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RELIABILITY OF MCDM METHODS

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Abstract

This paper addresses working with MCDM methods unable to model correctly a scenario. Most Decisions Makers (DM) are forced to select a method even knowing that it does not fulfill it, while others are conscious that they are simplifying the scenario. The result for the abridged version or proxy of the real scenario may be correct, but it does not represent the real one, and consequently, the extracted conclusions do not pertain to the original problem. Since no mathematical formula exists to solve problems of this nature, and because results cannot be validated, it is easy to state, as many authors do, that the problem was successfully solved using a particular method, although obviously no consideration is given to the true nature of the problem, which is usually easily seen by reading its characteristics and by examining the process used to solve it. In addition, this paper sustains that an MCDM problem is a system of linear equations, and as such, everything must be accounted for and solved at the same time; this concept is overlooked by most MCDM methods. Some emphasise partitioning a complex problem and solving each part separately, which is beneficial because it facilitates the comprehension of the problem, but it does not mean that the problem is solved in its integrity. Usually, the whole is something more than the sum of the parts.

Keywords: MCDM, alternatives, criteria, modelling, networks, SIMUS.

1 Introduction

Multicriteria Decision-Making Methods start with the initial decision matrix formed by alternatives in columns and criteria in rows in some methods (or vice versa, in others). The way an alternative complies with a criterion is reflected by its performance value, that is, the cardinal quantity, subjective or objective, that denotes its contribution (in all methods).

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These values are absolute – either in quantitative or in qualitative criteria – meaning that they are independent. For instance, for a criterion related to costs, each performance value for an alternative is independent of the cost value for another alternative for the same criterion. The same holds for a qualitative criterion; for example, the opinion of people regarding alternative A may be not related to their opinion for alternative B. Most models work with this kind of absolute initial matrix, but there are methods that use relations between values. All methods process this information by using different algorithms and deliver a result and a ranking. The ranking is expressed as a sequence of activities in decreasing order, determined by their scores. In case of equal or very similar scores between two alternatives, the ranking is uncertain and then, some means must be developed to break the tie.

The objective of this paper is to make practitioners aware that most MCDM methods, when solving a complex case, are unable to process all the characteristics of the problem because they are not prepared to deal with complex scenarios, therefore, they model as much as they can, and thus solve a scenario that is only a resemblance of the real one; that is, they are solving a proxy.

This paper is organized as follows: This introduction is followed by Sections 2, 3 and 4 which examine methods and their capacity to solve MCDM problems, not individually but in general; in particular, Section 5 analyses their reliability for scenarios modelling. Section 6 approaches the systematicity of MCDM scenarios, which is a fundamental concept, and examines the need to consider them as systems and not as disconnected data. Finally, in Section 7, a method is suggested, that in greater or lesser degree, can consider all characteristics of a scenario.

MCDM reliability has been investigated by numerous researchers:

Kokaraki et al. (2019) refer to the reliability of MCDM methods, Ergu and Saaty (2015) state "The question is how well does a MCDM method perform and how valid is its ranking and order?", Dhurkari (2022), in RAIRO, writes about difficulties and improvement efforts, Asadabadi et al. (2019) formulate questions about the usefulness of MCDM, while article (www 1) analyzes the strength and weakness of them.

Belton and Stewart (2002), were the first in making known a characteristic that affect all MCDM methods, that is, rank reversal, a topic that has been subsequently addressed by many researchers, and is still without an explanation. Chakraborty et al. (2023) assert that "Therefore, accuracy and reliability of the final decision entirely depend on selection of the most appropriate MCDM tool", that is, the emphasis is on the DM and his/her selection of the best method.

This paper introduces an issue that, as per this author's knowledge, was never considered, and is not related to any of the above cited causes; it is the inability of most MCDM methods to model reality properly. It transpires that development has been aimed at improving uncertainty, which is very important, but no attention is paid to the aspects and demands occurring in real scenarios, which is still more important.

2 MCDM and the decision-maker

An application of MCDM to solve a decision-making problem has three components: the problem, the MCDM method, and the Decision Maker (DM). Let's analyze briefly these three components.

The problem or scenario

The range of types of problems may be very vast for they belong to every step of life. Situations involving personal issues are in general very simple and share a common feature: The consequences of the results, good or bad, fall on their initiators, as in deciding a restaurant for dinner, a car to purchase or a place for vacations; i.e., the consequences revert to the person or persons making the decision. They are based on personal preferences and wishes, whether they are rational or not.

