



Received: 07 March, 2022

Accepted: 18 March, 2022

Published: 19 March, 2022

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Keywords: Linear programming; SIMUS; ERM matrix; PDM matrix; Sensitivity analysis; Ranking

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Research Article

The SIMUS method addresses two important MCDM drawbacks: Getting different results for the same problem, and the inability to model complex scenarios

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Abstract

This paper considers that actual methods for addressing MODM or MCDM scenarios share two shortcomings along these lines: a) Failing to show equal results when different MCDM methods solve the same problem. b) Inability to replicate actual scenarios, by not taking into account existing conditions, and thus, producing an approximate representation of reality, which obviously, renders not reliable results. This paper shows how the SIMUS method addresses these two shortcomings.

Introduction

This paper has as objective to illustrate the principles and functioning of SIMUS (Sequential Interactive Modeling for Urban Systems, Munier, 2011), a method aimed at solving two existing problems, as follows:

1. Different results when different methods solve the same problem.
2. Inability to mathematically model certain scenarios.

Different results

When different MCDM (Multi-Criteria Decision-Making) methods, address the same problem, usually their results are different.

It has intrigued researchers for decades, and it is still unexplained. This author attributes it to subjectivity since decision-making is in general a mix of objective, or quantitative data, and subjective or qualitative data.

While quantitative data is normally reliable since it pertains to tangible issues (like cost, quantities, environment contamination, etc.), the second is most of the times uncertain, either because of lack of dependable data or due to diverse human values, as in the case when a project may affect people in different manners, for instance, a plan to build a highway across a city. It can produce benefits to a certain segment of the population, as well as create diverse problems for the same or other sectors. It is how each method addresses the scenario which produces these different results.

Results can also be different when, even counting with only objective data, it is modified according to personal appreciations from the Decision-Maker (DM). This is one of the main causes for subjectivity because the criteria used to evaluate alternatives are weighted to determine their relative importance, and that weight affects the reliable data.

For instance, the DM may decide that criterion 'Damage to the environment has a certain weight that may be larger or smaller than the weight for criterion 'Construction time'. This

weight is then applied by the different methods to reliable data and then modifying them, when the rationale is that a solution must be based on original data and thus, without interferences from the DM. Even when the same criteria values are used in different methods, the results may be different because all employ different algorithms, and thus, the effect of weights on data may be direct or indirect.

Of course, the opinion and preferences of the DM are of great value, and in addition necessary, but it must be applied without modifying the initial data, at the end of the process, once the mathematical solution is known.

The active participation of the DM is paramount in this analysis, however, what is questioned is the moment of this fundamental intervention. Most of the methods assume that the DM must input his/her opinions, expertise, know-how, suggestions, recommendations, etc., from the very beginning of the process, i.e., when alternatives and criteria are already known, being criteria the first activity that the DM must perform, after consultation with stakeholders and experts, and then altering original data and after that processing the information by a selected MCDM method. This is known as the Top-Down (T-D) approach.

This paper assumes that the participation in determining the above-mentioned task of designing the set criteria is indeed the first and very important DM function, but also promotes that after that, he/she must apply the selected method without disturbing any data. In the end, when the method gives a solution, that is assumed correct since it is based on mathematical algorithms and grounded on original and unaltered data, this is the moment when the DM can apply his/her knowledge and expertise by examining it, and determining if it is acceptable or not, or even reject it. This is what is called the Bottom-Up (B-U) approach.

The difference between this tactic is evident: In the B-U the DM works with a mathematical result grounded on robust and stable data, yielding a solid platform, in contrast with the T-D approach that is based on muddy and unstable data, a consequence of altering data and using different opinions and yielding a wobbly platform. Naturally, because using mathematics, the mathematical result is correct, according to data input, but it may not represent the real problem.

In his analysis of the result in the B-U procedure, the DM may detect aspects that were unknown at the beginning of the process. For instance, assume that there are four alternatives involving purchasing a sophisticated lathe, out of four different brands, and that the method indicated lathe D as the best, by far, due to its elevated score in comparison with the other lathes. There is no reason to doubt about this selection, mathematically correct. Considering this result, the DM decided to investigate the performance of all lathes and consulted other users, that is, from the operating point of view. The answers he received confirmed that D is indeed a very good lathe, however, some users complained about a drawback related to the reliability of its electronic circuitry, something that was absent in the other lathes, which have another drawback. Most reasonable, the DM

decides not to buy this lathe but the following in the ranking, lathe B.

