100	European Commission

Table 2. Multicriteria evaluation of twenty one European countries.

	g_1	g_2	g_3	g_4	g_5	g_6	g_7	g_8
Belgium	86.5	81.5	3.3	92	0.59	28	15	68
Czech Rep.	94	90	3.3	85	0.13	35	47	22
Denmark	83.5	85.5	3.8	95	0.64	11	31	30
Germany	71.5	80.5	3.8	99	0.61	16	26	55
Estonia	86	78	4.0	97	0.69	35	18	21
Ireland	77	97	3.5	100	0.44	40	33	49
Greece	86.5	80.5	2.4	70	0.26	57	62	33
Spain	76.5	85	3.1	98	0.83	75	74	86
France	84	92	3.7	94	0.60	65	83	83
Italy	93.5	94.5	2.7	99	0.21	84	67	85
Hungary	90	80	3.4	80	0.31	57	79	80
Netherlands	75	87.5	3.5	97	0.60	80	83	80
Austria	83	78	3.3	100	0.50	85	87	90
Poland	77.5	60.5	2.7	87	0.24	88	81	81
Portugal	79	81	3.8	100	0.27	79	59.5	75.5
Slovenia	68	72.5	3.4	99	0.51	91	87	68.5
Slovakia	87	77	3.1	81	0.07	91	93	94.5
Finland	67	70	4.3	96	0.41	51	80	93.5
Sweden	79.5	65.5	4.1	99	0.49	70	88	92.5
Norway	88.5	90	2.5	92	0.50	83.5	89	87
Un. Kingdom	83.5	87.5	4,3	97	0,77	83.5	76.5	91

All details about the criteria construction techniques are thoroughly described in Siskos et al. (2012). Tables 1 and 2 present the criteria evaluation scales and the criteria scores achieved by the twenty one European countries, respectively.

3 Assessing an Overall Evaluation Model

The main target of the proposed methodological frame is the assessment of a multicriteria additive value system, for a single decision maker, that is described by the following formulae:

$$u(\boldsymbol{g}) = \sum_{i=1}^{n} p_i u_i(g_i) \tag{1}$$

$$u_i(g_{i*}) = 0, \qquad u_i(g_i^*) = 1, \qquad \text{for} \qquad i = 1,2,\dots,n \tag{2}$$

$$\sum_{i=1}^{n} p_i = 1 \tag{3}$$

$$p_i \geq 0\,, \qquad \text{for} \qquad i = 1,2,\dots,n \tag{4}$$

where $\boldsymbol{g} = (g_1, g_2, \dots, g_n)$ is the performance vector of a country on the n criteria; g_{i*} and g_i^* are the least and most preferable levels of the criterion g_i, respectively; $u_i(g_i)$, $i = 1,2,\dots,n$ are non decreasing marginal value functions of the performances g_i, $i = 1,2,\dots,n$; and p_i is the relative weight of the i-th function $u_i(g_i)$. Thus, for a given country a, $\boldsymbol{g}(a)$ and $u[\boldsymbol{g}(a)]$ represent the multicriteria vector of performances and the global value of the country a respectively.

Both the marginal and the global value functions have the monotonicity property of the true criterion. For instance, in the case of the global value function, given two countries a and b the following properties hold:

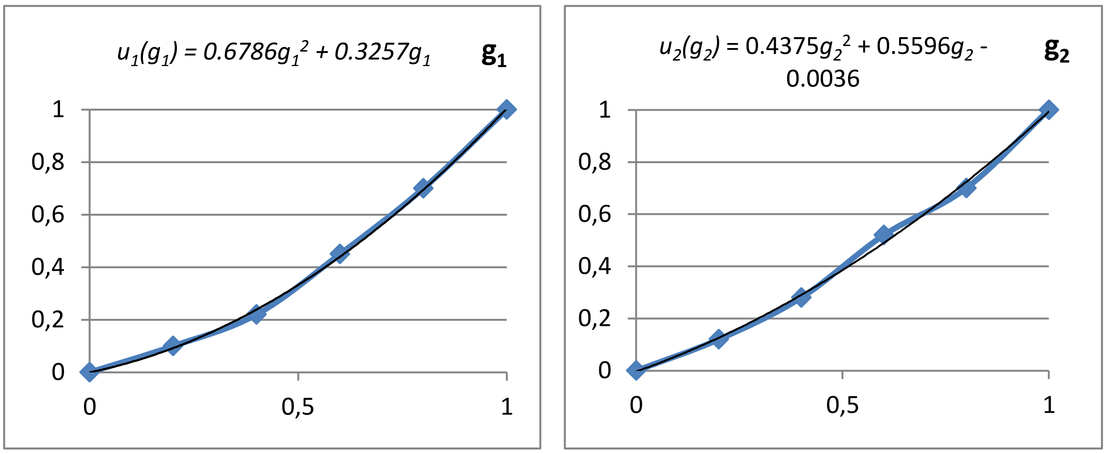
$$u[\boldsymbol{g}(a)] > u[\boldsymbol{g}(b)] \Leftrightarrow a\ P\ b \quad \text{(Preference)} \tag{5}$$

$$u[\boldsymbol{g}(a)] = u[\boldsymbol{g}(b)] \Leftrightarrow a\ I\ b \quad \text{(Indifference)} \tag{6}$$

The necessary hypothesis to validate an additive value function for a given decision maker (DM) is the preferential independence of all the criteria (see Keenney and Raiffa, 1976, Keeney, 1992 for instance). A pair of criteria (g_i , g_j) is preferentially independent from the rest of the criteria when the trade-offs between the g_i and g_j criteria are not dependent on the values of the rest of the criteria. All criteria are supposed to be preferentially independent when the same condition holds for all pairs of criteria. When the u_i functions in formula (1) are already assessed, the linear model (1)-(4) exists if and only if the inter-criteria parameters (weighs) p_i are constant substitution rates (value trade-offs) between u_i.

This value system can be obtained utilizing various methods (see Keeney and Raiffa, 1976, Keeney, 1992, Figueira et al., 2005). Because of the objective difficulties to convince decision makers in externalizing tradeoffs between heterogeneous criteria and verify the preferential conditions cited above, decision analysts usually prefer to infer the DM's additive value function from global preference structures, by applying disaggregation or ordinal regression methods (see Jacquet-Lagrèze and Siskos, 1982, 2001, Greco et al., 2008, 2010).

In this study the disaggregation UTA II method is implemented by assessing the additive model (1)-(4) in two phases: In the first phase the expert is asked to assign some value points $u_i(g_i)$ of the corresponding evaluation scale for every criterion separately. Then, each marginal value function is optimally fitted (see Fig. 1) and accepted by the DM. In a second phase, the criteria weights p_i are estimated using inference procedures (see next section).



