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Criteria Uncertainty in Multiple Criteria Decision Analysis of Sustainable Manufacturing Systems

Supervisor: Emanuele Pagone
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ABSTRACT

Multiple Criteria Decision Analysis (MCDA) is a discipline used by decision makers to evaluate conflicting features when choosing among alternatives. MCDA methods are applied in the field of sustainable manufacturing to weigh the importance of traditional criteria when compared to sustainability indicators. However, a recurring issue in MCDA is the uncertainty in the assessments of alternatives.

In this project, a novel framework to deal with uncertainty in MCDA has been developed. It uses scenario planning to get optimistic and pessimistic assessments for the different alternatives. Then, assigning probabilities to the scenarios and applying COPRAS-N, an introduced modification of COPRAS-G, 11 weighted scenarios are calculated. Finally, the relative significance and ranking of each alternative are graphed according to the weighted scenarios so that their evolution and the different situations are represented.

With the presented approach, internal and external uncertainties can be dealt with at the same time. The final decision is made by analysing the graphics and results and, if necessary, looking at the concepts of expected scenario and average performance introduced in this project.

The framework has been applied to 3 case studies with a focus on sustainability found in the literature. The results show that providing a final ranking of alternatives without considering other likely scenarios may lead to wrong decisions. In fact, in Case study 1, the choice of the best alternative would have changed if the developed framework had been applied. Representing all the scenarios has proved to ensure the final decision and enable to evaluate all the possible outcomes, solving in this way the uncertainty.

Keywords:

MCDA, Multiple Criteria Decision Analysis, uncertainty, scenario, probabilities, sustainable manufacturing, sustainability, COPRAS.

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MCDA	Multiple Criteria Decision Analysis
FS	Fuzzy sets
T-2FSs	Type-2 Fuzzy sets
IFSs	Intuitionistic Fuzzy sets
IVIFSs	Interval-valued Intuitionistic Fuzzy sets
HFSs	Hesitant Fuzzy sets
HIVFSs	Hesitant Interval-valued Fuzzy Sets
AHP	Analytical Hierarchy Process
RS	Rough sets
COPRAS	Complex Proportional Assessment
A	Alternative
C	Criterion

1 Introduction

Multiple Criteria Decision Analysis (MCDA) is a discipline used by decision makers to evaluate conflicting features when choosing among alternatives. After assessing alternatives according to a set of criteria, MCDA methods are applied to select the best alternative. MCDA is applied in the area of sustainable manufacturing to weigh the importance of traditional criteria, such as cost or quality, when compared to sustainability indicators, such as environmental impact or recycling capability. However, a recurring problem in MCDA is the uncertainty, which can be present in different stages of the decision making and forms, especially, in the assessment of alternatives. Therefore, dealing accordingly with uncertainty is essential to obtain a meaningful final ranking of alternatives and make the right decision. Otherwise, the final resolution may change and not be the appropriate for the problem presented.

The aim of this project is to develop a novel approach to deal with criteria uncertainty in MCDA, which is intended to be designed, and applied, after reviewing the existing methods. This aim will be accomplished by fulfilling the following objectives:

- Conduct a literature review to know the state of the art of MCDA and the methods used to deal with uncertainty.
- Develop a new method to model and deal with criteria uncertainty in MCDA.
- Apply the developed framework to case studies found in the literature.
- Analyse the results and compare them with those calculated in the papers.
- Evaluate the multi-disciplinary trade-offs in manufacturing systems, with a focus on sustainability.
- Assess the potential and benefits of applying the new framework.

2 Literature review

2.1 Uncertainty in MCDA

In general, uncertainty is understood as something not definitely known, which is subject to doubt or question. Actually, at the time of applying MCDA, uncertainty plays an essential role and the understanding of its types and forms can make a difference. For instance, not always all the data is at the disposal of the decision makers or, when assessing the different alternatives, there is subjectivity and diversity of opinions. Even sometimes stakeholders are not completely sure about their evaluations.

2.2 Types of uncertainty in MCDA

Different classifications of the types of uncertainty in MCDA have been done by the literature. Nonetheless, they are not exclusive but complimentary.

Stewart and Durbach [1] differentiate internal and external uncertainty. Internal uncertainty concerns the model adopted in the decision making and the judgemental inputs. As for external uncertainty, two kinds are specified: uncertainty about environment, which represents issues out of the control of stakeholders that could affect the decision, and uncertainty about related decision areas, which reflects on how the decision is interconnected with others that may be made in a nearby future.

Briggs et al. [2] talks about heterogeneity and stochastic, parameter and model uncertainty. Heterogeneity is referred as the variability that can be attributed to the background of the source, stochasticity encompasses the random variability brought by the decision makers, the parameter uncertainty concerns the error done by estimating, and the structural uncertainty reflects if the criteria and the procedures are appropriately chosen.

Pelissari et al. [3] stand for three types of uncertainty: ambiguity, when data has more than one interpretation; stochasticity, when input data is aleatory because of the doubt brought by stakeholders or the method used to get information (e.g. forecasting); and partial information, where part of the data is not available.

Comparing Pelissari et al. [3] with the previous classification, the concept of stochasticity is shared. On the other hand, the terms partial information and ambiguity are newly added. However, ambiguity, although with a different approach, may coincide with the heterogeneity previously explained owing to they refer to the decision maker.

In conclusion, the classifications made by Briggs et al. [2] and Pelissari et al. [3] are complimentary and share some similarities. Combined, they make a complete and detailed classification within the category of internal uncertainties made by Stewart and Durbach [1], who classify uncertainties from a bigger scope and explain external uncertainties too .

2.3 Methods to deal with uncertainty in MCDA

There are different methods to deal with uncertainty in MCDA. They will be explained in this section and are represented in Figure 2-1.

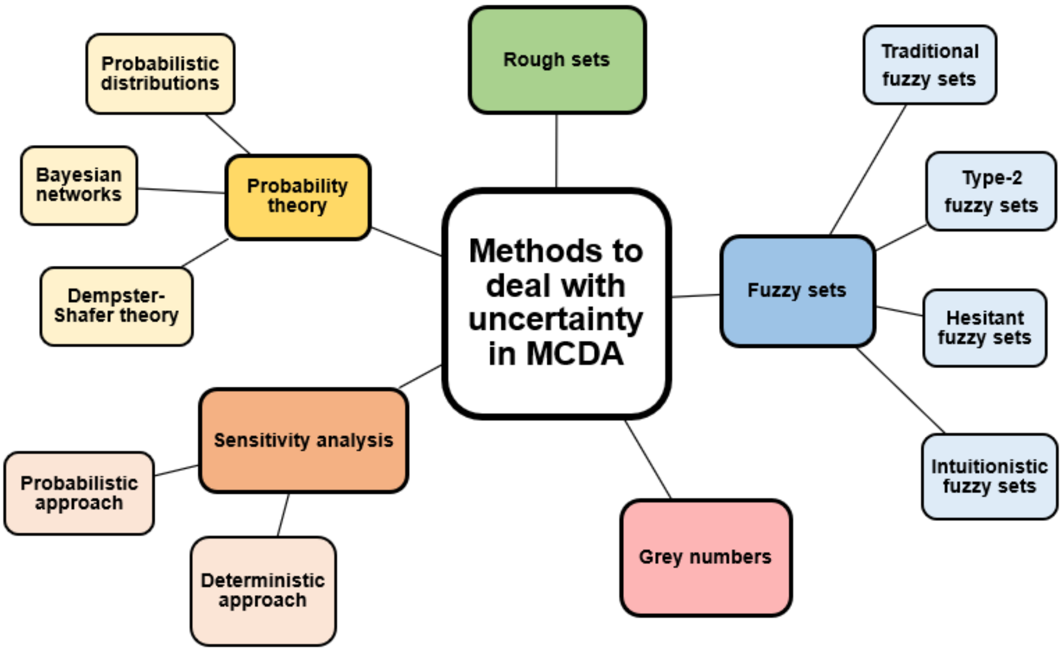

Figure 2-1 Methods to deal with uncertainty in MCDA

2.3.1 Fuzzy sets

The principle of fuzzy sets (FSs) is assigning a degree of membership between 0 (not a member) and 1 (definitely a member) to the alternatives according to the different categories. This theory has evolved into different variations.