There are very complex projects whose execution affected many people, in the thousands and even millions, such as the construction of large hydro power plants, e.g. Three Gorges in China, or Itaipú in Brazil, where a large number of people was affected, and not even consulted about the project, and that changed their lives forever.

There are very complex and difficult projects such as those related to logistics, with many players, with different interests, possibly related and competing among them, as in the case of selecting suppliers for a variety of products and in each specialty competing among them. A set of very important factors intervene here: time of the year, transportation time, people demand, competition, weather, delays, changes of consumer preferences, etc.

In this category are also projects that are sequentially interlinked, as for instance those in the oil industry, starting with prospection and extraction, transportation, refining, storage and transportation of final products to gas stations, where all of these stages must be coordinated, since the output of one is the input of the next one; for instance, the final products such as gasoline, kerosene, fuel oil, etc., depend on the market, and temporary storage is necessary because of market variations.

Other complex problems are those that occur not in a single but in multiple scenarios such as the case of multinationals producing alike products simultaneously in several countries.

There is no doubt that no MCDM method exists at the moment that can solve this kind of problems or others, by far less complex ones.

The method

From this point of view there are two approaches: The Prescriptive and the Normative. In the first, usually known as the American School (Lootsma, 1999), the decision is based on the DM's appreciation of the situation. There is not too much rationality, since the individual acts according to his/her intuition. This approach is closely related to psychology; it was pioneered by Saaty (2001) who created the AHP method. The normative approach, usually known as the European School (Lootsma, 1999), VIKOR (Opricovi, 1990) TOPSIS, (Hwang and Yoon, 1981), is the opposite. It relies on facts, rational thinking and research. Most MCDMs follow the European School, pioneered by Roy (1968), creator of the ELECTRE method.

There is a third approach that, to this author's knowledge, was the basis for MCDM, and it is Linear Programming, or Mathematical Programming, created by Kantorovich (1939), and with strong resemblances to the European School. It is the most mathematical and rational of all methods and the only one that can give optimal results, from the Pareto point of view.

This method, whose calculations are rather complex, was significantly improved with the work of Dantzig (1951) that made it possible to be solved by the Simplex algorithm. It is most likely the best approach to both simple and complex scenarios. One of its advantages is that since 1993 it is an Excel add-on and thus can be freely used. As per this author judgment, this method allows for modelling of very complex scenarios, although it also has its drawbacks, since it is mono-objective, instead of being multi objective, a feature that restricted its use to very large projects, such as those in the steel, pulp and paper, oil industries, etc. This is nevertheless a method that solves this problem; see Section 7.

The decision-maker (DM)

Without a doubt the most important member of the trilogy (project, method, decision). He/she is responsible for:

1. Contacting the interested parties and stakeholders, requesting information on number, type and characteristics of alternatives, and extracting from them information about aspects they think must be considered, their needs and expectations, as well as their reasoning. The DM only takes notice of all these aspects because, among other things, he/she is not qualified to challenge the person responsible for each area of the project he/she is related to.

   The DM must consider all of them but without taking sides, since this is not his/her function. He/she must only register what the interested parties want and translate their requests into the initial decision matrix. It is usual, for instance, for the financial manager to oppose to increments requested by the production manager when asking for funds to buy new equipment. Both defend their positions, and it is for the DM to register them, and for the method to find a compromise.

2. Determining on the basis of questions and consultations with stakeholders, the criteria in number and in concept, verifying them with the stakeholders and taking account of their suggestions and demands, which may include adding or deleting criteria. When doing this, the DM obtains the performance values, i.e., the quantities which each alternative contributes to each criterion. In case of subjective criteria, the DM needs to perform surveys to gauge people's opinions about each project.
3. Building, using this information, the initial decision matrix. This action should be independent of the number of alternatives and criteria. The number of criteria must never be a limit in a method, because it would amount to conditioning reality on an algorithm. Since the number and type of different options or alternatives comes from the high levels of the organization, the DM is usually in no position to challenge them. Again, this is not his/her function.

   With all this data the DM is ready to select the MCDM method to use. The selection is rather simple, since it is a matter of choosing the method that best satisfies the characteristics of the problem. Munier and Hontoria (2021) provide a simple procedure to perform this selection, starting with the problem conditions, and that automatically indicates the different MCDM methods that can handle the sum of determined characteristics of the scenario. It is simply based on choosing the method that satisfies the maximum number of criteria.
4. Analysing it, once a method is applied and a result obtained, by conducting a sensitivity analysis and considering aspects which are usually external to the scenario which have not been taken into account.

