Select the most economically advantageus tenders in public works contracts: MCDA models and MACBETH used to analysis and comparison using a case study[1]

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***Abstract*[2]—**In Member States 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 the commissioning body may base the choice of contractor of public works on two award criteria:

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

In Italy 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),) have transposed the requirements of 2004/18/EC.

Legislative Decree No 163/2006, in accordance with european legislation, provides that decision by the commissioning body about award criteria 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.

The P.D. No 207/2010 suggests to use one of five MCDA models: Weighted Sum Model (WSM); Analytic Hierarchy Process (AHP); ELimination Et Choix Traduisant la REalité (ELECTRE); EVAluation of MIXed criteria (EVAMIX); Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS).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*—** Appraisal, MACBETH, Most economically advantageous tender, Multicriteria Decision Analysis, Public Works.

I. CRITERIA FOR THE AWARD OF PUBLIC WORKS CONTRACTS IN ITALY

In Member States the procedures that the commissioning body must follow when choosing the contractor, are indicated in 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/Ce) [10] [3].

In Italy Directive 2004/18/EC about award criteria of public works contracts 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) [11] which indicates the selection criteria for tenders, and its implementing decree, Presidential

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[3]"The Journal of the European Union L 94 of 28 March 2014, were published three new EU directives reforming the areas of contract and concessions: Directive 2014/25/EU contract in "special sectors" (water, energy , transport and postal services), Directive 2014/24/EU public contract in the ordinary sectors and Directive 2014/23/EU on the award of concession contracts. Directives came into force on 18 April 2014 Member States will transpose the provisions of the new rules into national law by 18 April 2016.

Decree No 207 of 2010 and subsequent amendments (P.D. No 207/2010) [9], which defines in detail the methodologies to be applied to make this selection.

The Italian legislation implementing the european indicates that the criteria for the award of tenders in contracts for public works contract are:

- the lowest price (Legislative Decree No 163/2006 art. 82);
- the most economically advantageous tender (Legislative Decree No 163/2006 art. 83).

The choice of the criterion for the award is within the discretion of the contracting technique (Legislative Decree No 163/2006 art. 81) who must assess their 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 the award criterion of the lowest price is evaluated only the economic aspect of the tenders submitted; the contracting authority finds the contractor in accordance with the offer with the highest percentage of the total decline of the tenderers. This policy is used when the characteristics of the service to be performed are not characterized by a particular value of technology, or the contracting authority has already determined the specific qualitative and thunderstorms that are no longer editable. In case of use of this criterion is not necessary to create a real competition commission being sufficient presence of a president and two witnesses (Legislative Decree No 163/2006 art. 10).

With the criterion of the most economically advantageous are evaluated jointly the economic, technical and quality of the tenders received. It can be applied when the objective characteristics of the contract suggest relevant for the purposes of the award, as well as other factors such as technical merit; the aesthetic, functional, temporal and environmental (Fig. 1).

	ASPECT CONSIDERED	CRITERIA (L.D. 163/2006 art. 81) Most economically advantageous	Lowest price
Quantitative	*Price*	x	x
	Environmental and containment of energy consumption and environmental resources of the work or product	x	
	Cost of operation and maintenance	x	
	Profitability	x	
	Date of delivery or the delivery or of performance	x	
Qualitative	*Quality*	x	
	Aesthetic and functional characteristics	x	
	Technical merit	x	
	Technical support	x	
	Commitments with regard to spare parts	x	
	Security of supply	x	
	After-sales service	x	
	Duration of contract	x	
	Management mode	x	
	Level and criteria to update the tariffs to be charged	x	

Fig. 1 Aspects considered for the selection of the most economically advantageous

The contracting authority (Legislative Decree 163/2006 Article 84) shall appoint a special board for the performance of all activities necessary to identify the best bid among those submitted with the criterion of selecting the most economically advantageous tender. This committee is composed of an odd number of components (three to five) and is a temporary, collegiate body, whose technical decisions are discretionary; and which is appointed only after the expiry of the deadline for the submission of tenders in order to ensure their impartiality to the tenderers.

Decree 163/2006 also indicates the types of contracts for which the contracting authority must necessarily apply the criterion of the most economically advantageous (Fig. 2): complex works (art.53, paragraph 2); concessions (Art.143); project financing (Article 153); finance leases (art.160 a) and volume contracts (art.160 b.).