2.3.1.1 Traditional Fuzzy sets

It consists of associating a fuzzy number from a defined FS to the evaluations in order to express their degree of membership according to a category [3]. The most used fuzzy numbers are triangular, more common due its simplicity, and trapezoidal. Usually, a fuzzy number is assigned to a linguistic evaluation of a fuzzy scale (from very poor to very good). Then, MCDA methods can be applied to these numbers until getting the final result, which is defuzzied into an ordinary number [4].

2.3.1.2 Type-2 Fuzzy sets

In Type-2 Fuzzy sets (T-2FSs) theory, the degree of membership is given, instead of just a fuzzy number, by a FS [3] made of fuzzy numbers that represent an upper and lower membership function. Thus, T-2FSs are an extension of the previous type, which represents more uncertainty and adds complexity in calculations. For instance, Ilieva [5] used two trapezoidal numbers to represent a range of linguistic terms.

2.3.1.3 Intuitionistic Fuzzy sets

Intuitionistic Fuzzy sets (IFSs) are used in situations in which there is also uncertainty about the degree of membership of an element to a set. In this case, each element is assigned a membership and a nonmembership degree between 0 and 1 according to category and are used in the calculations of a MCDA method [6]. Unlike the previous cases, there is an indeterminacy degree since normally the addition of the membership and nonmembership degrees does not add 1. Evidently, this can be represented either with a fuzzy number or a FS, a variation called Interval-valued Intuitionistic Fuzzy sets (IVIFSs) [3].

2.3.1.4 Hesitant Fuzzy sets

Hesitant Fuzzy sets (HFSs) are characterised by assigning several membership degrees to the elements between 0 and 1, not just one as the traditional theory. They are very useful to join opinions of different decisions makers or to complete missing information [7]. All the same, apart from fuzzy numbers, the memberships degrees may be represented by a FS, what is known as Hesitant Interval-valued Fuzzy Sets (HIVFSs) [3].

2.3.2 Sensitivity analysis

Sensitivity analysis and MCDA can be combined to assess the robustness of the model to the changes in the weights or assessments made by the decision makers when there is uncertainty.

2.3.2.1 Probabilistic approach

These methods incorporate probabilistic distributions in the evaluation of alternatives and criteria weights. Probabilistic distributions can be attributed to uncertain variables in simulations to acquire a range of results, enabling a complete analysis [8]. Additionally, probability-based methods allow to treat results in a statistical manner, like showing the final rank between alternatives in percentage (out of all simulations) or the contribution of each parameter in the final outcome [9]. Probabilistic distributions are usually integrated with MCDA by running a Monte Carlo simulation that generates values from the distributions to use these as inputs to the MCDA method. [3]

2.3.2.2 Deterministic approach

Deterministic sensitivity analysis in MCDA can be classified in simple sensitivity analysis or threshold analysis. In the first one, one model parameter is varied at a time, and the impact of its variation on the ranking of alternatives is observed. If it does not change the ranking, the decision is considered robust with regards to this change and not sensitive [10]. On the contrary, threshold analysis focuses on assessing how much model parameters need to vary before there is a change in the final rank, it can be applied to check how robust is the model when criteria weights are varied and to get the range of values that provide a specific ranking [11].

2.3.3 Rough sets

Rough sets (RSs) can deal with a set of inconsistent data or evaluations. In the RS theory, any set can be represented with the concepts lower and upper approximation. The lower approximation is the set of all objects that can be certainly included, while the upper approximation consists of the elements which cannot be classified with certainty if they belong or not to the defined set, which is linked to the data and attributes present in the MCDA problem. Between the upper and lower approximation there is the boundary, which is formed of the elements that can neither be ruled in nor ruled out of the defined set. Lee et al. [12] grouped individual subjective evaluations using RSs, which were the input of an adapted MCDA method.

2.3.4 Grey theory

In grey theory, numbers can be either black, white, or grey type. Black numbers represent a complete lack of knowledge (their range is from minus infinity to plus infinity), while white numbers represent complete knowledge (no range of numbers). Grey numbers are characterised by a lower bound and an upper bound, that is to say, an interval [10]. The limits of this interval are used in the MCDA calculations to represent optimistic and pessimistic outcomes. Furthermore, both values can be combined to get a result in the middle of this interval using a modified grey MCDA method [13].

2.3.5 Probability theory

Probability is used in many fields and approaches. Nonetheless, there are three main areas with regards to its use in MCDA.

2.3.5.1 Probabilistic distributions

Not always probabilistic distributions are used together with a sensitivity analysis. They can be used independently to represent uncertainty. In fact, combined whit Analytical Hierarchy Process (AHP), one of the most used MCDA methods, pairwise comparations can be done using probabilistic distributions between the criteria and alternatives to get the final weights of the criteria and the ranking of alternatives [14]. In contrast, in traditional AHP, instead of probabilistic distributions, integer numbers are used.

2.3.5.2 Bayesian networks

A Bayesian network is a directed acyclic graph in which the edges indicate conditional dependency and the nodes, variables. Bayesian networks allow decision makers to explicitly model the interdependency of decision-related elements according to the different probabilities that have associated [10]. Bayesian networks have been used to calculate the probabilities, which serve as the input of a MCDA method, of a set of events given the probabilities of their antecedents [15].

2.3.5.3 Evidential reasoning

Dempster–Shafer theory is an evidential reasoning-based method that has been applied combined with MCDA. The method departs from the frame of discernment, a set of hypotheses that may be chosen. The first step consists of assigning a probability mass to the hypotheses according to the criteria. Then, lower and upper boundaries of evidential support, called belief and plausibility, are calculated per hypothesis using Dempster's rule of combination to join scores coming from different sources, if applicable, and form the different criteria. A supplier choice with this method is done by Hua, Gong and Xu to deal with the uncertainty provided by having some missed data.[16]

2.4 Sustainability in MCDA

This project is aimed to deal with uncertainty in the field of sustainable manufacturing. Sustainable manufacturing concerns developing sustainable products considering the whole life cycle. It implements sustainable processes and systems that minimise negative environmental impacts and the consume of materials, energy, and other resources, being safe for all stakeholders while economically beneficial for the society. Also, it involves financial profitability, social equity and environmental integrity. Sustainability should be present in every business operation, encompassing production, design and supply chain, among others. [17]

MCDA and uncertainty methods may be applied in any area but, with the current trend towards sustainability, and the concern for the environment driven by the increasing social awareness and the approval of new regulations, sustainable manufacturing is expected to gain prominence. Actually, among the 17 research areas of the All Science Journal Classification (ASJC), it was found that environmental science, the branch that studies the environment and the solution of their problems, was the third with more publications dealing with uncertainty in MCDA [10]. Furthermore, social and economic sustainability is present in most of the current business decisions.

MCDA methods allow to integrate, compare and weigh traditional and sustainability indicators in the decision making, which is the first step towards sustainable manufacturing.

2.5 Research gap and analysis

In section 2.3, the different strategies to address uncertainty in MCDA have been explained. Generally, the uncertainty is modelled and then a MCDA method is applied to get a ranking of alternatives. All methods presented have been proved to be useful facing uncertainty by different researches. However, their application has to suit the problem studied, the type of uncertainty and the MCDA method used. In fact, they differ in aspects beyond the method itself. For instance, sensitivity analysis and evidential reasoning ask for further analysis once the calculations are done, unlike other methods that provide a fix final ranking. The first ones allow to reason the final decision, while the others does not promote discussion. Therefore, there is not a method that works in every case.

The methods presented have some limitations. When fuzzy or rough sets are used in group decisions, the statements of stakeholders are combined in another set, that could not be representative of their initial judgements or be exclusive for some opinions. Furthermore, making an approached or fuzzy representation, uncertainty is not solved but it continues. Even in the deffuzification step, when a real number is obtained, the result does not guarantee certainty. On the other hand, sensitivity analysis is a work performed that does help in the decision making analysing how sensitive is the problem to changes, but it does not deal directly with uncertainty. Besides, Bayesian networks are based on many calculations that have to be updated continuously based on estimated and not certain probabilities. Furthermore, in the Dempster-Shafer theory, the final result is given in plausibility and belief, variables characterized by being uncertain.

Also, without considering the methods themselves, most of the literature is focused on internal uncertainties such as the subjectivity in the assessments of stakeholders, their disagreements, ambiguity, missing information, etc. External uncertainties tend to be excluded. Thus, a new method to deal with uncertainty that enables a comprehensive analysis and takes into account all types of uncertainties is demanded.

