Include Macbeth in the MCDA Models Suggested by Italian Legislation for the Selection of the Most Economically Advantageous Tender in Contracts for Public Works. Comparison and Application of MCDA Model to a Case Study[1]

Maria Rosaria Guarini
Department of Architecture and Design (DIAP)
Faculty of Architecture, "Sapienza" University of Rome
Rome, Italy
mariarosaria.guarini@uniroma1.it

Claudia Buccarini
Department of Architecture and Design (DIAP)
Faculty of Architecture, "Sapienza" University of Rome
Rome, Italy
claudia.buccarini@uniroma1.it

Fabrizio Battisti
Department of Architecture and Design (DIAP)
Faculty of Architecture, "Sapienza" University of Rome
Rome, Italy
fabrizio.battisti@uniroma1.it

***Abstract*—Directive 2004/18/EC of the European Parliament and of the Council of 31 March 2004 on the coordination of procedures for the award of public works contracts, public supply contracts and public service contracts, (2004/18/EC), provides that in Member States the commissioning body may base the choice of contractor on two award criteria**

- **the lowest price, where only the economic aspect is evaluated;**
- **the most economically advantageous tender, where a number of factors are evaluated.**

In Italy, the 2004/18/EC directive has been adopted by the Code of Public Contracts for works, services and supplies, Legislative Decree No 163 of 2006 and subsequent amendments (Legislative Decree No 163/2006) and its implementing decree, Presidential Decree No 207 of 2010 (P.D. 207/2010), which, in accordance with European case law, indicate complete equivalence between the two award criteria.

In accordance with the 2004/18/EC directive, Italian legislation provides that, between the two award criteria, the commissioning body must choose the most appropriate one depending on the nature of the contract. This decision by the commissioning body must be made by applying the criteria and objectives, and by ensuring compliance with the principles of transparency, non-discrimination and competition.

In order to rank the different tenders for the award of public works contracts using the criterion of the most economically advantageous tender, Legislative Decree No 163/2006 and P.D. No 207/2010 require the use of a Multicriteria Decision Analysis (MCDA) model.

Five MCDA models are suggested:

- **Weighted Sum Model (WSM, Einhorn and McCoach, 1977);**
- **Analytic Hierarchy Process (AHP, Saaty, 1977);**
- **ELimination Et Choix Traduisant la REalité (ELECTRE, Roy, 1968);**
- **EVAluation of MIXed criteria (EVAMIX, Voogd, 1982);**
- **Technique for Order of Preference by Similarity to Ideal Solution (Topsis, Hwang and Yoon, 1981).**

[1] This article is a revised and expanded version of a paper entitled "Proposta per l'utilizzo di un nuovo modello di analisi multicriteriale per scegliere l'offerta economicamente più vantaggiosa nei contratti di appalto dei lavori pubblici" presented at "Società Italiana Estimo e Valutazione" (SIEV) Seminary: Analisi Multicriteri, Valutazione, Processi decisionale, Torino, 29 30 maggio 2014

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But the possibility of using any of the methods to be found in scientific literature is also indicated.

The aim of the text is to propose the application of a new MCDA model: the Measuring Attractiveness by a Categorical Based Evaluation TecHnique (MACBETH, Bana e Costa, Vansnick, 1994) has not yet been applied in the approximate evaluative field, in verifying either similarities/differences with other MCDA methods suggested by Italian legislation, or with reference to a case study, the advantages/disadvantages arising from the operational application of different MCDA methods considered.

Keywords— Multicriteria Decision Analysis, MACBET, Most economically advantageous tender, Appraisal, Public Works

CRITERIA FOR THE AWARD OF PUBLIC WORKS CONTRACTS IN ITALY

Directive 2004/18/EC of the European Parliament and of the Council of 31 March 2004 on the coordination of procedures for the award of public works contracts, public supply contracts and public service contracts, (2004/18/EC) [9] governs, for all Member States, the procedures that the commissioning body must follow when choosing the contractor, indicating that the criterion for the award can be referred to:

- the lowest price;
- the most economically advantageous tender.