TYPE OF CONTRACT	CRITERIA (L.D. 163/2006 art. 81) Most economically advantageous tender	Lowest price
Ordinary works (art. 81)	x	x
Complex works (art. 53 paragraph 2)	x	
Concessions (art. 143)	x	
Project financing (art. 153)	x	
Finance leases (art. 160 a)	x	
Volume contracts (art. 160 b)	x	

Fig. 2 Selection of the award criteria depending on the type of contract

With regard to the award of public works contracts with the criterion of the most economically advantageous tender must be applied evaluation methods that allow to make choices transparent, consistent and controllable, making it possible to ascertain which of the proposed alternatives, the most suitable to meet the requirements of the contracting authority. To this end the P.D. No 207/2010Annex G (field work):

- stipulates that it is necessary to employ a Multicriteria Decision Analysis (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 , Einhorn and McCoach, 1977) [12];
  - Analytic Hierarchy Process (AHP, Saaty, 1977) [28], [29];
  - ELimination Et Choix Traduisant la REalitè (ELECTRE, Roy, 1968) [25], [26], [27];
  - EVAluation of MIXed criteria (EVAMIX, Voogd, 1982) [31], [32];
  - Technique for Order of Preference by Similarity to Ideal Solution (Topsis, Hwang and Yoon, 1981) [18], [19].
- still leaves the commissioning body the possibility of using any of the MCDA methods to be found in scientific literature.

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) [3], [4], [5], [6], [7] 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 [17].

Then in the text are briefly highlighted the basic principles of Legislative Decree 163/2006 and DPR207/2010 concerning the award of public works contracts with the criterion of the most economically advantageous.

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.

II. The MCDA Models Indicated by P.D. no 207/2010 for the Award of Public Works Contracts and the MACBETH Model

The MCDA models are multiple parameter, mathematical assessment tools used by the assessor to support decision-making processes as they allow conscious adoption of appropriate solutions to the problem posed achieved by benchmarking different alternatives that take into account complex, heterogeneous qualitative/quantitative information [20], [23], [24].

Building a comparative framework for comparison (Fig. 3) 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.

All major MCDA models considered are divided into phases that are successive and preliminary among themselves [16]:

A. Construction of the evaluation matrix of coefficients (WSM, AHP) of performances (ELECTRE, EVAMIX, TOPSIS) of data(MACBETH);

A1. Standardisation of data of the evaluation matrix of performances (ELECTRE, EVAMIX, TOPSIS) of data (MACBETH);

B. Weighting the criteria and weighting the data matrix of normalised performance (ELECTRE, EVAMIX, TOPSIS), the coefficients (WSM, AHP), and the scale criteria (MACBETH);

C. Aggregation of weighted data and ranking of alternatives.

A. Construction of the evaluation matrix of coefficients (WSM, AHP) of performances (ELECTRE, EVAMIX, TOPSIS) of data(MACBETH)

Construction of a square type matrix (J * I), Jj criteria (j=1,…, j) and Ii alternatives (i=1,…, 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);
- mixed values: coefficients (0 to 1) and absolute values (ELECTRE, EVAMIX, TOPSIS);
- absolute values (MACBETH).

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 data of the evaluation matrix of performances (ELECTRE, EVAMIX, TOPSIS) of data (MACBETH);All tables and figures will be processed as images

Application of linear[4] (TOPSIS) or utilities[5] (ELECTRE, EVAMIX, MACBETH) to make the elements of the MV Eji homogeneous and comparable; the data thus Nji normalised must be counted in:

- standardisation matrix (SM): (TOPSIS, ELECTRE, EVAMIX) of square of order type (J * I);
- criteria scale (CS): (MACBETH) one for each criterion considered in the decision problem, are graphs of a size characterised by a Euclidean metric whose origin coincides with the point 0 and the opposite extreme with 100.

The complexity of implementation of the functions used

[4]The linear functions assign to every Eji element of the valuation matrix a non-dimensional value, they can vary as a function of the criterion being examined; the most commonly used linear functions are:

- Row maximum: Eij/Eij max;
- Ideal value: (Eij - Eij min id.)/(Eij max id.- Eij min id..);
- Average value: Eij/Eij mean;

Interval standardisation (Eij - Eij minrow)/(Eij max row- Eij min row).

[5]The utility functions assign to each element of the evaluation matrix Eji a cardinal value (generally between 0 and 1) that represents the degree of utility associated with the single Eji element. The values assigned to the Eji elements are included in a predetermined interval whose extremes indicate a situation of minimum utility (lower bound) and maximum utility (upper bound) .Such functions must necessarily vary according to the policy you are considering, and are of the type:

U= F(j)
With :
U= utility
F (j) = [(f1 (j), f2 (j), …, fn (j)]
fn (j) = function of utility for criteria j.

to construct the matrix of normalised performance requires the use of properly structured software and/or spread sheets for the management and processing of data, which are not always easy to use.