There is no method that encompasses both external uncertainties, which cannot be controlled, and the internal uncertainties previously named. Moreover, there is no need to make a blurry representation of uncertainty because it continues being uncertain. Instead, subjectivity has to be ruled out and the limits of the unknown must be defined. Finally, different likely and plausible options have to be considered when thinking about all possible scenarios around the decision making, owing to the dynamic conditions, constant change and ignorance regarding the future in the areas where MCDA methods are used.

In conclusion, there is a gap that needs to be addressed in uncertainty and MCDA. All possibilities have to be calculated to know the risks and opportunities of a decision, without excluding any assessment in the decision making. Also, in the same model, external and internal uncertainties have to be addressed. Finally, the decision does not need to be made by an MCDA method, the decision makers can select the best alternative analysing the results, reaching in this way a reasoned and supported decision fitted for the context presented. All this will be included within the developed approach explained in section 3.

3 Methodology

Once the research gap was identified after a literature review trough Scopus and Google Scholar, a new method to deal with uncertainty in MCDA was developed. Then, a modification of an existing MCDA method was done allowing it to be integrated with the method developed. The new approach, which used an excel sheet for the calculations, was applied to 3 case studies found in the literature to analyse its potential and compare the results obtained. Finally, an analysis and discussion about the work was done. This process is shown in Figure 3-1.

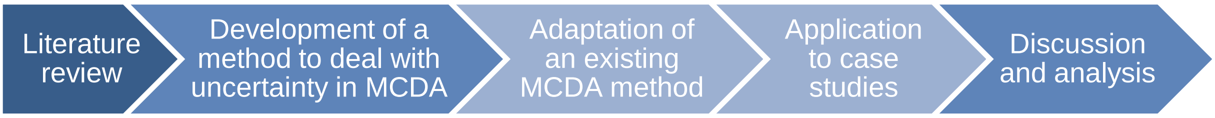

Figure 3-1 Methodology

3.1 Grey scenarios

The method to deal with uncertainty developed uses grey numbers, explained in section 2.3.4, probabilities and introduces scenarios to MCDA. The scenarios describe two situations, optimistic and pessimistic, in which the alternatives are assessed. Then, weighing the scenarios with the use of the probabilities, middle weighted situations between the scenarios are calculated. Finally, external and internal uncertainties are dealt with at the same time owing to the use of intervals and scenarios.

The method developed consists of the next steps:

1. Selection of the criteria and alternatives that will be considered in the model.
2. Study of the problem and identification of the uncertainty.
3. Specification of the certain and fixed assessments and the weights of the criteria.
4. Acknowledge external circumstances that may affect uncertain values.

5. Selection of two plausible scenarios describing a likely future framework. As a result, there will be one scenario more favourable that will encompass the optimistic assessments and another less favourable, which will have the pessimistic values. The variations between the two scenarios may be relevant or just little details, it will be adaptative to the case. Even one scenario may not introduce changes regarding to the present time.
6. Doing a linguistic pairwise comparison between the two scenarios according to their likelihood , definition of the expected final outcome. The expected scenario will be described by two probabilities, which must add 1, assigned to the optimistic and the pessimistic scenario. This probabilities will be the result of the pairwise comparison done making use of Table 3-1. If there is more than one decision maker, the expected scenario will be chosen by ordering the forecasts from more pessimistic to more optimistic and selecting the weighted scenario placed in the middle position (odd number of decision makers). On the contrary, if the number of decision makers was even, the expected scenario would be placed between the two assessments located in the middle positions.

Table 3-1 Pairwise comparison between optimistic and pessimistic scenario

	Likelihood comparison	Prob(o)	Prob (p)
Pessimistic	Complete pessimism	0	1
	Extremely more likely	0,1	0,9
	Strongly more likely	0,2	0,8
	More likely	0,3	0,7
	Moderately more likely	0,4	0,6
Middle point	Equal likelihood / Ignorance	0,5	0,5
Optimistic	Moderately more likely	0,6	0,4
	Strongly more likely	0,7	0,3
	More likely	0,8	0,2
	Extremely more likely	0,9	0,1
	Complete optimism	1	0

7. Assessment of alternatives for the optimistic and pessimistic scenarios. The variables with internal uncertainty will include the worst values in the less favourable scenario and the best ones in the favourable one. For the external uncertainty, the same logic will be applied and the evaluations will be affected by the conditions described in the scenario. Note that, if there is more than one assessment for the alternatives, the worst, for the pessimistic scenario, and the best, for the optimistic one, will be used as the values in these scenarios so that no assessment is excluded. For the certain variables, their values will remain the same in both scenarios.
8. Apply COPRAS-N, further explained in section 3.2, 11 times to get all the weighted scenarios shown in Table 1. Starting by assigning the probability of 1 to the pessimistic scenario and 0 to the optimistic scenario, subsequently 0,1 is subtracted to the probability of the pessimistic scenario and added to the optimistic situation, until getting the last combination where all the probability is assigned to the optimistic framework.
9. After applying COPRAS-N to all the combinations of scenarios, calculate the average relative significance, $\bar{\boldsymbol{Q}}$, and ranking, $\bar{\boldsymbol{R}}$, of each alternative taking into account the results of all the scenarios.
10. Graphical representation of the ranking and relative significance of each alternative according to all combinations of probabilities.
11. Analysis of results and deliberation. The analysis must take into account the expected scenario, the average relative significance and ranking and the evolution of the relative significance of each alternative and its ranking throughout the different weighted scenarios. Finally, the decision making will use personal judgement to assess the risks and certainty for every decision. If there were disagreements, the best alternative in the previously forecasted expected scenario would be elected.

3.2 COPRAS-N

The MCDA method used, which is based on COPRAS-G [18][19] , consists of the following steps:

1. Determining the decision matrix composed by *n* alternatives and *m* criteria. In each position, there will be the values, or assessments, for the optimistic, x^o, and pessimistic, x^p, scenario.

$$X = \begin{bmatrix} [x_{11}] & \cdots & [x_{1m}] \\ \vdots & \ddots & \vdots \\ [x_{n1}] & \cdots & [x_{nm}] \end{bmatrix} = \begin{bmatrix} [x_{11}^p; x_{11}^o] & \cdots & [x_{1m}^p; x_{1m}^o] \\ \vdots & \ddots & \vdots \\ [x_{n1}^p; x_{n1}^o] & \cdots & [x_{nm}^p; x_{nm}^o] \end{bmatrix} \quad \textbf{(3-1)}$$

2. Normalisation of the decision matrix, in which *i* refers to criteria and *j* to alternative. *Prob(o)* and *Prob (p)* represent the probability of the optimistic and pessimistic scenario, respectively.

$$\overline{x_{ji}^o} = \frac{x_{ji}^o}{Prob\ (o) \cdot \sum_{j=1}^{n} x_{ji}^o + Prob(p) \cdot \sum_{j=1}^{n} x_{ji}^p}; \quad \textbf{(3-2)}$$

$$j = 1, n\ and\ i = 1, m$$

$$\overline{x_{ji}^p} = \frac{x_{ji}^p}{Prob\ (o) \cdot \sum_{j=1}^{n} x_{ji}^o + Prob(p) \cdot \sum_{j=1}^{n} x_{ji}^p}; \quad \textbf{(3-3)}$$

$$j = 1, n\ and\ i = 1, m$$

$$\bar{X} = \begin{bmatrix} [\overline{x_{11}^p}; \overline{x_{11}^o}] & \cdots & [\overline{x_{1m}^p}; \overline{x_{1m}^o}] \\ \vdots & \ddots & \vdots \\ [\overline{x_{n1}^p}; \overline{x_{n1}^o}] & \cdots & [\overline{x_{nm}^p}; \overline{x_{nm}^o}] \end{bmatrix} \quad \textbf{(3-4)}$$