Agreed, consultations with former users should have been a criterion created at the very beginning, but it wasn't, probably because the DM did not know about it. This procedure allowed him to acknowledge his omission. He introduced it in the originals matrix and run the software again, and got the same result, indicating that this drawback was more than compensated by another characteristic of lathe D. This can be also done with the T-D procedure, however, the alteration of data could darken the values of the performances of all lathes, and yielding a different result.

As a bottom line, this example tries to point out that there is a mathematical result that may be modified by operating performance.

Inability to model scenarios

Another circumstance that adds to getting different results, is the different capacity of different methods to model reality. Some -very few- may consider most of the characteristics of a scenario, while others are only able to take into account one or two of them. For instance, all scenarios whatever their purpose depend on resources, money, manpower, electric power, water, etc., however, out of the more than 100 MCDM methods available, only three or four methods consider resources, and then, it is evident that the balance of methods assumes that resources, of any kind, are infinite, which, of course, is false.

There is a large variety of scenarios, from elemental, like deciding to purchase a car, involving a personal decision, to complex and very complex, that include aspects like:

- 1) Dependent and independent alternatives, for instance in an oil refinery, where the output of an activity is the input to another.
- 2) The mix of dependent and independent criteria, as found for instance when a developer plans to build a certain number of houses, considering their different models,
- 3) Stakeholders with contradictory interests, for instance, when the financial department establishes goals for returns and the engineering department demands higher funds for working capital,
- 4) Establishing minimum and maximum limits for the same criterion, as for example, in production problems, and related to keeping a certain inventory of raw materials,
- 5) Correlation among criteria, usually in some road construction in mountainous countries, related to events like heavy snowfalls that can influence the maximum speed,
- 6) A sizable number of alternatives with maybe be hundreds of criteria, as in thermodynamical projects,



- 7) The necessity to work with binary variables, as in the case on inclusive or exclusive alternatives, for instance deciding a highway that competes with another, and where only one has to be built,
- 8) Precedence or equality between alternatives, common in international bids, when two different bidders' joint efforts, in what is called a 'joint venture'.
- 9) Complex scenario structure involving multiple relationships between alternatives and criteria and among themselves,
- 10) Multiple scenarios where an alternative may be in different sites and situations, as is the case of multinational with sites in different countries and different crops,
- 11) Equalization of performance between several alternatives, as is the case of an international railway network,
- 12) Multiple variables, for instance in irrigation problems with different land sizes, various depths for extracting water, different water needs, etc.
- 13) In multiples projects that involve for instance the construction of several high-rises in a plot of land, and subject to a construction schedule, it is considered that all buildings start and finish at the same time, which of course is a misconception since the schedule and the financial plans are ignored.

This inability to represent most faithfully a certain scenario is possibly the largest challenge in MCDM. It is worth investigating what causes this inability. This author's research reveals that assuming that a scenario follows a hierarchical structure, automatically inhibits in most cases its modeling, since most scenarios have a network structure, and work as a system, not as isolated subsystems, which may be following a linear hierarchy.

Failure is also due to the mathematical algorithm used in each method, not because it is erroneous, but for assuming a tight linear representation of criteria, which usually leaves no margin for variations, related with other criteria, and which is the core of a system, i.e., get a balance among different criteria to reach a compromise solution.

The latter is the large difference with SIMUS that works with inequalities where the left side is the performance values and the right side the resources and/or limits, and both linked by ' \leq ', ' \geq ', ' $=$ ' symbols, which represent 'Less or equal than...' applied to maximization criteria, 'Greater or equal than...', applied to minimization criteria, and 'Equal than...' applied to equalization criteria, and that can participate in any quantity and mix in a problem.

These inequations, except the equality, represent spaces and then allow to make comparisons among criteria and thus, able to represent real scenarios, because the set of inequations

and equalities define a common space, in any dimension, where all feasible solution exists. This is the core of LP and can be graphically and easily understood as depicted in hundreds of publications on this discipline, since its conception (Kantorovich, 1939).