   For instance, if the best alternative is dependent of five different criteria, the DM should investigate the historical performance of these external factors that can influence them. Such external factors may be international export prices of a product, competition, government policies, etc.

   It may happen, too, that the DM obtains the best project and then has to find out other information, if possible. For instance, in the case of selecting a precision machine, this can be the industry's opinion about performance and reliability of this equipment. If not satisfied, the DM can dismiss this alternative and choose the second one. This is the function of the DM.

3 Analysis of methods

All MCDM methods are based on dedicated algorithms with different procedures, assuming various hypothesis, which unfortunately are usually not explained, let alone demonstrated as regards their rationality. Most allow the DM to select a procedure according to his/her own judgement as to the relative importance of criteria, or accepting that trade-offs can be used to determine criteria weights, or they can be based on psychological considerations, or assuming certain thresholds, etc.

There is no surprise that different methods applied to the same problem give different results. According to researchers' consensus, no MCDM method is better that another one, something about which this author disagrees. There are some very good rational methods and others blatantly irrational and defying common sense.

However, this author agrees that a perfect method does not exist; all of them have drawbacks in one sense or another, and in his opinion, this is due to the magnitude of these downsides. There is a set of very well-known methods that are chosen by the largest number of researchers and practitioners, and there are reasons for that. For instance, AHP (Saaty, 2001), is extensively used, as well as PROMETHEE (Brans et al., 1986), ELECTRE (Roy, 1968), TOPSIS (Hwang and Yoon, 1981) and VIKOR (Opricovic, 1990). Fuzzy logic (Zadeh, 1965) is also very popular, although the latter is used to decrease uncertainty. Methods using the Simplex algorithm (Dantzig, 1951) and SIMUS (Munier, 2011), are used for very complex scenarios, and are probably the only ones that can treat them. This assertion is largely commented and documented in Section 7.

MCDM is a complex procedure that may include hundreds of different alternatives or variables, a similar number of subjective and objective criteria, usually with unequal relative importance, in different units. Since they are objectives, they have goals or targets established by the DM, and related to the nature of the scenario, social issues, economics, financial, engineering, environmental and sustainable issues.

The object of a method is to find the alternative that best complies with the criteria. That is, it tries to find the common space determined by a certain number of criteria, where all feasible solutions of the problem reside, and selects the best solution. It is a formidable problem, and there is no mathematical formula that gives the result, as is the case in many engineering problems.

The consequence of this difficulty is that in MCDM one gets results that cannot be compared to the actual situation. For instance, a common road engineering problem is to determine the number of vehicles passing per hour on a certain route between two cities. The gravity model (Crymble et al., 2017) can be used to determine this traffic analytically. Its formula specifies that traffic is directly proportional to the population between the two cities, and inversely proportional to the distance, and is affected by a coefficient expressing importance, which must be estimated.

Usually, this metric is obtained experimentally using sensors embedded in the pavement that register the passing of each vehicle. Consequently, it is feasible to calibrate the importance of the distance in the gravity formula until it gives similar results as the physical measures do. However, it is not possible to replicate this procedure in MCDM, because there is no yardstick to compare the analytical results. Apparently, this simple reasoning is not applied in MCDM practice, where it is quite normal to read a paper in a journal that asserts that the method gives optimal results, something that, as explained, nobody knows.

In addition, using the word 'optimal' is incorrect, since in multicriteria problems there exist opposite criteria, such as benefits and costs. It is evident that it is not possible to optimize them at the same time; it is one or the other, but not both. What all MCDM methods do is to find a logical solution, a balance, a compromise among all intervening factors. From the above, it is evident that there are drawbacks in all MCDM methods. Lack of knowledge among practitioners about the potentials and limitations of each method, as well as about the real essence of the MCDM methods, is also evident.

For instance, AHP is the best known and widely used method; its creator, Saaty (1970), clearly specified that criteria must be independent. This author read hundreds of published papers and found that it is almost a constant that in those dealing with problems solved by AHP, this independency is blatantly ignored. Therefore, we cannot blame the method, but its users.

4 Are MCDM methods capable of solving a real problem?

The answer is related to modelling capacity. It means that for solving a problem a method must be able to mathematically model it with enough completeness, i.e., considering as much as possible all its characteristics. According to some researchers, selecting a method is an MCDM problem by itself. This is an opinion not shared by this author, because in usual problems there are a lot of uncertainties, while selecting an MCDM method is simply a question of choosing the one that best models a scenario and discarding the others. For instance, in a scenario with independent criteria – something easily checked – certain methods cannot be used, which is the main reason for not considering them. If, in addition, some alternatives are exclusive and other inclusive, the DM must find the MCDM method that can handle it. Usually, this condition demands a matrix with binary performance factors, as well as integers. This circumstance greatly reduces the number of MCDM methods available.