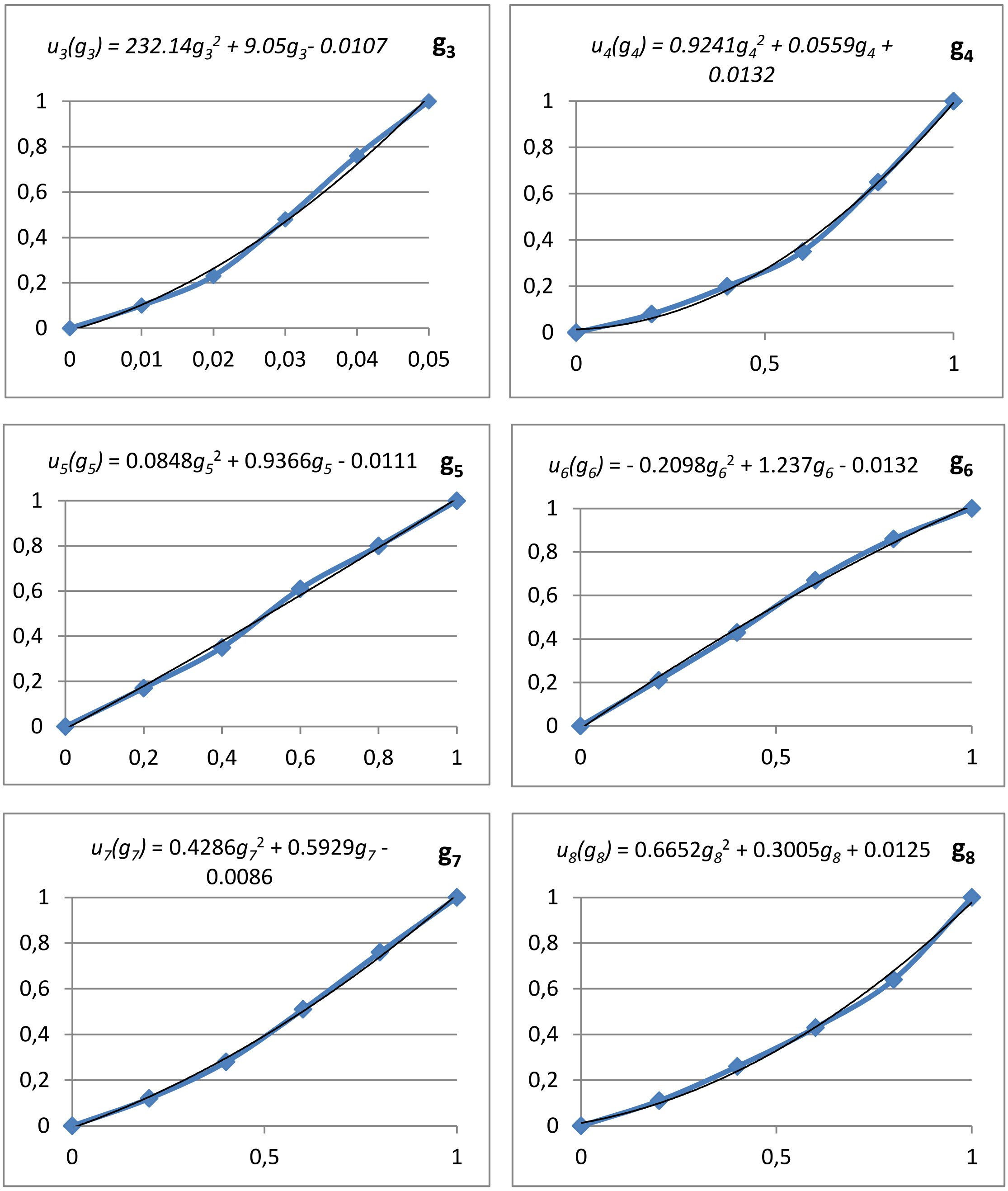


Fig. 1. Marginal value functions of the eight criteria

4 Estimation of Weights and Extreme Ranking Analysis

Through this phase the UTA II disaggregation procedure is used to infer the inter-criteria parameters p_i, $i = 1,2, \ldots, n$. Specifically, the DM-evaluator is asked to give a ranking (weak order) on a set of reference countries $A_r = (a_1, a_2, \ldots, a_k)$, that are fictitious country profiles differing on two or at most three criteria values. The reference countries are ranked by the DM in such a way that a_1 is the head and a_k the tail of the ranking.

Therefore, for every pair of consecutive countries (a_m, a_{m+1}) holds, either $a_m P a_{m+1}$ (preference of a_m) or $a_m I a_{m+1}$ (indifference). UTA II solves the linear program (7)-(11) below that has k constraints because of the transitivity of the (P, I) preference system.

$$[min]F,\ F = \sum_{\iota=1}^{k}\left(\sigma^{+}(\alpha_\iota) + \sigma^{-}(\alpha_\iota)\right)$$

(7)