3. Calculation of the weighted decision matrix.

$$[\hat{x}_{ji}^{p}; \hat{x}_{ji}^{o}] = [\overline{x_{ji}^{p}}; \overline{x_{ji}^{o}}] \cdot w_i;\ j = 1, n\ and\ i = 1, m \tag{3-5}$$

$$\hat{X} = \begin{bmatrix} [\widehat{x_{11}}] & \cdots & [\widehat{x_{1m}}] \\ \vdots & \ddots & \vdots \\ [\widehat{x_{n1}}] & \cdots & [\widehat{x_{nm}}] \end{bmatrix} = \begin{bmatrix} [\hat{x}_{11}^{p}; \hat{x}_{11}^{o}] & \cdots & [\hat{x}_{1m}^{p}; \hat{x}_{1m}^{o}] \\ \vdots & \ddots & \vdots \\ [\hat{x}_{n1}^{p}; \hat{x}_{n1}^{o}] & \cdots & [\hat{x}_{nm}^{p}; \hat{x}_{nm}^{o}] \end{bmatrix} \tag{3-6}$$

4. For each alternative, sum the attributes of criteria which are intended to be maximised, *k* in total.

$$B_j = Prob\ (o) \cdot \sum_{i=1}^{k} x_{ji}^{o} + Prob(p) \cdot \sum_{i=1}^{k} x_{ji}^{p};\ j = 1, n \tag{3-7}$$

5. For each alternative, sum the attributes of criteria which are intended to be minimised, *k* minus *m*.

$$C_j = Prob\ (o) \cdot \sum_{i=k+1}^{m} x_{ji}^{o} + Prob(p) \cdot \sum_{i=k+1}^{m} x_{ji}^{p};\ j = 1, n \tag{3-8}$$

6. Calculate the relative significance, or performance score, of each alternative.

$$Q_j = B_j + \frac{\sum_{j=1}^{n} C_j}{C_j \cdot \sum_{j=1}^{n} \frac{1}{C_j}};\ j = 1, n \tag{3-9}$$

If there were no criteria which low values are preferred, this step (6) would be omitted and the relative significance would be equal to B [20] .

4 Results

The method has been applied to 3 case studies related with sustainability. Their raw data will be adapted to fit the developed framework and the upper and lower values will be used as they were the consequence of planning an optimistic and pessimistic scenario. All the assessments, criteria and figures of relative significance and ranking for each case study are displayed in this section. In the Appendices, tables with the results of the relative significances and rankings are provided for each weighted scenario and Case study.

4.1 Case study 1

In Case study 1, An Exploratory Analysis for the Selection and Implementation of Advanced Manufacturing Technology [21], 5 different alternatives (A) are evaluated according to 5 criteria (C) by three evaluators, whose linguistic assessments are translated into fuzzy numbers. For the criteria weights, the evaluations are grouped and the defuzzied value from the fuzzy numbers is used as the weight (Table 4-1). For the assessment of alternatives, to adapt this example to the method presented, the limits of the fuzzy number resulting from grouping the assessments are taken as the evaluations for the pessimistic (Table 4-2) and optimistic (Table 4-3) scenario. The criteria of the case study are:

- C1: Yield rate
- C2: Quickness of delivery
- C3:Volume flexibility
- C4: Environmental cognitive hazards
- C5: Dissemination of material

Table 4-1 Criteria - Case study 1

	C1	C2	C3	C4	C5
Weight	0.188	0.209	0.188	0.250	0.165
Optimisation direction	MAX	MAX	MAX	MIN	MIN

Table 4-2 Pessimistic values - Case study 1

	C1	C2	C3	C4	C5
A1	6.33	4.33	7	7.67	6.33
A2	5	9	7.67	8.33	8.33
A3	5	7	6.33	10	9.33
A4	8.33	5.67	7.67	10	6.33
A5	7.67	4.33	7	6.33	10

Table 4-3 Optimistic values - Case study 1

	C1	C2	C3	C4	C5
A1	9.67	8.33	9.67	3.67	2.33
A2	8.67	10	10	4.33	4.33
A3	8.67	9.67	9.67	8.33	5.67
A4	10	9.33	10	9	2.33
A5	10	8.33	9.67	2.33	8.33

The graphical representation of the relative significance and ranking for all the weighted scenarios can be seen in Figure 4-1 and Figure 4-2, respectively. The detailed results for each scenario are shown in Appendix A.