The criterion of lowest price only considers the economic aspect of the tender and is adequate for meeting the requirements of the commissioning body when the work covered by the contract does not have by a particular technological value, or the commissioning body has already determined the qualitative and time specifications that are most modifiable.

The criterion of most economically advantageous tender permits evaluation of a number of aspects of the tender; it can be adopted when the objective characteristics of the contract suggest the relevance, for the purposes of the award, also of other factors: technical merit, aesthetic, technical, functional and time characteristics.

In Italy, Directive 2004/18/EC has been adopted in the Code of Public Contracts for works, services and supplies, Legislative Decree No 163 of 2006 and subsequent amendments (Legislative Decree No 163/2006) [10] which indicates the selection criteria for tenders, and its implementing decree, Presidential Decree No 207 of 2010 and subsequent amendments (P.D. No 207/2010) [8], which defines in detail the methodologies to be applied to make this selection.

The choice of the award criterion falls under the technical discretion of commissioning bodies, which must assess its adequacy with respect to the objective characteristics of the contract, applying criteria which ensure compliance with the principles of transparency, non-discrimination and equal treatment.

With regard to the award of public works contracts using the criterion of the most economically advantageous tender, P.D. No 207/2010:

- stipulates that it is necessary to employ a Multicriteria Decision Analysis[2] (MCDA) model but without giving instructions on the method of choice;
- tentatively suggests five possible MCDA models for developing in detail their structure and mode of application; refer to the consolidated bibliography:
    - Weighted Sum Model (WSM[3], Einhorn and McCoach, 1977) [11];
    - Analytic Hierarchy Process (AHP, Saaty, 1977) [21], [22];
    - ELimination Et Choix Traduisant la REalitè (ELECTRE, Roy, 1968) [18], [19], [20];
    - EVAluation of MIXed criteria (EVAMIX, Voogd, 1982) [26], [27];
    - Technique for Order of Preference by Similarity to Ideal Solution (Topsis, Hwang and Yoon, 1981) [14], [15];
- still leaves the commissioning body the possibility of using any of the MCDA methods to be found in scientific literature.

In practice, the model most used by commissioning bodies appears to be the WSM, which is considered the easiest to use.

The aim of the text is to propose application of the Measuring Attractiveness by a Categorical Based Evaluation Technique (MACBETH, Bana e Costa, Vansnick, 1994) [2], [3], [4], [5], [6] for the choice of the most economically advantageous tender in contracts for public works contracts, in order to highlight at operational level the possible advantages and disadvantages of its use in comparison with other adoptable MCDA models.

In the text, an introductory framework section will be followed first by a comparison between the structure of MACBETH and of other MCDA models suggested by Italian legislation (WSM, AHP, ELECTRE, EVAMIX, TOPSIS), to explain the differences and similarities; the different models will then be applied to a concrete case study; the results obtained from their application will be briefly explained in such a way as to highlight in the comparison the similarities and possible advantages/disadvantages in their operational use.

THE MCDA MODELS INDICATED BY ITALIAN LEGISLATION FOR THE AWARD OF PUBLIC WORKS CONTRACTS AND THE MACBETH MODEL

Building a comparative framework for comparison (Fig. 1) of the configuration and division into phases of MACBETH and of the MCDA models suggested by Italian legislation, the similarities and differences in the method to be used in data processing emerge.

[2] MCDAs are multi-parametric evaluation tools of a mathematical nature used to support decision-making processes. They make it possible to perform comparative evaluations of alternatives through the definition of a scale of preference, defined as a function of the synthesis of complex and heterogeneous information that is both qualitative and quantitative.

[3] In P.D. No 207/2010, the model is indicated with the Italian term Aggregativo Compensatore (Aggregative Compensator) (AC)

All major MCDA models considered are divided into phases that are successive and preliminary among themselves:
A. Construction of the evaluation matrix;
A1. Standardisation of data of the evaluation matrix (only for certain models);
B. Application of weights to standardised data;
C. Ranking of alternatives.