If there is also a requirement of precedence between alternatives, the DM must look for the method that can also consider this characteristic.

Obviously, if all these conditions are added, the list of possible methods will be very short, if not empty, and the DM may end up with only one or two of them.

Mathematical modelling involves many different aspects such as project conditions and demands, alternatives and their values, acceptance by people, criteria to judge alternatives, environment regulations, health policies, economics limits, etc. If they are not included in the initial matrix, it is not representing the given problem, but something different.

5 Are present-day MCDM methods reliable?

In this author's opinion present-day methods are not reliable, due to the following reasons:

1. They are too limited in simulating reality, except for the usual issues of maximizing benefits, minimizing costs and minimizing environment damage, and ignoring vital characteristics, for instance, time. As an example, in a portfolio of projects, usually not all of them start and finish at the same time, and even for the same project performance values vary with time. That is, in MCDM methods different times and periods are not accounted for, and thus, these methods are static, which is totally unrealistic.
2. Many methods ignore resources and their availability, as well as established limits, goals or targets. For instance, many do not put a maximum limit for investment, or they don't take it into account that there is a minimum cost, or environmental limits that must be preserved, such as maximum allowable contamination by SOx established by national and international authorities. They assume that all values can be either infinite, as in case of maximizing, or zero, as in the minimizing one. As an example of the latter, when minimizing environmental contamination of CO_2, it is assumed that it must be zero, which is usually unrealistic, since even the sheer act of human and animal breathing generates this gas. That is, they set arbitrary numbers without considering reality.
3. Some scenarios require that a criterion or all criteria be maximized and minimized simultaneously, that is, that the same criterion refers to two different targets. As an example, assume that in a manufacturing plant production lines receive stored parts from the warehouse. For economic reasons, they process as many parts as they can, but to insure continuity of production they must fix a minimum or reorder point for suppliers external to the plant. Consequently, the highest value indicates the number of parts to be stored, while the lowest one warns about the reordering time. This is the system used in supermarkets. More details can be found in Section 6, under 'duality'.
4. In some scenarios, it may be necessary to maximize and minimize the same criterion. For instance, water consumption in households must be less than a maximum allowable, and at the same time, no less that a minimum required.

   The former is set with the objective of avoiding waste and responding to economic and water capacity requirements in water management problems; the latter, as a limit fixed by the World Health Organization, for instance, and is due to health reasons. This is a common occurrence in construction problems, not only for water, but also for gas, electricity, sewage, etc.
5. Solving problems with MCDM involves working with systems. A system demands that, in general, everything be directly or indirectly related. Conse-

quently, it is incorrect to partition a project, solve each part separately and then add up results; this is against Systems Theory. Such procedure, however, is heralded as an advantage by some MCDM methods. As an example, in the factory plan for the production of a new car, the engine cannot be designed independently of the aerodynamics of the vehicle, the size of the tires, the transmission, the battery, the fuel consumption, etc., all must agree and be in a certain proportion. The same holds for MCDM methods.

6. Most methods tend to agree more with theory than with real-life facts. For instance, assuming that real-life processes are transitive or consistent, simply because the method's structure demands transitivity of values. They tend to subordinate life to a dubious mathematical assumption, which is obviously illogical. Real-life cannot be subordinated to our convenience.
7. Exercising assumptions without any mathematical support. For instance, using subjective weights to evaluate alternatives, when in fact, weights have been estimated independently of alternatives, and are computed to compare criteria. They assume, without any support, that weights are equal or equivalent to trade-offs, which have a very different meaning and use.

   Or deciding that there is compensation, i.e., that losses or gains in one criterion can be compensated by gains or losses in another one. This is irrational, for it is applied to criteria that can be completely unrelated, as in the case of comparing bus fuel consumption with government regulations in importing potatoes.
8. It may happen that a DM decides on a project ignoring the opinions of thousands of people who will be affected by it, violating Arrow's Impossibility Theorem. The construction of large hydropower dams is a good example: thousands of people are displaced to make room for the lake, without any consultations. This example supports Arrow's point of view because it says that this procedure amounts to dictatorship. Nobody can vote for other people.
9. The use of pair-wise comparisons, where two criteria are compared and assigned a numerical value of preference, based only on intuition. What is worse, very highly subjective aspects, such as love and tenderness, are given a value of preference, as if it were possible.