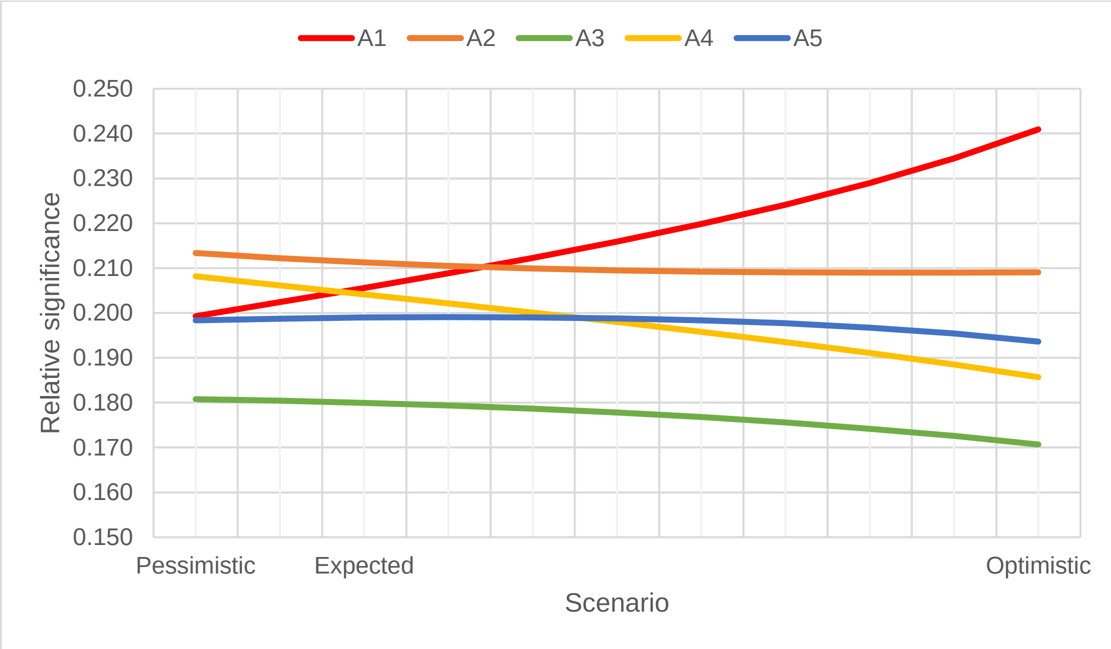

Figure 4-1 Relative significance according to the scenario – Case study 1

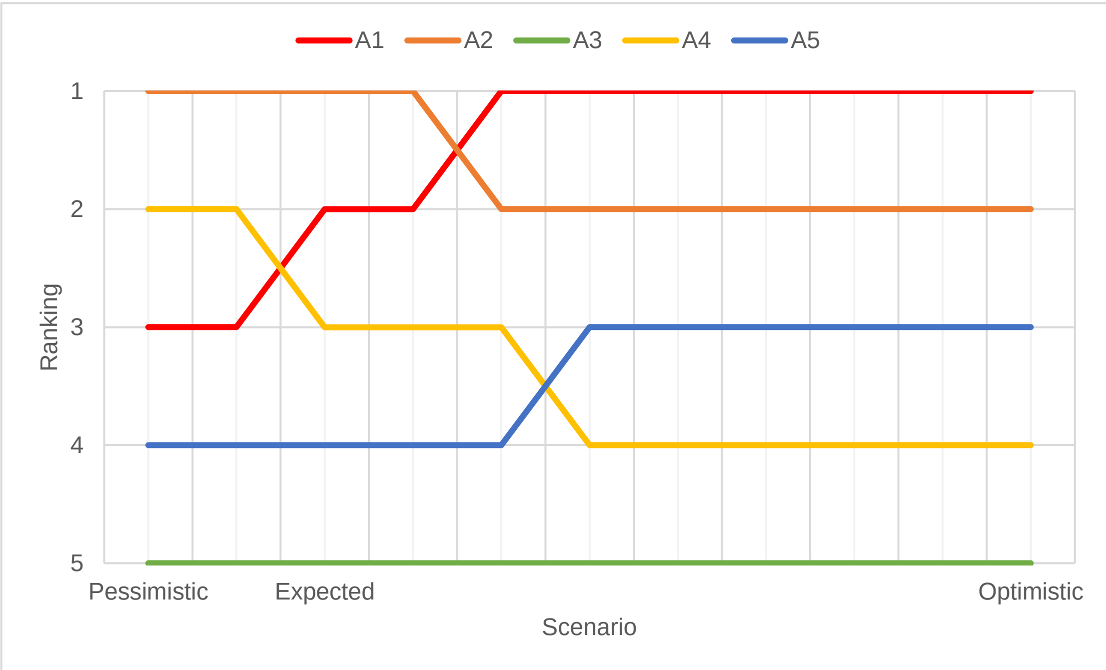

Figure 4-2 Ranking according to the scenario - Case study 1

4.2 Case study 2

Sustainable third-party reverse logistics provider evaluation and selection [22] define a bigger case with a focus on sustainability. It studies a subsidiary of SAIPA, the second car manufacturer in Iran. There are 16 criteria, encompassing environment, social, economic and risk dimensions and 7 candidates to be evaluated by 12 industry experts. Their linguistic assessments are translated into triangular fuzzy numbers. To make the case fit the developed approach, the criteria weights are set getting the centre values of the fuzzy number (Table 4-4). Regarding the evaluations, all the assessments are grouped in another fuzzy number, whose limits are taken as the assessments of the pessimistic and optimistic scenario, shown in Table 4-5 and Table 4-6 respectively, to enable the application of COPRAS-N. The criteria according to the field are:

- Economic criteria:
    - C1: Cost
    - C2: Lead Time
    - C3: Delivery and services
    - C4: Transportation
- Environment criteria:
    - C5: Recycle
    - C6: Disposal
    - C7: Remanufacture and reuse
    - C8: Green technology capability
    - C9: Environment protection certification
    - C10: Eco-design production
- Social criteria:
    - C11: Health and safety
    - C12: Voice of customer
    - C13: Employment stability
- Risk criteria:
    - C14: Operational risk
    - C15: Financial risk

Table 4-4 Criteria - Case study 2

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
Weight	0.165	0.124	0.083	0.055	0.044	0.106	0.053	0.035	0.018	0.014	0.009	0.08	0.053	0.043	0.078	0.039
Optimisation direction	MAX	MIN	MIN	MAX	MAX	MAX	MAX	MAX	MAX	MAX	MAX	MAX	MAX	MAX	MIN	MIN

Table 4-5 Pessimistic values – Case study 2

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
A1	0.2292	0.8542	0.75	0.3333	0.4167	0.4583	0.3542	0.4375	0.25	0.3958	0.5417	0.4792	0.2917	0.3542	0.6458	0.7708
A2	0.2708	0.7708	0.7917	0.2917	0.2083	0.4792	0.3958	0.4167	0.3125	0.2083	0.3125	0.3542	0.3542	0.25	0.8542	0.75
A3	0.2917	0.6667	0.5833	0.2292	0.3125	0.1875	0.1458	0.3125	0.3333	0.375	0.2292	0.2292	0.2917	0.2917	0.6042	0.7292
A4	0.1875	0.7292	0.6042	0.2292	0.1875	0.375	0.2708	0.2917	0.3333	0.2708	0.2708	0.3125	0.1667	0.3542	0.7083	0.7292
A5	0.2917	0.7917	0.625	0.125	0.1875	0.1458	0.3333	0.1042	0.2083	0.1458	0.2292	0.1458	0.1875	0.2292	0.75	0.625
A6	0.3333	0.7917	0.8333	0.25	0.2708	0.2708	0.2708	0.2292	0.3958	0.1975	0.2083	0.2292	0.1667	0.3125	0.5625	0.8125
A7	0.2708	0.5833	0.625	0.3125	0.3333	0.2917	0.1875	0.3333	0.25	0.3125	0.1875	0.3958	0.3542	0.3125	0.5625	0.5

Table 4-6 Optimistic values - Case study 2

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
A1	0.5417	0.4375	0.3958	0.7083	0.7917	0.8333	0.6875	0.8333	0.7083	0.7292	0.9375	0.8542	0.6667	0.75	0.2708	0.3542
A2	0.7083	0.3125	0.4167	0.75	0.6042	0.8958	0.7708	0.8333	0.7083	0.667	0.7917	0.7083	0.75	0.6667	0.4167	0.3542
A3	0.7083	0.2292	0.1875	0.6458	0.75	0.6042	0.5208	0.6458	0.75	0.75	0.6458	0.6667	0.6875	0.7292	0.2083	0.2917
A4	0.5833	0.25	0.2292	0.6667	0.5417	0.8333	0.7292	0.6875	0.8125	0.625	0.625	0.7292	0.6042	0.77	0.2917	0.25
A5	0.7083	0.3542	0.2083	0.5417	0.5625	0.5833	0.7708	0.5417	0.6458	0.5833	0.6875	0.6042	0.5833	0.5833	0.3542	0.2083
A6	0.7292	0.3542	0.4375	0.6875	0.6667	0.6875	0.7708	0.6458	0.7708	0.625	0.66458	0.7083	0.625	0.75	0.1458	0.4375
A7	0.6042	0.125	0.25	0.7083	0.75	0.7083	0.5625	0.7083	0.5833	0.75	0.6458	0.8125	0.75	0.6667	0.1875	0.125

The graphical representation of the relative significance and ranking for all the weighted scenarios is displayed in Figure 4-3 and Figure 4-4, respectively. The detailed results for each situation are shown in Appendix B with the use of tables.