Subject to:

for $m = 1, 2, \ldots, k-1$

$$\sum_{i=1}^{n} p_i\, u_i[g_i(a_m)] - \sigma^{+}(\alpha_m) + \sigma^{-}(\alpha_m) - [\sum_{i=1}^{n} p_i\, u_i[g_i(a_{m+1})] - \sigma^{+}(a_{m+1}) + \sigma^{-}(a_{m+1})] \geq \delta\,,\ \text{ if } a_m \text{ P } a_{m+1}$$

(8)

or

$$= 0 \quad \text{if } a_m \text{ I } a_{m+1}$$

(9)

$$\sum_{\iota=1}^{n} p_i = 1$$

(10)

$$p_i \geq 0, for\ \ i = 1, 2, \ldots, n;\ \sigma^{+}\left(a_j\right) \geq 0, \sigma^{-}\left(a_j\right) \geq 0, for\ j = 2, \ldots, k$$

(11)

where δ is a small positive number, equal to 0.001 for instance; $g_i(a_m)$ is the evaluation of the a_m country on the i-th criterion and $u_i[g_i(a_m)]$ its corresponding marginal value; $\sigma^{+}\left(a_j\right)$, $\sigma^{-}\left(a_j\right)$ are the over-estimation and the under-estimation errors concerning the j-th country's position, respectively.

This technique was applied for a set of thirteen country profiles and a zero error sum was obtained ($F = 0$). The optimally most characteristic weighting factors are reported in formula (12) while the corresponding ranking of the European countries is presented in Table 3. More details about UTA II illustration is given in Siskos et al. (2012).

$$u(\boldsymbol{g}) = 0.1276u_1(g_1) + 0.1607u_2(g_2) + 0.1097u_3(g_3) + 0.2579u_4(g_4) + 0.0743u_5(g_5) + 0.1209u_6(g_6) + 0.0536u_7 + 0.0952u_8(g_8) \qquad (12)$$

$\boldsymbol{g} = (g_1, g_2, \ldots, g_8)$, is the performance vector of a country on the eight criteria.

Table 3. E-government ranking of the twenty one European countries.

Rank position	European Country	Global Value
1	Sweden	0.825
2	Denmark	0.821
3-4	Finland	0.796
3-4	Netherlands	0.796
5	Norway	0.765
6-7	Germany	0.745
6-7	United Kingdom	0.744
8	France	0.738
9	Estonia	0.729
10-11	Austria	0.701
10-11	Slovenia	0.701
12	Spain	0.693
13	Belgium	0.686
14	Ireland	0.679
15	Portugal	0.633
16	Czech Republic	0.582
17	Slovakia	0.578
18	Hungary	0.568
19	Poland	0.548
20	Italy	0.533
21	Greece	0.467

However, the above estimation procedure bears robustness issues. In fact, there exists an infinite number of weighting vectors that are optimally consistent with the whole set of constraints (8)-(11). In order to study the impact of this indetermination on the ranking of the countries the extreme ranking analysis of Kadzinski et al. (2012) has been applied with the aid of the GAMS platform.

The extreme ranking analysis algorithm examines each country individually and estimates the best and worst possible rank it can achieve. The methodology leading to the estimation of the best possible rank of each country is outlined below.

In order to determine the best possible rank of a country A, taking into consideration all the possible combinations of the criteria weighting factors, the number N_A^* of the countries that surpass country A in the ranking under any circumstances is calculated. The countries that surpass country A in the ranking for a limited number of combinations of the criteria weights are not included in the N_A^* set. Therefore, the best possible ranking position that can be achieved by the country A is N_A^*+1.

Thus, the problem is reduced to the calculation of the N_A^* set for each individual country. This set is calculated through the modeling and the solution of the mixed integer programming problem presented below:

$$[min]F = \sum_{b \in A \setminus \{a\}} u_b \quad (13)$$

Subject to:

$$\text{Constraints (8) – (11)} \quad (14)$$

$$U(\alpha) \geq U(b) - Mu_b, \forall \; b \in A \setminus \{\alpha\} \quad (15)$$

where M is an auxiliary variable equal to a big positive value, and u_b is a binary variable associated with comparison of the country *A* to another country *B*. There exist $N - 1$ such variables, each corresponding to $b \in A \setminus \{\alpha\}$. N is the total number of the countries under evaluation, i.e. 21.