A. Construction of the evaluation matrix (EM)

Construction of a square type matrix (alternatives j x criteria i) whose elements Eji represent the performance that the different alternatives j possess with respect to each of the criteria i considered (quantitative and/or qualitative); these elements, depending on the MCDA model applied, can be expressed as:

- coefficients from 0 to 1 (WSM, AHP);
- absolute values (MACBETH);
- mixed values: coefficients (0 to 1) and absolute values (ELECTRE, EVAMIX, TOPSIS);

Therefore depending on the model used, the EM will be constituted by elements Eji expressed with values that are:

- homogeneous, immediately comparable (WSM, AHP): matrix of coefficients;
- non-homogeneous and therefore not comparable: performance matrix (ELECTRE, EVAMIX, TOPSIS) and data matrix (MACBETH). In order to then proceed with comparison between the data entered in these two matrices, these data must be "standardised".

A1. Standardisation of the EM data (only for ELECTRE, EVAMIX, TOPSIS, MACBETH)

Application of mathematical functions, which differ according to the model used, to make the elements Eji of the EM homogeneous and comparable; structuring of the standardised data Nji EM in:

- standardisation matrices (SM): square type (alternatives $_j$ x criteria $_i$) whose elements N_{ji} consist of the EM data made dimensionless through linear functions (ELECTRE, EVAMIX, TOPSIS);
- criteria scales (CS): whose steps consist of cardinal values N_{ji} that represent the ranking of the alternatives for each criterion considered, obtained through readjustment functions (MACBETH).

The complexity of the linear functions used for the construction of the SM makes application of automated computer supports necessary.