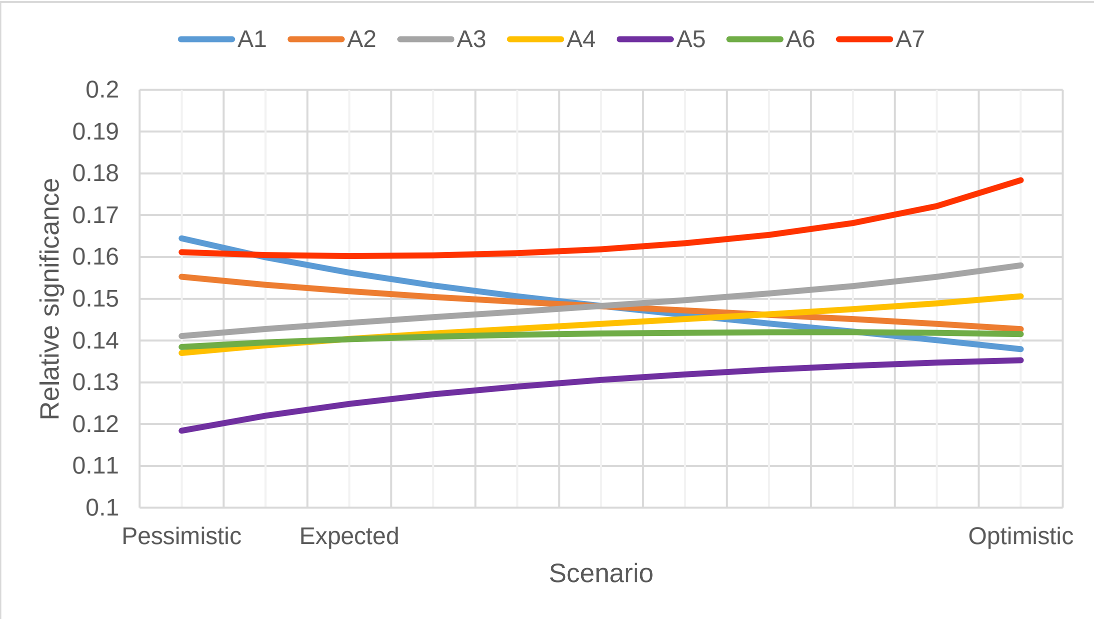

Figure 4-3 Relative significance according to the scenario – Case study 2

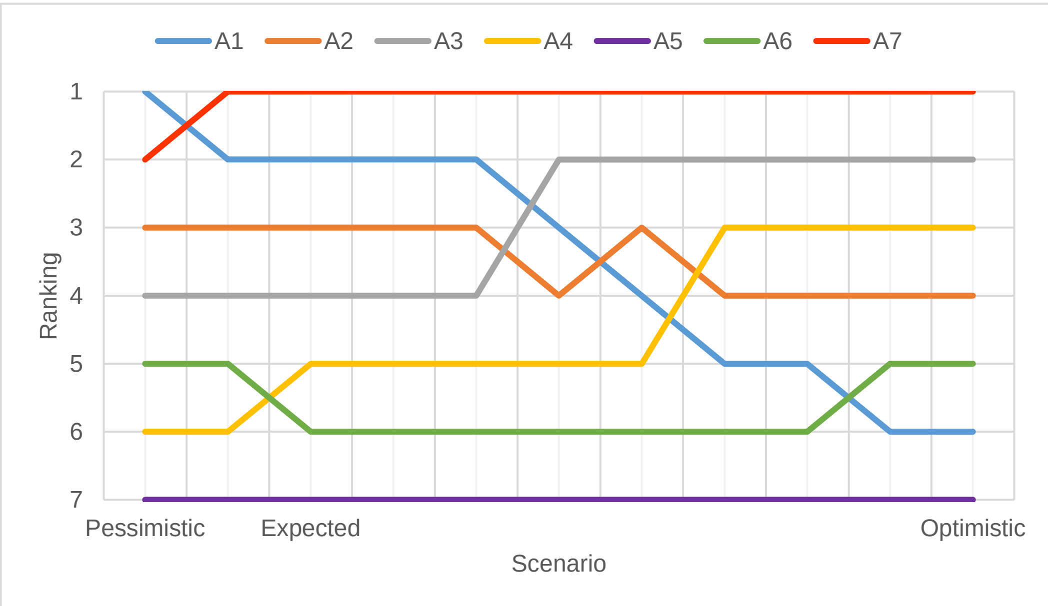

Figure 4-4 Ranking according to the scenario – Case study 2

4.3 Case study 3

Effective green supply chain management practices are evaluated for a Moroccan corporation of chemical industry with the aim of directing the manufacturing strategy towards a sustainable development [23] . The linguistic assessments of the decision makers are translated into triangular fuzzy numbers. For the weights, they use a fuzzy AHP to obtain the values. For the assessments, the limits of the grouped fuzzy numbers in the paper are taken as the pessimistic (Table 4-8) and optimistic (Table 4-9) values, so that COPRAS-N can be applied. 10 alternatives are evaluated according to the criteria specified in Table 4-7, which encompasses economic, environmental and organizational areas:

- Organizational criteria:
    - C1: Lack of Human resources
    - C2: Lack of technological infrastructure and technical expertise
    - C3: Lack of proper organizational structure to create and share knowledge
    - C4: Increase in productivity
- Economic criteria:
    - C5: Decrease costs of material purchasing and energy consumption
    - C6: Increase firm's competitiveness
    - C7: Increase in profitability
- Environment criteria:
    - C8: Improvement in environmental quality of products/processes
    - C9: Reduction in air emissions, liquid and solid wastes
    - C10: Decrease in use of harmful/hazardous materials/components

The results of relative significance, represented in Figure 4-5, and ranking, graphed in Figure 4-6, for each of the weighted scenarios are shown in Appendix C.

Table 4-7 Criteria - Case study 3

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
Weight	0.011	0.024	0.052	0.075	0.056	0.059	0.232	0.294	0.138	0.058
Optimisation direction	MAX	MAX	MAX	MAX	MAX	MAX	MAX	MAX	MAX	MAX

Table 4-8 Pessimistic values - Case study 3

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
A1	0.176	0.15	0.176	0.35	0.176	0.35	0.15	0.412	0.176	0.176
A2	0.412	0.35	0.412	0.15	0.176	0.15	0.35	0.176	0.412	0.412
A3	0	0.15	0.176	0.55	0.176	0	0.15	0	0.176	0
A4	0	0.15	0.412	0.15	0.412	0.35	0.15	0.412	0	0
A5	0.412	0	0	0.15	0.176	0.15	0	0	0.176	0.176
A6	0.412	0.15	0.176	0.15	0.412	0.55	0.35	0.176	0.412	0.412
A7	0.176	0	0.176	0.15	0.176	0.15	0	0.412	0.176	0.176
A8	0.176	0.15	0	0.15	0.176	0.15	0.15	0	0.176	0.176
A9	0	0.35	0.176	0.15	0.176	0	0.35	0	0.176	0
A10	0.176	0	0.176	0.15	0.176	0.15	0	0.176	0.176	0.176

Table 4-9 Optimistic values - Case study 3

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
A1	1	0.85	1	1	0.765	0.85	0.65	1	0.765	1
A2	0.765	1	1	0.65	1	1	1	1	1	1
A3	1	0.85	1	0.85	0.529	0.65	0.85	1	1	1
A4	0.765	0.65	1	0.85	1	0.85	0.65	1	0.765	1
A5	1	0.45	1	0.85	1	0.65	0.85	0.765	1	1
A6	1	1	0.765	0.85	1	1	1	1	1	1
A7	1	0.85	0.765	1	1	0.85	1	1	1	1
A8	1	0.65	1	0.65	1	0.85	0.65	1	1	1
A9	1	0.85	1	1	0.765	0.65	1	1	1	1
A10	0.765	0.45	1	0.85	1	0.85	0.65	1	1	1