B. *Weighting the criteria and weighting the data matrix of normalised performance (ELECTRE, EVAMIX, Topsis), the coefficients (WSM, AHP), and the scale criteria (MACBETH)*

The weighting of the criteria is used to define their order of importance, it being an expression of the priority given to each aspect considered in the decision problem.

PHASES			MCDA MODELS P.D. No 207/2010					MACBETH
			ELECTRE	EVAMIX	TOPSIS	WSM	AHP	
CONSTRUCTION OF THE EVALUATION MATRIX (EM)	Square type: alternatives j * criteria i		performance			coefficients		data
	whose elements Eji considered criteria:	quantitative	absolute values			coefficients (0-1)		absolute values
		qualitative	coefficients (0-1)					
STANDARDISATION OF THE EM DATA IN HOMOGENEUS ELEMENTS Nji	By applying functions		utility		linear	Already standardised		utility
	Structuring of the Nji in		Standardisation matrices (SM) Square type matrix (J * I)					Criteria scales (CS) Linear graphic
WEIGHTING THE CRITERIA AND THE STANDARDISATION DATA	By applying		Logical steps	Mathematical Formulae				
	wich consists in		Define the differences between the alternatives	Multiply each element of the SM/EM for its weights Nwji= Nji x Wi		Multiply the EM for the vector weights Nwij= [MV] x [W]		Multiply each element of the CS for its weights Nwji= Nji x Wi
AGGREGATION OF WEIGHTED DATA IN TOTAL SCORE (TSj)	By applying method of		Indices of concordance and	Weighted sum	Indices of concordance and	Weighted sum		
	wich consists in		Pairwise comparison of all the alternatives j and measurement of concordance and discordance indices	Sum of the weighted elements (Nwji) Relative to the alternative J-th TSj= ∑Nw j	Pairwise comparison of all the alternatives j and measurement of concordance and discordance indices	Sum of the weighted elements (Nwji) Relative to the alternative J-th TSj= ∑Nw j		
AND								
RANKING OF ALTERNATIVES	By applyng method of		Placing the TSj in order from highest to lowest					

Fig. 3 Comparison between the structure of the MCDA models listed in the DPR 207/2010 and the model MACBETH

The terms of weighting most commonly used are:

- Direct assignment: the weights are assigned directly by redistributing among all the criteria a total score (sum of the weights equal to 100)
- Pairwise comparison: the weights are assigned to each criterion by performing a series of pairwise comparisons between these and expressing them through a scale consisting of real numbers, integers, finite degrees of preference among the criteria.

In both methods, the weights are assigned depending on the objective of the decision problem and needs expressed by those involved in it.

The weightings never have absolute values but only relative ones which are going to represent the marginal rate of substitution between the various criteria.

Once a weight is assigned to each criterion, they should only be assigned to Nij normalised data through the application of mathematical formulas (AHP, WSM, TOPSIS, EVAMIX, MACBETH), multiplying each element normalised to its weight, or logical steps (ELECTRE), calculating the "waste" among the alternatives.

Doing so, it gives each Nij normalised element the weighting of criterion, which expresses the importance of that aspect for those who must express assessment opinions on obtaining normalised weighted data (NPji).

C. *Aggregation of weighted data and ranking of alternatives*

With reference to each alternative, the previously weighted data (NPij) are aggregated in order to obtain the ranking between the different alternatives.

The aggregation allows the total score (TSJ) of each alternative to be quantified according to all criteria considered in the decision problem. Depending on the AMC model used they will use:

- The weighted sum (WSM, AHP, EVAMIX, MACBETH): the sum for each alternative of the elements previously weighted NPij;
- Indices of concordance and discordance (ELECTRE, Topsis): pairwise comparison of all the weighted NPij elements and measured indices:
  - Correlation: measures the maximum satisfaction to choose an alternative over another; it is calculated as the sum of the weights only for those which are important for choosing the first alternative compared to the second;
  - Discordance: measures the minimum satisfaction in discarding an alternative over another; it is calculated as the difference between the NPji elements of those criteria for which it manifests the lowest satisfaction for choosing the second alternative over the first.
  - Placing the scores thus obtained in order from highest to lowest will give the ranking of the alternatives.