   In addition, there are projects with a set of criteria that pertain to different activities such as economics, environment, public health, government regulations. Is it supposed that the DM is an expert in all of them so that he/she is able to make comparisons? Even if there are available experts in each field, how can a teacher, very knowledgeable in education issues, discuss with an expert in international commerce or with another in forestry? In each case one expert knows nothing about another one, therefore one wonders how they can reach an agreement. It is a completely inconsistent system.

10. Modifying actual values directly or indirectly by using subjective weights. The alteration of performance values by their multiplication by subjective weights alters the original relationships between criteria, without any justification or benefit.

    Of course, the DM's experience and know-how is valuable and must be considered, but this should not be done by modifying arbitrarily real data. His/her experience is needed when evaluating results and suggesting modifications according to his/her experience. These abilities must be applied when results based on actual and original data are obtained.
11. Using fuzzy logic (Zadeh, 1965) to improve dubious values, for instance, by using weights obtained by AHP. This author fails to understand the reasoning of using a sophisticated and valid procedure to improve fictitious values.
12. Results depend on who is doing the analysis. What happens if another person thinks differently? Groups are useful, but since a single result must be reached, the result is usually enforced by other people's opinions, as it happens in the Delphi method. The advantage is that in groups there is, at least, reasoning, analysis and experience.
13. Many methods consider vertical relationships or linear hierarchies between alternatives and criteria, which was pioneered by Saaty in his AHP method. About mid-20th century, the prevalent industrial structure was the top-down one, i.e. one in which orders and decisions flow from the top to lower levels of the organizations, it is based on centuries-old tradition – and this was the reason for the rapid acceptance of the AHP method. In the subsequent decades, companies realized that their rigid top-down structure was no longer efficient, and switched to more sophisticated ones, such as networks. But 50 years later, many MCDM methods still adhere to this structure, in one way or another. Consequently, some MCDM methods use algorithms that do not reflect reality structurally, since information and decisions can flow in any direction.
14. Not considering inclusive or exclusive alternatives. For instance, in the problem of selecting a project involving crossing of a wide river, there could be several alternatives, single or combined, such as constructing a bridge (a), a tunnel (b) or a ferryboat facility (c).

    If only one must be selected, the three alternatives are exclusive. However, there could be that building a tunnel (b) requires also establishing a ferry service (c). That is, both are inclusive, but for whatever reasons the bridge (b) and the ferry services (c) are exclusive, i.e., we have to choose both or the remaining alternative. This information needs to be included in the model; unfortunately, that these requirements cannot be modelled by MCDM methods because none of them, except one or two, can handle a complication of this magnitude or mixing binary and integers values in the same decision matrix.

15. Most methods do not have the means to consider precedence. For instance, consider a City Hall that has a portfolio of several projects on an island, one of them being building a bridge to mainland. It is obvious that the bridge must be selected with priority over other undertakings and has to be included in the final solution. Thus, there is a mandatory precedence that must be indicated in the model, because otherwise it could happen that several construction projects are selected, but there is impossible to bring labor and materials to construct them. This is the type of factual aspects that are usually ignored in many MCDM projects.

    If they are not accounted for by the DM, he/she will be solving a situation that is adjusted to the capacity of the method used. This is the type of problems that are called 'proxy' in this paper, for they are fictitious and suitable only as an exercise.
16. Performing a top-down analysis when it should be a bottom-up one. In the former, data are altered by weights, in the latter, sound algebraic results are analyzed by the DM regarding actual conditions and using the DM's know-how and experience. The DM can modify data or even reject the solution, but he/she can do that because he/she has the support of a solid and realistic mathematical procedure.
17. Not determining to what extent objectives are achieved. For instance, if one objective calls for maximising job generation, and up to a certain value (or target, in number of people), the result must show how close or far from this target is the best alternative. Otherwise, a result is obtained, but there is ignorance about its effectivity. This is not related with sensitivity analysis and the strength of the alternative selected, but with the closeness in which an objective target is attained. This allows the DM to modify this achievement by modifying, in a bottom-up procedure, some values in the decision matrix.