As examples (refer to the above numeric list):

1- This can be considered by placing '1s' below each alternative, using the symbol ' $=$ ' and the value '1' in the RHS, if they are exclusive, and the value '2' if they are inclusive. In this way, the software is instructed to select only one alternative if exclusive, and the two of them if inclusive, 4 – Creating a criterion aiming and maximizing usage of raw materials up to a limit (\leq) and establishing as RHS that limit. This is done to avoid using more raw materials than are available in stores.

Creating another criterion, with the same values as before, but using the (\geq) symbol, and putting a minimum limit. This is done to avoid running out of stock.

In this way, the software is instructed to find intermediate values between the minimum and the maximum, and this selection is related to all the other criteria, for instance, funds, demands, and manpower following the concept of a system.

5- Use in a criterion the expression 'IF (...then....)'. If it is usual that snowfalls reach certain limits, this will modify the maximum speed, lowering it, and maybe influencing the ranking.

7 – Already illustrated in (1-).

11 – Already illustrated in (1-).

13- Developing the usual initial decision matrix, but adding a criterion corresponding to each year for the duration of the whole undertaking. In each year, the performance values will be different, because they will reflect the progress of each alternative in accordance with the construction schedule developed by the project management

The method

SIMUS (Sequential Interactive Method for Urban Systems) [1] is an MODM (Multi-Objective Decision-Making) method based on Linear Programming (LP) [2], which, although not guaranteeing an optimal solution (provided that it exists) as LP does, gives a compromise solution (Zeleny, 1974), that is, a balance or equilibrium of compliance, in a lesser or greater degree of what the set of criteria demand, the same as other heuristic methods.

SIMUS characteristics

SIMUS has some characteristics or features that allow a satisfactory approach to real scenarios, although unfortunately, unable to exactly replicate them. They are:

- * It does not use weights, the main culprit for differences.
- * Permits *reproducing faithfully* most actual conditions



and scenario characteristics, because of its algebraic structure, using inequations instead of equations.

- * Works with *real limits* for criteria, i.e., restrictions to each one of them, normally established by resources, as well as considering limits established from the environmental and social point of view. This fact is an inherent component of all projects, since resources are not unlimited, and also because there are always minimum and maximum percentages for social and environmental issues. Real projects consist usually of established maximum and minimum water consumption, minimum floor space in a house according to the number of people, maximum allowed values for air, water, and soil contamination, maximum available funding, or even for an exact investment.
- * Allows *breaking ties* for alternatives. This is a serious problem because often different alternatives get the same score of importance. This fact puts the DM in a difficult position – he/she is again at square one – since does not have a way for determining which of the two alternatives is better, when both have the same importance.
- * Accepts correlation between criteria [3], another important fact. If a certain variation of one criterion, directly or indirectly affects other.
- * Permits *Group Decision Making* [4]. This is another serious problem. There are different MCDM methods that address this issue; however, the main problem is to reach an agreement between the different DMs. of the group.

SIMUS works in a different way since once the opinion of one or more DMs on a certain issue – which may be quite different among them – is introduced in the decision matrix, the method gives a quantitative measure that can be compared with the precedent. If they are maximizing, and if this result is higher than the precedent, obviously the proposal or proposals of the DMs are accepted or rejected if it is lower. The same happens with the criterion that calls for minimization; the new result is accepted if it is lower than the precedent and rejected if it is higher. Therefore, there is no uncertainty.

SIMUS operation

Columns analysis of the Efficient Result Matrix (ERM): Starting with the initial table or numerical Decision Matrix completed (Figure 1) that is, with a cardinal value at the intersection of each alternative or project column with each target or criterion row, it takes the first target and uses it as an objective function, i.e., it removes the first row and then uses the values 42, 18 and 25 as coefficients for Z, the objective function, as schematized in Figure 1.

After processing this information using the Simplex algorithm [5], and Solver software [6] it replaces the three values into de decision matrix. See Figure 2.

Assume that after running the software solving for this objective, the result shows the following scores: For project A=0.23, and project C=0.56, with no score for project B, meaning that this alternative does not match this criterion or target 1.

The software places those values on the ERM matrix (Table 1), in the first row and under A and C respectively. These are optimal values for that objective.