In this phase, the ELECTRE model, compared to the other, permitting a partial order of tenders, going directly to eliminate those that are completely dominated.

III. THE ITALIAN LEGISLATION FOR THE AWARD OF PUBLIC WORKS CONTRACTS WITH THE MOST ECONOMICALLY ADVANTAGEOUS CRITERION

The requirement to use MCDA models for choosing the most economically advantageous bid derives from the need to:

- Make aggregated assessments for aspects expressed according to different scales and units of measurement and therefore not directly comparable to each other;
- Identify the most advantageous with a single final numeric parameter (Total Score);
- Take into account the different weights that the contracting authority has attributed to the criteria themselves.

In practice, the Italian model used by contracting authorities to determine the most economically advantageous tender appears to be the WSM, which is considered easier to use because of its data processing simplicity [2].

In order to ensure the most economically advantageous award criteria are properly enforced, it is essential to take account of the distinction, from the notice and tender documents, between the requirements that competitors must fulfil to participate in tenders and the criteria for the award of the offer [6] [1]:

- The suitability of the tenderers shall be evaluated in accordance with the economic, financial and technical criteria (2004/18 / EC art. 47-52; Leg. Decree 163/2006 art. 40);
- The offer must be evaluated by the different qualitative and quantitative contents of the contract. Therefore, in this context the subjective qualities of the tenderers cannot be considered (2004/18 / EC art. 53, Legislative Decree 163/2006 art. 83).

In relation to the multiple public interests pursued, the contracting authority has a wide discretion in the choice of criteria on which to base the evaluation of the bids.

However, in order to ensure compliance with the principles of transparency, non-discrimination and equal treatment, this freedom of choice is limited. The contracting authority is obliged to give an account of its choices with clarity in the notice and, in doing so, bind itself to the assessment of future tenders on the basis of the predetermined objective criteria [1].

The same freedom enjoyed by the contracting authority in the choice of criteria is also reflected in the weighting of these criteria in relation to the objectives pursued. The discretion of the awarding authority, according to the case, is only limited with regard to "manifest irrationality" in the distribution of points in relation to the purpose of the operation[7].

The contracting authority may appoint one or more experts whom it entrusts with the task of selecting criteria for evaluation and assigning relative weighting (Legislative Decree 163/2006 art. 83, paragraph 4).

In order to apply the MCDA models indicated by the Italian legislation, the Board, appointed to carry out all the activities necessary to identify the best bid among those submitted, must first calculate the coefficients from 0 to 1 to be allocated to each bid for each criterion (construction of the evaluation matrix). These coefficients are calculated by different methods depending on whether they relate to quantitative (tangible characteristics) or qualitative (intangible characteristics) criteria.

It should be noted that the term "quantitative" refers to all those aspects which are directly measurable (price, time of execution of the work, performance, duration of the concession, the level of fees).

For the criteria of a quantitative nature, coefficients are calculated by linear interpolation between the coefficient, equal to one, attributed to the values of the items offered cheaper for the contracting authority, and coefficient equal to zero, given to the values of the elements offered equal to those forming the basis of the tender"(DPR207 / 2010, Annex G, Article 120).

Assuming that the quantitative criterion is the price, coefficients are obtained by the formula:

$Eji=Ri/Rmax$

With:

Eji = nth coefficient of the offer $0 \leq Eji \leq 1$;

Ri = Reduction in the nth offer expressed as a percentage;

$Rmax$ = Maximum reduction among the bids expressed as a percentage.

For the criteria of a qualitative nature, the coefficients can be calculated with any of the following (DPR207/2010, Annex G, Article 120):

- "The average of the coefficients, variable between zero and one, calculated by each commissioner by comparing in pairs;
- The transformation in variable coefficients between zero and one of the sum of the values attributed by each member by means of the pairwise comparison;
- The average of the coefficients, variable between zero and one, calculated by the single commissioners through the comparison in pairs, following the criterion based on the calculation of the main eigenvector of the complete matrix of pairwise comparisons;
- The average of the coefficients, variable between zero and one, attributed discretionally by individual commissioners;
- A different method of determining the coefficients, ranging between zero and one, specified in the notice or in the contract notice or in the invitation letter".

[6]The Community system indicates that a distinction between these aspects must be guaranteed, prescribed by the judgment of the European Court of Justice, sec. I, 24 January 2008 in Case C-532/06 and the circular of the Prime Minister, Department for Community Policies, March 1, 2007: "Principles to be applied by the contracting authorities in the choice of the selection criteria and the award of a public service contract"

[7]This limit has been sanctioned by the Lazio Regional Administrative Court, sec. III - c, 13/11/2008, n. 10141

In relation to qualitative criteria, the contracting authority must indicate in the tender process which methods of calculation of coefficients will be applied during the evaluation of tenders.