    Obviously, he will be altering some original data, or giving a certain weight to a criterion, but he can do that legitimately because he has a reason, and after an analysis of the result.
18. 'Solving' mathematically a problem without knowing if the problem is feasible. For instance, there is a shortage of investment, and with the available amount it is impossible to build a project. Most methods do not take into account this, and even so, a 'solution' is found.
19. Performing sensitivity analysis based on premises not reflecting reality or good practices. For instance, varying only one arbitrarily chosen criterion and keeping the others constant. This is not reasonable; this is called 'ceteris paribus' in economics and rejected by most economists.
20. A common practice is to solve a problem using different MCDM methods. Once the rankings are known, the DM compares their similarities by performing a cor-

relation analysis. This procedure only says that methods M and P have similar rankings, but that similarity is irrelevant to the determination of the reliability of each method, because no yardstick ranking exists to compare them.

As can be seen, there are many aspects that must be considered. How many MCDM methods comply with them? Out of more that 150, probably only two.

6 The MCDM as a system

As can be seen, "system" is a fundamental concept in MCDM and most of the time it is ignored.

6.1 What is a system?

According to Merriam-Webster Dictionary it is a regularly interacting or interdependent group of items forming a unified whole.

Since an MCDM process is a system consisting of alternatives, criteria, performance values and targets or limits, all its elements must be linked, because usually one of them affects the others. Unfortunately, this is not reflected in most models; quite the opposite, many boast that partitioning is highly beneficial. This partitioning reveals relationships only, which is not very useful, because what is needed is to determine how one of two linked elements affects the other one, not their relative importance.

For instance, assume that it is necessary to select two different equipment pieces for power generation, each producing a different level of CO_2. The cost of each equipment piece constitutes the cost criterion, while the amount of CO_2 produced by each is included in the environmental contamination criterion.

There is obviously a link between the two criteria, cost and contamination; most likely, the lower the cost the higher the contamination. This is quite understandable; however, some methods consider them as independent, that is, they assume that cost and contamination are not related. No mathematical analysis needs to be done to show that this procedure is incorrect; common sense is more than enough to understand it.

As another example of this interaction and dependency, assume that two types of concrete structures have to be built in an earthquake prone area, which are subject to two criteria, such as structure stability and earthquake magnitude. The risk is the product of the probability of earthquake occurrence and the damage or impact it can have. If the probability is high, but the event happens in a desert area, the risk is very low. If the probability is low in a densely populated area, the risk may be very high.

An important issue is to determine the value of the impact that this phenomenon may have on each structure and then combine both, as structural engineers do, not aiming at determining if stability is more important than earthquake impact, which is the main objective of currently used methods. There is a risk, which is the product of a cause-effect relationship, that demands taking appropriate measures, and this is important, while a mere comparison, is irrelevant.

6.2 The pair-wise comparison procedure

The pair-wise comparison, an integral part of many MCDM methods, is an old concept attributable to Benjamin Franklin, and further developed by Thurstone (1927). It is a useful concept, but the problem is how to measure the preference of one material or immaterial factor over another one.

A person can say that from his/her point of view, living in a house is better that living in an apartment, and this is valid, but to assert, for instance, that a house is three times more comfortable or important or preferable than an apartment, is simply fiction. However, this is the comparison procedure used in most MCDM methods.

How is it that new methods appear and many continue to be based on this absurd assumption?

It is logical to say that one thing is preferred over another, we do it every day, but to put a value on this preference is a difficult if not impossible task. In addition, the comparison may be valuable for the person doing the analysis, but perhaps not by another one. It is even less likely that their degrees of preference will coincide.

The use of pair-wise comparisons either for criteria or for alternatives, and their quantification according to personal preferences of the DM, is a highly controversial matter that has been debated by most researchers since the 1980s and continues to be debatable. Many present-day methods, however, use pair-wise comparisons and thus ignore these claims. Progress in the development of new techniques and methods has been achieved, but it addresses mainly the reliability of the performance values, which is very important indeed; unfortunately, none of these methods tackles the above-mentioned issue.

6.3 The use of weights

This is one of the most controversial issues in decision-making. Weights are not irrelevant, because they are needed, since it is evident that not all criteria have the same importance. This importance is nowadays assessed qualitatively or quantitatively using pair-wise comparison; but no method can produce reliable qualitative or subjective weights, due to the fact that in real-life projects decisions are not taken by a person, but usually by a group, with each participant having a different and opposite objective; as may occur, for instance, between financing and production, or between the quality and cost department.

There are also quantitative criteria, such as units to be purchased, price, manpower, water consumption, that are consolidated values, and thus don't have to be assessed. They are also affected by weights that require estimates.