The determination of the worst possible ranking of a country *A*, requires a similar procedure. In this case, however, it is estimated the number of countries N_{A*} that achieve a worse ranking position for all possible combinations of the weighting factors. Therefore, the worst possible rank a country *A* can achieve is $N - N_{A*}$.

N_{A*} set is calculated through the solution of the integer programming problem outlined below:

$$[min]F = \sum_{b \in A \setminus \{a\}} u_b \quad (16)$$

Subject to:

$$\text{Constraints (8) - (11)} \quad (17)$$

$$U(b) \geq U(\alpha) - Mu_b, \forall \; b \in A \setminus \{\alpha\} \quad (18)$$

The extreme ranking positions of the 21 European countries assessed, are graphically presented in Fig. 2.

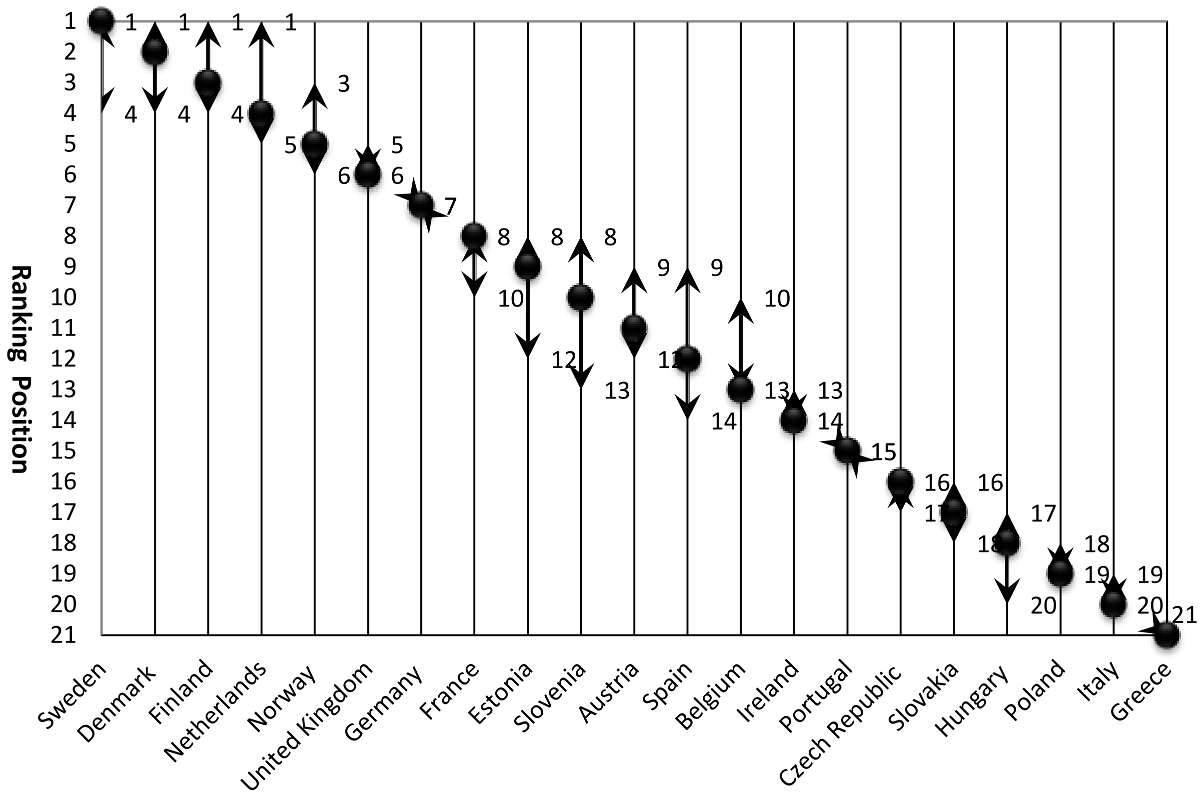


Fig. 2. Extreme ranking positions of twenty one European countries.