The method now replaces the values that were used for the objective function in the first row of the decision matrix (Figure 2), removes the three values 36, 9, and 47 that are on the second row, and uses them as a second objective function, run the process and the results placed on the second row of Table 1. Assume that these values are 0.21 for project A, 1.23 for Project B, and 0.15 for project C. *These three optimal values* for this objective are placed in the second row of the ERM matrix, Table 1.

		Projects				
		A	B	C		
Objective function					Action	Thresholds or limits
Target 1	42 18 25				≥	-----
Target 2	36 9 47				≤	-----
Target 3	4 11 15				≤	-----
Criterion 1	15 13 13				≤	-----
Criterion 2	76 49 72				≤	-----
Criterion 3	8 5 9				≥	-----
-----	- - -					-----
-----	- - -					-----
Criterion 10	51 56 48				≥	-----

Figure 1: First criterion or target extracted to be used as an objective.

		Projects				
		A	B	C		
Objective function					Action	Thresholds or limits
Target 1	42 18 25				≥	-----
Target 2	36 9 47				≥	-----
Target 3	4 11 15				≤	-----
Criterion 1	15 13 13				≤	-----
Criterion 2	76 49 72				≤	-----
Criterion 3	8 5 9				≥	-----
-----	- - -					-----
-----	- - -					-----
Criterion 10	51 56 48				≥	-----

Figure 2: Objective equation is returned to the decision matrix as criterion or target.

Table 1: Construction of the Efficient Results Matrix (ERM).

	Projects		
	A	B	C
Target 1	0.23	---	0.56
Target 2	0.21	1.23	0.15
Target 3		1	
SC	0.44	2.23	0.71
PF	2/3	2/3	2/3

Scores: 0.29 1.478 0.468
ERM ranking: Project B – Project C - Project A



The same procedure is followed for each criterion, or for the number of criteria established by the DM, until all criteria have served as objective functions, and thus, completing the ERM matrix. In reality, this ERM matrix is the mapping of the original or initial matrix, by using the Simplex algorithm, and thus, the initial decision matrix has been transformed into a matrix where each row, known now as objective, is Pareto efficient.

Once this is done SIMUS uses two different procedures

First procedure: Computing column values in ERM, following the simple additive weighting procedure. Table 1.

Guideline 1: It aims at determining the importance or worth of the projects, by adding up the scores found for each one. Proceed as follows (Table 1) (ERM Matrix).

- Normalize scores along each row of the ERM matrix.
- Add up scores in each column (SC), i.e., for a variable or project 'j' and 'n' targets.

Guideline 2: It aims at considering the level of participation of each project regarding a number of targets. This is the 'Participation Factor (PF), obtained as the ratio between the number of criteria each alternative satisfies, and the total number of criteria. This PF is then normalized (NPF) and then multiplied by the SC. Adding up these weighted values gives the score of each alternative or project, and thus, the respective ranking, which is also done by the method.

As can be seen, the best is Project B (1.478), followed by project C (0.468) and project A (0.29). The software produces this ranking and writes it as shown.

Second procedure: Computing row values in ERP, following the outranking procedure.

In this case, a square matrix is built with projects in columns and rows.

Row analysis of the Efficient Result Matrix and construction of the Project Dominant Matrix (PDM): It is based on the ERM matrix (Table 1), which is now analyzed horizontally. A squared matrix called 'Project Dominant Matrix' (PDM) is built (Table 2). The method looks for the first row of the ERM in order to determine which is the project with the highest score. In this case, it is project C with a score of 0.56 and dominates all others.

The method works by determining by subtraction row by row, how larger is this value regarding the values of other projects.

First ERM row: Project C dominates project A in $0.56 - 0.23 = 0.33$. Then, this value is placed in cell CA. This indicates that for this objective project C dominates project A by 0.33.

Second ERM row: Project B dominates both projects A and C.

Consequently, $1.23 - 0.21 = 1.02$ in cell BA, and $1.23 - 0.15 = 1.08$ in cell BC.

Project A also dominates project C as $0.21 - 0.15 = 0.06$, thus, in cell AC we put 0.06.

Third ERM row: project B dominates both A and C with $1 - 0 = 1$

1 is added in cell BA and in cell BC.

The sum of values in each row gives the total domination value for that row

The sum of values in each column gives the total dominated value for that column

The difference, for the same project, between the row and the column values, gives the score of each project.