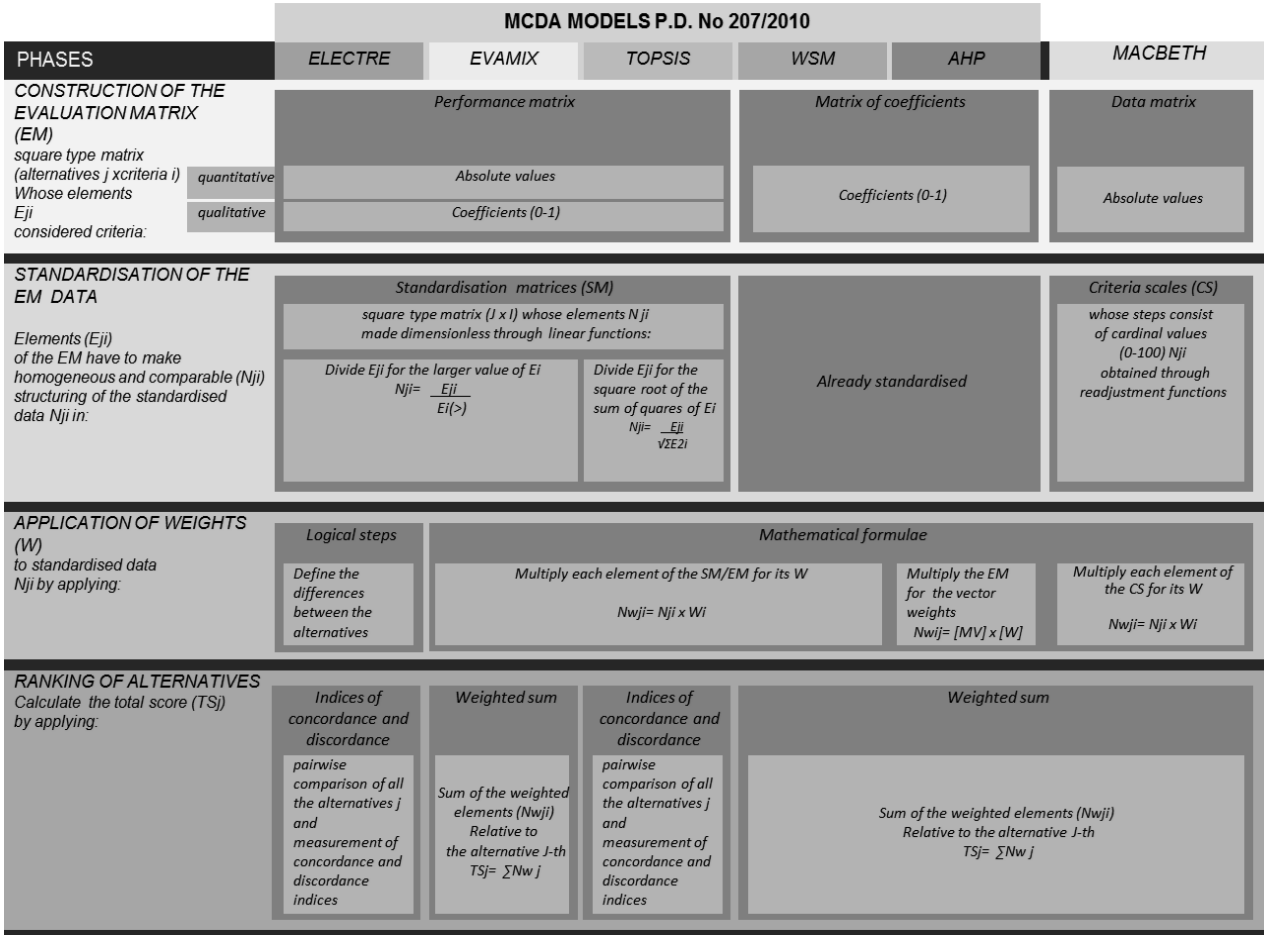

Fig. 1 Comparison between the structure of MCDA models listed in P.D. No 207/2010 and the MACBETH model

B. Application of weights to standardised data

Weigh the standardised values Nji by applying, according to the model used, mathematical formulae/logical steps that make it possible to assign to each criterioni the weight Wi of the importance that it assumes for persons who must make judgmental evaluations.

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C. Ranking of alternatives

Calculate the total score (TSj) of each alternativej taking into account the different criteria considered. Depending on the MCDA model used:

- weighted sum: sum of the weighted elements NW_{ji} relative to the alternative J-th; (WSM, AHP, EVAMIX, MACBETH);
- indices of concordance and discordance: pairwise comparison of all the alternatives $_j$ and measurement of concordance and discordance indices that quantify respectively the satisfaction/regret with choosing one alternative over another (ELECTRE, TOPSIS).

From comparison of the MCDA models, it emerges that (Fig. 2) MACBETH permits processing the data in the EM more quickly than with other models (ELECTRE, TOPSIS, AHP), whose methods require complex logical/mathematical steps.

Even compared with models (WSM, EVAMIX) whose application requires simple steps, the MACBETH model presents the advantage of requiring only absolute values for construction of the EM.

This simplicity of processing makes the model manageable and usable without invoking computer support for the management and processing of input data.

The MACBETH model also enables formulation of a complete ranking of the alternatives with respect to ELECTRE which, instead, defines a partial ranking.

Compared with other MCDA models, the MACBETH model requires the evaluator to provide a preferential judgment with respect to the difference in attractiveness among the alternatives; such a subjective type evaluation could affect the final result of the processing of the model, making it unverifiable.

	MCDA MODELS P.D. No 207/2010				MACBETH
	ELECTRE	EVAMIX	TOPSIS	WSM	
LIMITS					
Long processing times of the model	X		X		
Permits a partial ranking of tenders	X				
Does not directly provide a ranking of tenders, expressed on a cardinal scale, compared on the basis of the individual criteria considered	X				
Does not require the evaluator to provide a preferential judgment					X
POTENTIAL					
Short processing times of the model		X		X	X
Permits a complete ranking of tenders		X			
Provides for each criteria a ranking of tenders, expressed on a cardinal scale from 0 to 100, by evaluating the different appreciation for tenders on the basis of the individual criteria considered					X
Requires the evaluator to provide a preferential judgment with respect to the difference in attractiveness among the alternatives	X				

Fig. 2 Limits and potential of MCDA models indicated in P.D. No 207/2010 and the MACBETH model