5 Conclusion

The paper addressed the robust assessment of global e-government based on multiple criteria and special extreme ranking procedures. The proposed approach focused on the evaluation of European countries according to the standards of a benchmark.

The e-government evaluation process is an independent procedure enabling each individual to specify his (her) own preferences on criteria value functions and weights, and results in a personalized ranking of the countries. In other words, each evaluator has control over his (her) set of criteria and the assessment of his (her) own evaluation model. The proposed multicriteria techniques offer the possibility to combine different preferences and considerations of multiple decision makers and merge them easily through interactive iterative processes.

The next research steps include the development of robustness control procedures based on cardinal and visualization measures as well as the development of a decision support system aiding anyone to form his own e-government benchmarking.

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References

1. Bannister, F.: The curse of the benchmark: an assessment of the validity and value of e-government comparisons, *International Review of Administrative Sciences*, 73 (2), pp. 171-188 (2007).

2. European Commission: *Digitizing public services in Europe: Putting ambition into action*, 9th benchmark measurement, Directorate General Information Society and Media, Brussels (2010).

3. Figueira, J., Greco, S., Ehrgott, M.: *State-of-Art of Multiple Criteria Decision Analysis*, Kluwer Academic Publishers, Dortrecht (2005).

4. Greco, S., Mousseau, V., Słowiński, R.: Ordinal regression revisited: Multiple criteria ranking using a set of additive value functions, *European Journal of Operational Research*, 191 (2), pp. 416-436 (2008).

5. Greco, S., Słowiński, R., Figueira, J., Mousseau, V.: Robust ordinal regression. Chapter 9 [in]: M. Ehrgott, J. Figueira, S. Greco, (eds.), *Trends in multiple criteria decision analysis*, Springer, New York, pp. 241-283 (2010).

6. ITU: *Measuring the information society: The ICT development index.* Retrieved November 10, 2012, from http://www.itu.int/ITU-D/ict/publications/idi/2009/material/IDI2009_w5.pdf (2009).

7. Jacquet-Lagrèze, E. and Siskos, J.: Assessing a set of additive utility functions for multicriteria decision making, *European Journal of Operational Research*, 10 (2), pp. 151-164 (1982).

8. Jacquet-Lagrèze, E. and Siskos, J.: Preference disaggregation: 20 years of MCDA experience, *European Journal of Operational Research*, 130, pp. 233-245 (2001).

9. Kadzinski, M., Greco, S., Slowinski, R.: Extreme ranking analysis in robust ordinal regression, *Omega*, 40, pp. 488-501 (2012).

10. Keeney, R.L.: *Value-focused thinking: A path to creative decision making*, Harvard U.P., London (1992).

11. Keeney, R.L. and Raiffa, H.: *Decisions with multiple objectives: Preferences and value trade-offs*, John Wiley and Sons, New York. (1976).

12. Ojo, A., Janowski, T., Estevez, E.: *Determining progress towards e-Government - What are the core indicators?* (2007). Retrieved November 10, 2012, http://www.iist.unu.edu/newrh/III/1/docs/techreports/report360.pdf

13. Rorissa, A., Demissie, D., Pardo, T.: Benchmarking e-Government: A comparison of frameworks for computing e-Government index and ranking, *Government Information Quarterly*, 28, pp. 354-362 (2011).

14. Roy, B. : *Méthodologie multicritère d'aide à la décision*, Economica, Paris (1985).

15. Siskos, E., Askounis, D., Psarras, J.: *Multicriteria decision support for global e-government evaluation*, Working paper, Decision Support Systems Laboratory, School of Electrical & Computer Engineering, National Technical University of Athens, Greece (2012).

16. United Nations: *E-government survey 2012, E-government for the people* (2012). Retrieved November 10, 2012, http://www2.unpan.org/egovkb/global_reports/12report.htm