As expected, because we are using different procedures, the scores of alternatives considering simple additive weighting and outranking are different, however, both procedures give the same ranking.

It means that one procedure checks the other.

Example using SIMUS and SIMUS software [7] in solar and photovoltaic alternatives in a new undertaking

Projects: An electricity company is considering using a plot of land for installing an electric generation plant based on solar radiation, either by using solar dishes (also known as solar thermal), and/or photovoltaic panels.

Criteria: Five criteria are considered, such as:

Data: Data is depicted in Table 3. Observe that for each criterion there is an RHS (Right-Hand Value of the criterion),

Table 2: Project Dominance Matrix (PDM).

Projects	Projects			Sum of rows	Net difference	
	A	B	C			
A		0.23	0.06	0.29	$0.29 - 2.35 = -2.06$	Third
B	$1.02 + 1$		$1.08 + 1$	4.10	$4.10 - 0.79 = 32.31$	First
C	0.33	0.56		0.89	$0.89 - 1.14 = -0.25$	Second
Sum of columns	2.35	0.79	1.14			

The ranking is: Project B – Project C – Project A

Table 3: Data for electric generation system based on solar radiation.

Criteria	Alternatives		Action	Operator	RHS
	Solar thermal (SE)	Photovoltaic (PV)			
Unit Cost	0.72	0.68	MIN	\geq	0
Efficiency index	0.85	0.75	MAX	\leq	1
Financial index	0.78	0.98	MIN	\geq	0.84
Land use index	0.82	0.65	MAX	\leq	0.94
Generation index	0.99	0.6	MIN	\geq	0.8



that is, a limiting value for each one. For the first criterion obviously, the unit cost can not be negative, therefore, it has a lower limit greater than zero.

This data is fed to SIMUS software either manually or electronically, as shown in Figure 3.

Introducing weights: Even when SIMUS does not need weights, the system allows to consider them if the DM wants to assign his own weights. Weights can be placed for criteria or for projects, or for both simultaneously. It also permits to request of different types of results such as decimal, integer, or binary.

Type of results or scores: A *decimal result* indicates the scores for each project, that is, a measure of their importance, the higher the better. The integer condition specifies that a project *cannot be a decimal*. The binary result indicates that it is must be *one project or another*. However, if both locations are allowed, for instance, that certain parts of an automobile are manufactured in one plant and others in another, the method can be instructed to consider them in cooperation.

RHS (Right Hand Side) or limits: Indicated in the RHS column. These can be expressed in decimals, integers, or mathematic formulas. To place these limits, use the 'Define or edit formulas' key. If limits are unknown, as in for instance in

qualitative criteria, do not put any number, just leave it blank. Input data into the software, Figure 4 shows data inputted into de SIMUS software.

The DM may choose between partial or step-by-step results, or final. If he selects the first, a result will appear boxed (Figure 3).

Notice that for the first objective 'Minimization of unit costs', the method gives preference to 'Solar energy', since score 0.56 > 0.41 as shown on the first row of the ERM matrix (at left), in Figure 3.

Figure 5 displays the final results when all objectives have been analyzed, either using the step-by-step procedure or the automatic key.

The ERM matrix shows in the solid row box the scores for each project, and below the corresponding ranking based on these scores.

Immediately below is the PDM matrix.

It shows in the solid column box the final scores for each project and below the corresponding ranking based on these scores.

Observe that both rankings coincide.

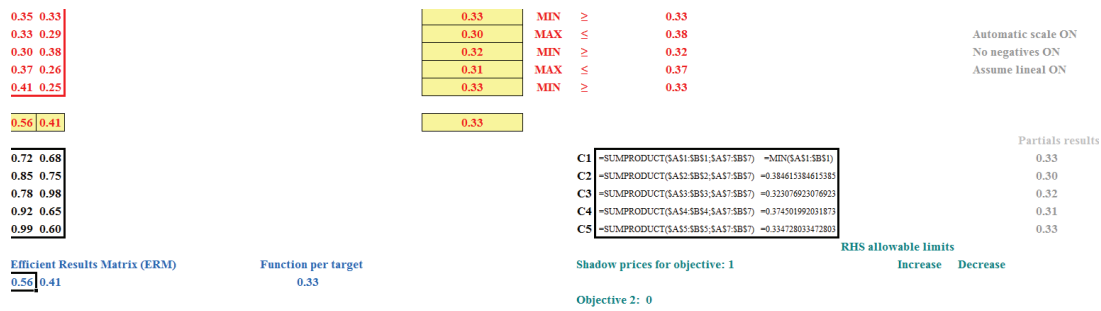


Figure 3: Program stops after processing first objective allowing the DM to examine results and take actions.