Once the coefficients from 0 to 1 to be attributed to each offer for each criterion have been calculated, the Board may proceed with the application of the MCDA model previously indicated in the tender notice and identify the most economically advantageous bid from among those submitted.

IV. 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" [8].

In the tender notice the contracting authority indicated the WSM of the MCDA model to select the most economically advantageous tender.

For the case study, the following were assumed for operational application of the models (Fig. 4):

- the set of criteria (architectural value, technical value, functional value, economic offer, time);
- their weights (20, 25, 25, 20, 10).

CRITERIA	WEIGHTS
Architectural value	20
Technical value	25
Functional value	25
Economic offer	20
Time	10

Fig. 4 Criteria e weight

By the acts of the commissioning body were derived coefficients from 0 to 1 assigned to the four tenders submitted (A, B, C, D) (Fig. 5).

CRITERIA	TENDERS			
	A	B	C	D
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	0,3	0,18	0,08	1
Time	0,75	1	1	1

Fig. 5 Coefficients from 0 to 1 assigned to the four tenders submitted

These coefficients were calculated by the Selection Board applying the procedure, indicated in the notice, "transformation into variable coefficients between zero and one from the sum of the values assigned by individual commissioners by the pairwise comparison".

The EM for the different models considered was constructed on the basis of these data, applying the procedures formalised for each one:

- coefficients (WSM);
- performances (EVAMIX, TOPSIS, ELECTRE)
- data (MACBETH) (Fig. 6).

Subsequently, the non-homogeneous data contained in the EM were standardised, constructing the:

- SM: (EVAMIX, TOPSIS, ELECTRE);
- CS: (MACBETH).

weights (taken from the invitation to tender) were then applied to the standardised data:

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
	Economic offer	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. 6 Evaluation matrix

- multiplied by the standard elements for its weight (WSM, TOPSIS, EVAMIX, MACBETH);
- Calculated the differences between the alternatives (ELECTRE).

Finally, through the operations of processing of the weighted data, a ranking of the tenders according to each MCDA method was obtained (Fig.7):

- Weighted sum (WSM, EVAMIX, MACBETH):
- Indices of concordance and discordance (ELECTRE, TOPSIS).

MODELS	RANKING OF TENDERS			
	A	B	C	D
MACBETH	4	3	2	1
WSM				
EVAMIX				
TOPSIS			1	2
ELECTRE				

Fig. 7 Ranking of tenders

[8]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

In order to verify the applicability of the MACBETH model in the selection of the most economically advantageous bid, it was decided to process the data starting from the data matrix and the coefficient matrix (Fig. 8).

MATRIX	CRITERIA	TENDERS			
		A	B	C	D
Coefficients	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	0,3	0,18	0,08	1
	Time	0,75	1	1	1
Data	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. 8 MACBETH's matrix

Developing the model revealed that with both matrices we arrived at the same ordering of bids (Fig. 9) therefore, in the MACBETH model, it is possible to avoid the calculation of the coefficients.

MATRIX	RANKING OF TENDERS			
	A	B	C	D
DATA COEFFICIENTS	4	3	2	1

Fig. 9 Ranking of tenders MACBETH

V. Conclusions

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 [22].

This comparison shows that the MACBETH model allows you to process the data using less complex procedures during the aggregation of weighted data and ranking of the alternatives, in which other models (ELECTRE, TOPSIS) require the performing of multiple logical / mathematical steps (calculating correlation and discordance indices), which require the use of spread sheets or software specifically constructed for that purpose and not always easy to use [20].

In comparison to the others (WSM, ELECTRE, EVAMIX, TOPSIS), the MACBETH model provides for the construction phase of the evaluation matrix to compute the Eji elements expressed directly by means of the absolute values (data matrix) which can be derived from the bids submitted.

Therefore, even at this stage the model has fewer steps than the others, in fact is not necessary to perform the calculation of the coefficients from 0 to 1 (WSM quantitative / qualitative-criteria; ELECTRE, EVAMIX, TOPSIS qualitative criteria).

The comparison also shows that, unlike the other models considered, the MACBETH model, through the construction of the scales of the criteria, makes clear the quantification of appreciation of bids on the basis of individual criteria considered. In this way, the model is configured as a flexible operational tool able to provide rankings which take account of only one / some criteria at a time.

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