APPLICATION OF DIFFERENT MCDA MODELS TO A CASE STUDY FOR THE SELECTION OF THE MOST ECONOMICALLY ADVANTAGEOUS TENDER

The case study assumed for operational application of the different MCDA models indicated by P.D. No 207/2010 (WSM, ELECTRE, EVAMIX, TOPSIS) and MACBETH is the invitation to tender for an "*integrated contract through a procedure open to the most economically advantageous tender for award of design and construction of changing rooms with grandstand at the sports centre in the municipality of Rho, Milan*" [4]

For the case study, the following were assumed for operational application of the models (Fig. 3):

- the set of criteria and their weights, obtained from the invitation to tender;
- the scores assigned by the selection board to the four tenders submitted (A, B, C, D);

CRITERIA	WEIGHTS	SCORES OF TENDERS			
		A	B	C	D
Architectural value	20	15	10	12,5	13,5
Technical value	25	12	14,5	14,5	11
Functional value	25	9,2	11,2	16	11
Economic offer	20	15	9	4	50
Time	10	90	120	120	120

Fig. 3 Criteria, weights and scores of tenders

The EM for the different models considered was constructed on the basis of these data, applying the procedures formalised for each one (Fig. 4).

MODELS	CRITERIA	TENDERS A	B	C	D
WSM	Architectural value	1	0,67	0,83	0,9
	Technical value	0,83	1	1	0,76
	Functional value	0,57	0,7	1	0,68
	Offerta economica	0,3	0,18	0,08	1
	Time	0,75	1	1	1
EVAMIX TOPSIS ELECTRE	Architectural value	1	0,67	0,83	0,9
	Technical value	0,83	1	1	0,76
	Functional value	0,57	0,7	1	0,68
	Economic offer	15	9	4	50
	Time	90	120	120	120
MACBETH	Architectural value	15	10	12,5	13,5
	Technical value	12	14,5	14,5	11
	Functional value	9,2	11,2	16	11
	Economic offer	15	9	4	50
	Time	90	120	120	120

Fig. 4 Evaluation matrix

Subsequently, the non-homogeneous data contained in the EM were standardised, constructing the SM (WSM, EVAMIX, ELECTRE, TOPSIS) and the CS (MACBETH); weights (taken from the invitation to tender) were then applied to the standardised data.

Finally, through the operations of processing of the weighted data, a ranking of the tenders according to each

[4] All the information relating to the invitation to tender are present on http://www.comune.rho.mi.it/Bandi-Aggiudicati/Bandi-di-gara-e-Concorsi/Bandi-Aggiudicati/Archivio-Bandi-2011/Gara-dappalto-con-procedura-aperta-ad-offerta-economicamente-piu-vantaggiosa-per-laffidamento-della-progettazione-e-realizzazione-spogliatoi-con-tribuna-presso-il-centro-spor

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MCDA method was obtained (Fig. 5).

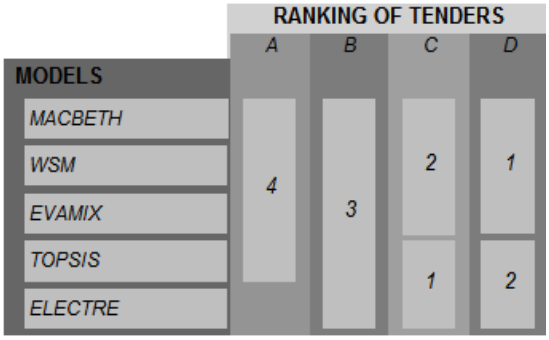

Fig. 5 Ranking of tenders

By comparing the results obtained from application of the models indicated by P.D. No 207/2010 and the MACBETH model, it was possible to find similarities and differences and possible advantages/disadvantages in their operational use.

It was also possible to verify, from the operational point of view, the validity of MACBETH as a tool for selection of the most economically advantageous tender in public works contracts.

Observing the different rankings of the alternatives produced by application of the models, it can be seen that, by applying the same methodology of data aggregation, WSM, EVAMIX and MACBETH permit formulation of results that are consistent with each other.

Compared with other MCDA models, ELECTRE permits only a partial ranking of tenders, eliminating those that are completely dominated [28].

In addition, the MACBETH model makes it possible to define the quantification of appreciation of the alternatives on the basis of the individual criteria considered, expressed on a cardinal scale from 0 to 100.

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