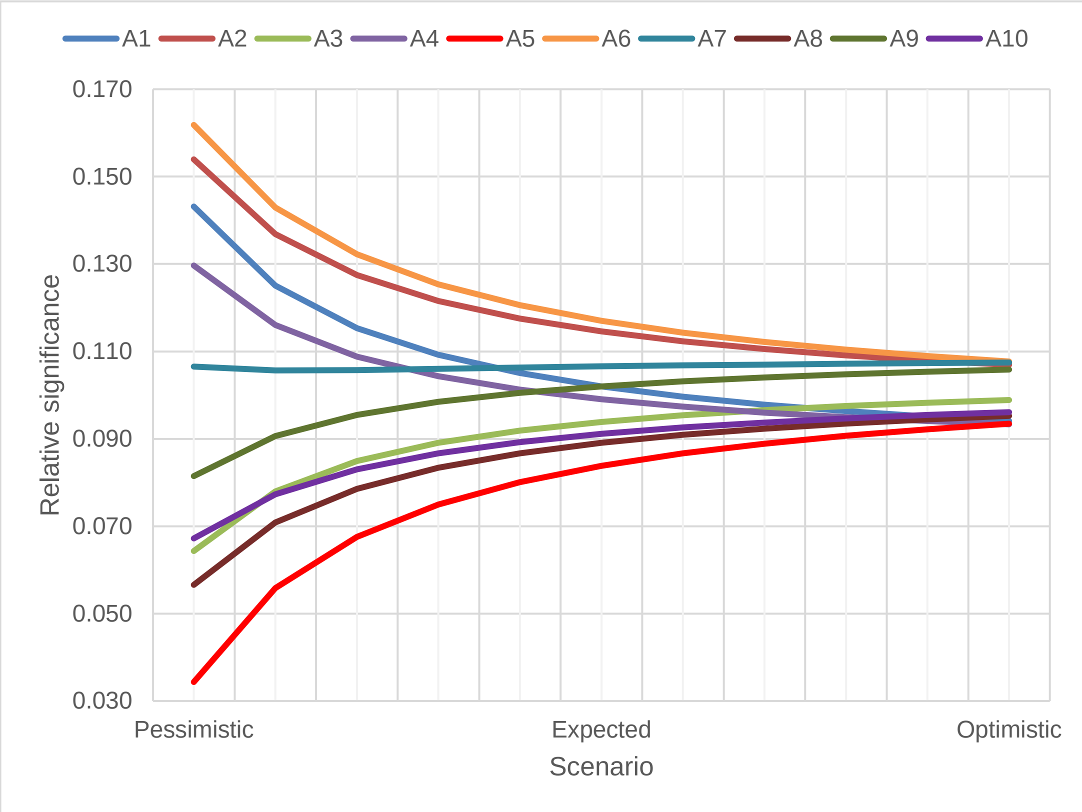

Figure 4-5 Relative significance according to the scenario – Case study 3

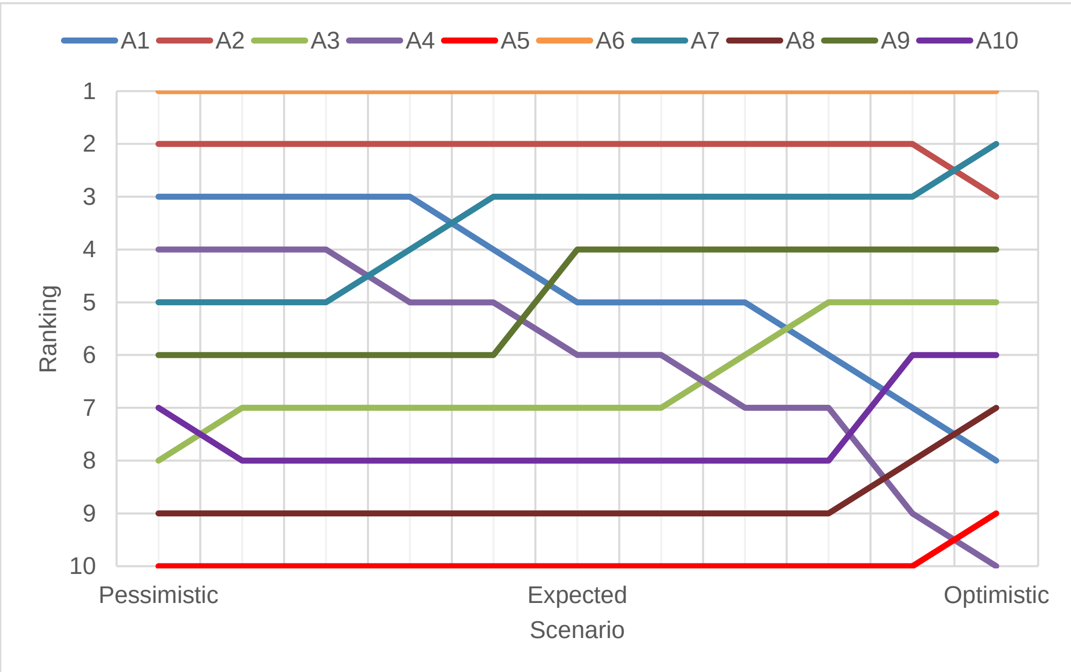

Figure 4-6 Ranking according to the scenario – Case study 3

5 Discussion

5.1 Case study 1

In Figure 4-2, the evolution of the different alternatives in the ranking is shown. The ranking when the same probability is assigned to the scenarios does not coincide with the results of COPRAS-G displayed in the paper. After a revision, it is thought that a mistake was committed by the authors using the raw rata. At the normalisation, some values of C5 and C4 are different and it has been checked that they do not derive from the decision matrix, what explains the differences in the results. Apart from that, they confuse the optimisation direction since the 'best' values for the criteria wanted to be minimised, are higher than the 'worst' values.

The ranking when the probabilities are varied is not constant. In particular, the best alternative (A1) using COPRAS-G, although continues being the preferred in the optimistic scenario, turns out to be the third one in the pessimistic scenario. So, it could be said that it is a risky choice. In Figure 4-1, even it can be seen how the relative significance of the A1 in the pessimistic scenario is close to the fourth position. The most stable and safe choice would be the A2, which if an unfavourable situation took place it would be the best alternative, but if an intermediary or optimistic situation occurred it would remain second, already being a good choice. If there were still doubts or disagreements, having set the expected scenario close to a pessimistic scenario beforehand could tip the scales to make the final decision taking the best alternative in the predicted situation, which again is A2.

Having such uncertainty in values represented by an interval and calculating just one case hides other likely situations. Being able to analyse all the possible situations could have meant a switch in the decision, fact that demonstrates how this novel method could make a difference. Furthermore, with regards to sustainability, environmental hazards have been weighted against other traditional criteria, having the highest weight.

5.2 Case study 2

The results when the same probabilities are assigned to the scenarios coincides with the results of the paper, which uses a fuzzy COPRAS. Nevertheless, in this article the authors could not check how robust was this choice to the different scenarios.

The A7 is the best alternative in all the cases except in the pessimistic scenario, as can be observed in Figure 4 4. The A1 should be chosen if the worst situation took place, but studying the evolution of its relative significance (Figure 4 3), it gets lower until be placed in the 6th position in the optimistic scenario. In fact, the relative significance of A7 significantly increases as it gets close to the optimistic case. In this case study there is no doubt that A7 is the choice.

Calculating all the possibilities has guaranteed that A7 is the best alternative, choice that could not have been made with a pessimistic attitude. Therefore, not only the developed method is applicable to the cases where there are remarkable variations in the ranking (Case study 1), but in the cases where there is a clear dominant in the ranking to assure the deliberation. The degree of certainty in a decision is not the same taking the output of a MCDA method than knowing the results for every scenario.

All dimensions of sustainability (social, economic and environmental) have been considered in this case as well as some risk factors. Although some of the criteria, such as cost or employment stability, are not usually linked to sustainability, they define an essential part of it. Without them, it would be impossible to comply with the standards of sustainable manufacturing. All the environment criteria amount to 0,235; being the second field, after the economic one, with more weight, followed by social and risk factors.

5.3 Case study 3

In this case, the choice of an alternative does not discards the others since the alternatives are practices to follow. Instead of selecting one, the strategy would be to apply as many as possible in the long run. Thus, a priority should be established. The average of the results, shown in Table C-1 and Table C-2 of Appendix C, for each alternative is very useful in this context because, assuming that many practices will be applied in the future, it provides the most regular alternative. However, not only the average is considered. Actually, as can be seen in Figure 4-5, there are significant differences among alternatives for the pessimistic assessments, fact that strongly affects the average and present as a consequence of taking into account the whole interval of numbers of the paper.

There would be two clear winning alternatives: A2 and A6. Their average rankings stand out (2.08 and 1). From this point, A7 would be the third choice looking at the expected scenario, set in the middle position, and its stability. Its average relative significance is the same as the A1, but the performance of A1 is very dependent on the scenario and unstable. Once the 3 alternatives are successfully implemented, the company shall acknowledge the scenario in which they are to select those practices which have not been elected yet that perform better in that context.

The results from COPRAS-G, when the same probability is assigned to the scenarios, share some similarities with those calculated in the paper, which uses a Fuzzy TOPSIS. Nevertheless, the position in the ranking of practices (Figure 4-6) are interchanged in the 4th and 5th position. Looking at the relative significance there are bigger differences due to the method used and the already named extreme pessimistic assessments, which are considered 'fuzzy' in the paper but as a part of the assessment in this project, what emphasises the differences.

Not only sustainable criteria are taken into account, but the alternatives themselves are practices towards sustainable manufacturing. The environment and economic criteria absorb most of the weight due to the nature of the case study.

5.4 Grey scenarios

The developed method covers the void previously identified in the literature and may be applied in the cases where the assessments are subject to uncertainty either due to external or internal circumstances. Using it, an assessment influenced by external factors can be associated to the scenarios while a decision maker who is doubtful to give a concise evaluation with certainty can establish the interval of values scoring optimistically and pessimistically an alternative.

It will avoid the spread and well-known answer ‘It depends’, given by those who cannot provide a clear and concise assessment. It is useful in situations where it is difficult to provide a fix value, but not an interval, and when future likely scenarios affect the decision. It has potential in the cases where there could be 2 different scenarios that are not mutually exclusive, enabling a situation between this two extremes.

It shows all the scenarios that may occur and innovates in the decision making. Instead of giving a ranking of alternatives which do not enable discussion, it demands for a comprehensive analysis to reach the final decision. Besides, apart from the ranking, the relative significance of the alternatives is of high importance to reach the final decision too. Finally, the average of results and impartially setting an expected scenario are some complements that support the deliberation in this method.

5.5 COPRAS-N

The COPRAS-N method, which is a generalisation of COPRAS-G, has been created to be applied together with the Grey scenarios method and enable the weighing of scenarios. In fact, its results when the same probability is assigned to the scenarios coincide with those using COPRAS-G. What is more, when the pessimistic and optimistic scenario are calculated (one of them has 0 probability), the calculations are simplified to the conventional COPRAS. Introducing the calculation of the average for each of the weighted scenarios, the result, although may be similar, is more representative than the results from COPRAS-G owing to the calculation of all the situations.

6 Conclusions

A novel framework to deal with uncertainty in MCDA has been successfully developed. It has enabled to address both internal and external uncertainties. The uncertainty in the assessments of decision makers is converted into an interval of numbers where all evaluations are included and whose limits correspond to an optimistic and pessimistic scenario previously designed. Indeed, 9 different situations between these scenarios are graphically represented, instead of just one, due to weighing the scenarios by assigning probabilities.