However, the most important aspect is that subjective weights do not participate in the evaluation of alternatives. They are only useful to estimate the relative importance between criteria. Here comes another of the biggest errors in most MCDM methods, since they are used to evaluate alternatives based on usually arbitrary weights. Alternatives must be evaluated by criteria importance which is measured by the distribution or discrimination of the performance values in each criterion, as per Shannon's Theorem (1948), the foundation stone of the present-day Information Theory. His concept of entropy, which measures this distribution, is what determines the importance and weight of each criterion. The lower the entropy, the larger the information content in each criterion and the greater the importance of each one.

Consequently, subjective weights, which are not even that but trade-off values, should not be used in MCDM.

7 The SIMUS method and its capacity to solve problems

Why is this MCDM method singled out from all the other MCDM methods? Because it can handle all the situations mentioned in Section 5. Obviously, this does not mean that it is perfect, it also has drawbacks, but it is important because it allows to model reality to a large extent, although possibly not completely.

The SIMUS method (Sequential Iterative Modelling for Urban Systems) (Munier, 2011), is based on Linear Programming (Kantorovich, 1939), using the Simplex algorithm (Dantzig, 1951). SIMUS works by considering sequentially all criteria as objective functions, and is different in this aspect to LP which works only with a unique objective and, for each one, it reaches an optimal solution, if it exists (for no solution exists if the problem is not feasible).

It employs no weights, and its strength comes from the Linear Programming technique that earned its creator the 1956 Nobel Prize in Economics. The SIMUS process also starts with a matrix and then it maps all values onto a new matrix using the Simplex algorithm as the mapping function.

This new matrix is called ERM (Efficient Results Matrix); performance values in the original matrix are replaced in this new matrix with score values, which result from considering simultaneously all relationships between performance values, resources and restrictions; the set of row scores forms a Pareto optimum. From this efficient matrix SIMUS makes two different calculations.

The first one examines the ERM matrix column by column and computes the weighted sum for each alternative or column; however, the weight corresponds to each alternative, not to each criterion, as is the case in models which follow the weighted sum procedure. The weight is calculated as the ratio between the number of times an alternative gets an optimal score in a criterion, or satisfies it, and the total number of criteria used in the computation, that is, it is a measure of how efficiently an alternative satisfies the criteria set.

The scores are obtained by the Simplex algorithm, and consequently, there is no subjectivity. The rationale of this procedure can be easily understood, since the importance of an alternative is the sum product of its scores and the number of criteria it satisfies.

The second procedure examines the ERM matrix row by row and finds, for each one, the difference between the values of the scores, from the largest to the second-largest, third-largest, etc.; also, from the second-largest to the third--largest, and so on. That is, it finds dominances; then, for each alternative, it determines the sum of the differences and saves them into a square matrix, formed by alternatives, and called PDM (Project Dominant Matrix).

After examining all rows of the ERM, the PDM matrix is complete. Summation of values for each alternative in each row gives the dominant value for each one. Summation of values for each alternative in each column gives the dominated value for each one. The difference between dominant and dominated values for the same alternative provides its score.

The scores from ERM and PDM are logically different, but the rankings resulting from each are identical. That is, starting from a Pareto row efficient matrix, SIMUS arrives at the same ranking using two different methods (Weighted sum and Outranking).

Why can SIMUS address all the aspects mentioned in Section 5? The reason lies in its structure, since SIMUS does not deal with linear equations but with linear inequalities. The former uses equalities (=), and thus, all values are on lines. The latter uses both lines and areas. The symbol (≤) indicates all values below a line, that is, it describes the area limited by that line (from above) and by the x-axis; it is used for maximization. The symbol (≥) indicates all values above a line, that is, it describes the area limited by that line (from below) and by the x-axis; it is used for minimization.

The former is restricted to operations with lines, while the latter deals with areas. A line has many points (different pairs of values in the Cartesian coordinate system), while an inequality describes areas. An inequality allows for representation of many more conditions than a linear equation, and most importantly, it allows for comparisons, precedence, binary values, etc. SIMUS expands this horizon by considering arbitrarily many criteria or areas.

Geometrically, linear equations represents allow to draw conclusions along lines and their intersections, while inequalities allow to draw them from intersecting or overlapping areas. The symbol (≥) (greater or equal than) means that no value below a certain quantity is admitted, while the symbol (≤) (lower or equal than) means that no value greater than a certain quantity is admitted. Together they form an area called a 'polygon', in a two-dimensional space, and a 'polytope' in an *n*-dimensional space, where all feasible solutions of the problem are found.

The two symbols permit to model a large range of characteristics of a problem, compared with the linear equation methods, which are all MCDM methods, except Linear Programming, Goal Programming (Lee, 1972) and SIMUS. Table 1 summarizes some of the different situations that can be addressed, modeled and solved by SIMUS.