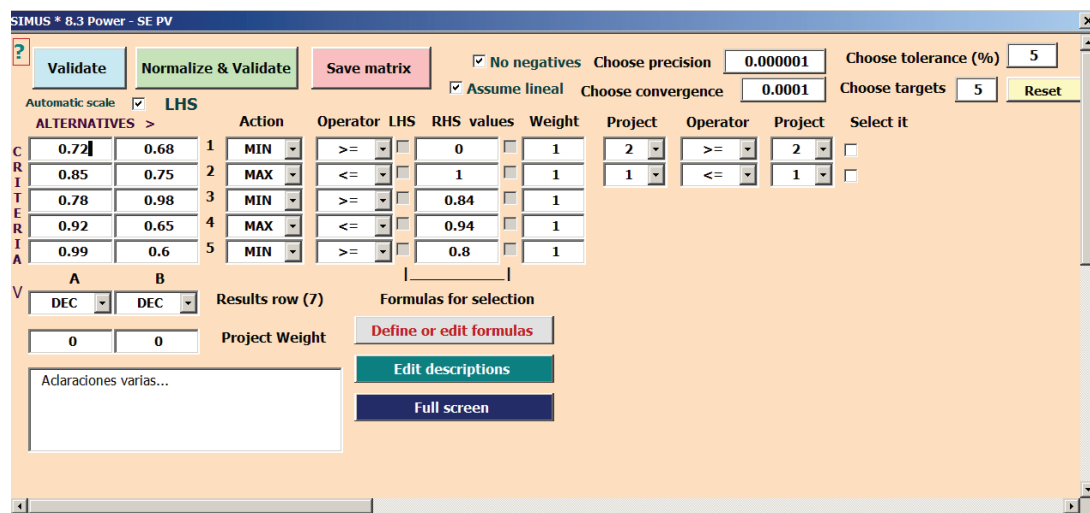


Figure 4: Initial SIMUS matrix with data.

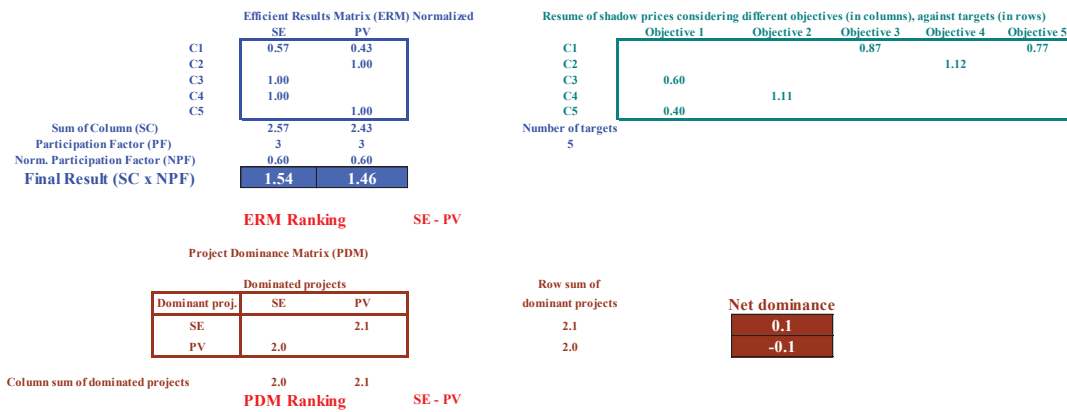


Figure 5: Final results: In solid row box for First Procedure. In solid column box for the Second Procedure.

Conclusion

This paper presented a new tool for MCDM scenarios. It is based on Linear Programming and its main characteristics are:

- * Except for the definition and quantities of criteria, common in all MCDM, it does not use weights, personal preferences, thresholds for outranking a project over another, or assumptions. It only works with data originally imputed.
- * The system permits modeling most real scenarios considering different conditions present in real life and accepting quantitative and qualitative criteria. between the scores of two or more alternatives or projects.

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