Table 1: Different characteristics that may appear in MCDM problems and their modelling

			Activities				
Problem characteristics	Action	Symbol	A	B	C	Resource or limit	Meaning
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
Precedence between alternatives	B precedes C Uses next column symbol	>		B > C			Alternative B must be executed before alternative C
Exclusive alternatives	Uses next column symbol	=	1		1	1	Alternatives A and C are mutually exclusive, meaning that only one of them may be selected
Inclusive alternatives	Uses next column symbol	=	1	1		2	Alternatives A and B are inclusive, meaning than both may be selected
Inclusive alternatives	Uses next column symbol	=	1	1	1	3	The three alternatives must be selected
There is a mix of integers and binary value	Uses next column symbols Minimize	= ≥	1 0.28	 0.23	1 0.17	2 5.69	This is a binary value This is an integer. They can be combined arbitrarily
Maximize for instance benefits	Maximize	≤	12.9	11.21	14.16	42.89	The maximum sum product of performance values and scores must be less or equal to 42.89 (Euros/ Investment)
Minimize for instance manpower	Minimize	≥	12	12	15	39	Minimize the sum product of performance values and scores (Number of personnel) but not less than or equal to 39

Table 1 cont.

1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
Match budget	Equalising	=	40.28	17.36	4.56	756.89	Sum product of performance values and scores must be exactly 756.89 Euros. Invest exactly 756.89 Euros
Duality. The same criterion must be used for max and min	This is used to established a gap between maximums and minimums, as in the case of water for households	≥	142	139	140	155	Sum product of water values for alternatives and scores must be as a minimum 155 litres/person-day
		≤	142	139	140	185	Sum product of water values for alternatives and scores must be as a maximum 185 litres/person-day
Conditions to be met by alternatives	Specifies the minimum number of criteria that each alternative must satisfy	≥	1		1	4	Alternatives A and C must satisfy at least four criteria. See Munier et al. (2019), Section 12.5
Limiting number of alternatives	=		1	1	1	25	A large number of alternatives (e.g. 140), can be reduced to a lower number (e.g. 25). See Munier (2011), Section 8.3.2.3
An alternative is under execution				1		1	If alternative B is being executed and we consider to initiate either A or C, then B must be in the final solution. To indicate this, insert 1 below B and 1 in the resources or limits column. If another alternative is being executed, repeat the procedure and insert 2 in the final column

Table 1 cont.

1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
Alternatives underdetermined			In this case some criteria constitute the best alternative See an example in Munier et al. (2019)				
Selecting predetermined strategies (alternatives) from SWOT			In this case, the strategies determined by SWOT (Strengths Weakness, Opportunities and Threats) are used as alternatives and the values corresponding to different assumptions are used as criteria SIMUS will find the best strategy (see example in Stoilova and Munier, 2021)				
Feasibility			Sometimes a problem is not feasible. While solving it, SIMUS indicates this through a message and by filling solid the criterion that cannot be satisfied				
Conditioning	>			A1 > A2			Suppose that an alternative such as construction of an orange concentrate plant (A2), is subject to the orange plantation project (A1) for supply of oranges. This can be indicated as a precedent of the plantation over the concentrate plant (see example in Munier et al., 2019)
Degree of objectives satisfaction			Simultaneously with the result, there is a very important information for the DM to take into account, namely, the quantitative degree of compliance with each objective goal. If the target is, e.g., 0.89, and the result shows the same value, the target has been 100% reached. Differences in plus or in minus between the objectives results and their targets indicate the efficiency of the selection				

8 Conclusion

This paper postulates that present-day MCDM methods cannot solve complex decision-making problems. As a fact, what is being done these days is to solve proxy scenarios that have some similarity to real-life problems.

To support this assertion, in Section 5 we examined, commented and exemplified briefly the reasons for that. Most of MCDM methods are not suited to tackle the modelling of all the characteristics that are present in real-life scenarios. This author examined hundreds of published papers and about 120 commented in writing and published on the ResearchGate platform and thus, open to discussion to anyone. The paper also enumerates and clarifies 17 characteristics of real-life problems that cannot be modelled by the current MCDM methods. All of these have been solved by this author using SIMUS, and published in papers and books. The conclusion is that new efforts must be done, old concepts reviewed and even eliminated, and new rational notions developed, especially ones pointing out more to real-life applications, than to theoretical developments. Precise mathematical procedures aiming at improving the reliability of the available data should also be developed; this appears to be the most important direction nowadays.

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