The method COPRAS-G has been modified into COPRAS-N to weigh the optimistic and pessimistic scenarios. In the presented framework, COPRAS-N is applied 11 times to cover all the situations and provide complete and representative results. The concepts expected scenario and average of results from all the scenarios are introduced to ease the final resolution, if this was not clear or there were disagreements. Actually, if the intention is to get just one ranking as conventional methods do (e.g. COPRAS-G), the average of results from the different scenarios provided by COPRAS-N is more reliable than the single results from the grey approach due to the comprehensive calculations. This fact promotes, either with or without scenario planning, the use of COPRAS-N.

The framework has been applied to 3 case studies enabling an analysis from a bigger scope, where all options between the two scenarios are considered and the risks, robustness, stability and advantages of each alternative can be evaluated. It has shown that a grey or fuzzy approach that does not consider different possible outcomes may result in a wrong decision. Calculating and graphing the ranking and relative significance in the pessimistic, optimistic and weighted scenarios allow to make a decision knowing how an alternative performances and evolutes depending on the situation, ensuring in this way the final choice.

The presented approach innovates in the way of deliberating. It enables discussion and analysis since the decision has to be made by the decision makers, not by the MCDA method, due to the final output is a set of results that demand for interpretation and reasoning. Finally, although COPRAS-N has been used, the adaptation of other grey MCDA approaches will work as well with the method Grey scenarios, but the results may change due to the different mathematical process involved. Likewise, the scenarios might be taken into account when calculating the weights of the criteria.

Sustainable manufacturing involves social, economic and environmental concerns, shown in the 3 cases studied with links to sustainability. They represent the current trend towards sustainable manufacturing, where MCDA will be essential in critical decisions that consider sustainability indicators. Nevertheless, the application of the method goes beyond sustainability and may be used in any field.

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APPENDICES

Appendix A Results Case study 1

Table A-1 Relative significance according to the scenario – Case study 1

Prob(o)	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1	$\bar{Q}$
Prob(p)	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0	
A1	0.199	0.202	0.206	0.209	0.212	0.216	0.220	0.224	0.229	0.234	0.241	0.217
A2	0.213	0.212	0.211	0.211	0.210	0.210	0.209	0.209	0.209	0.209	0.209	0.210
A3	0.181	0.180	0.180	0.179	0.179	0.178	0.177	0.176	0.174	0.173	0.171	0.177
A4	0.208	0.206	0.204	0.202	0.200	0.198	0.196	0.194	0.191	0.188	0.186	0.197
A5	0.198	0.199	0.199	0.199	0.199	0.199	0.198	0.198	0.197	0.195	0.194	0.198

Table A-2 Ranking according to the scenario – Case study 1

Prob(o)	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1	$\bar{R}$
Prob(p)	**1**	**0.9**	**0.8**	**0.7**	**0.6**	**0.5**	**0.4**	**0.3**	**0.2**	**0.1**	**0**	
A1	3	3	2	2	1	1	1	1	1	1	1	1.39
A2	1	1	1	1	2	2	2	2	2	2	2	1.55
A3	5	5	5	5	5	5	5	5	5	5	5	5.00
A4	2	2	3	3	3	4	4	4	4	4	4	3.26
A5	4	4	4	4	4	3	3	3	3	3	3	3.42

Appendix B Results Case study 2

Table B-1 Relative significance according to the scenario – Case study 2

Prob(o) **Prob(p)**	**0** **1**	**0.1** **0.9**	**0.2** **0.8**	**0.3** **0.7**	**0.4** **0.6**	**0.5** **0.5**	**0.6** **0.4**	**0.7** **0.3**	**0.8** **0.2**	**0.9** **0.1**	**1** **0**	$\bar{Q}$
A1	0.164	0.160	0.156	0.153	0.151	0.148	0.146	0.144	0.142	0.140	0.138	0.149
A2	0.155	0.153	0.152	0.150	0.149	0.148	0.147	0.146	0.145	0.144	0.143	0.148
A3	0.141	0.143	0.144	0.146	0.147	0.148	0.150	0.151	0.153	0.155	0.158	0.149
A4	0.137	0.139	0.140	0.142	0.143	0.144	0.145	0.146	0.148	0.149	0.151	0.144
A5	0.118	0.122	0.125	0.127	0.129	0.131	0.132	0.133	0.134	0.135	0.135	0.129
A6	0.138	0.140	0.140	0.141	0.141	0.142	0.142	0.142	0.142	0.142	0.142	0.141
A7	0.161	0.160	0.160	0.160	0.161	0.162	0.163	0.165	0.168	0.172	0.178	0.165

Table B-2 Ranking according to the scenario – Case study 2

Prob(o)	**0**	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**	**1**	$\bar{R}$
Prob(p)	**1**	**0.9**	**0.8**	**0.7**	**0.6**	**0.5**	**0.4**	**0.3**	**0.2**	**0.1**	**0**	
A1	1	2	2	2	2	3	4	5	5	6	6	2.99
A2	3	3	3	3	3	4	3	4	4	4	4	3.42
A3	4	4	4	4	4	2	2	2	2	2	2	2.74
A4	6	6	5	5	5	5	5	3	3	3	3	4.29
A5	7	7	7	7	7	7	7	7	7	7	7	7.00
A6	5	5	6	6	6	6	6	6	6	5	5	5.62
A7	2	1	1	1	1	1	1	1	1	1	1	1.07

Appendix C Results Case study 3

Table C-1 Relative significance according to the scenario – Case study 3

Prob(o)	**0**	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**	**1**	$\bar{Q}$
Prob(p)	**1**	**0.9**	**0.8**	**0.7**	**0.6**	**0.5**	**0.4**	**0.3**	**0.2**	**0.1**	**0**	
A1	0.143	0.125	0.115	0.109	0.105	0.102	0.100	0.098	0.096	0.095	0.094	0.107
A2	0.154	0.137	0.127	0.122	0.118	0.115	0.112	0.111	0.109	0.108	0.107	0.119
A3	0.064	0.078	0.085	0.089	0.092	0.094	0.095	0.097	0.097	0.098	0.099	0.089
A4	0.130	0.116	0.109	0.104	0.101	0.099	0.097	0.096	0.095	0.094	0.093	0.103
A5	0.034	0.056	0.068	0.075	0.080	0.084	0.087	0.089	0.091	0.092	0.093	0.074
A6	0.162	0.143	0.132	0.125	0.121	0.117	0.114	0.112	0.110	0.109	0.108	0.122
A7	0.107	0.106	0.106	0.106	0.106	0.107	0.107	0.107	0.107	0.107	0.107	0.107
A8	0.057	0.071	0.079	0.083	0.087	0.089	0.091	0.092	0.093	0.094	0.095	0.084
A9	0.081	0.091	0.095	0.098	0.100	0.102	0.103	0.104	0.105	0.105	0.106	0.099
A10	0.067	0.077	0.083	0.087	0.089	0.091	0.093	0.094	0.095	0.095	0.096	0.087

Table C-2 Ranking according to the scenario – Case study 3

Prob(o)	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1	$\bar{R}$
Prob(p)	**1**	**0.9**	**0.8**	**0.7**	**0.6**	**0.5**	**0.4**	**0.3**	**0.2**	**0.1**	**0**	
A1	3	3	3	3	4	5	5	5	6	7	8	4.45
A2	2	2	2	2	2	2	2	2	2	2	3	2.08
A3	8	7	7	7	7	7	7	6	5	5	5	6.37
A4	4	4	4	5	5	6	6	7	7	9	10	5.81
A5	10	10	10	10	10	10	10	10	10	10	9	9.90
A6	1	1	1	1	1	1	1	1	1	1	1	1.00
A7	5	5	5	4	3	3	3	3	3	3	2	3.41
A8	9	9	9	9	9	9	9	9	9	8	7	8.70
A9	6	6	6	6	6	4	4	4	4	4	4	4.81
A10	7	8	8	8	8	8	8	8	8	6	6	7.50

Appendix D Meeting notes

D.1 May

Supervision Meeting Notes

Taught ☒ Research ☐

Student Name	Nicolas Fernandez Perez					
Student Number	S340374					
Course	Management and Information Systems					
Supervisor	Emanuele Pagone					
Date of Meeting	06/05/2021					
Meeting by	In person	☒	Telephone	☐	Skype / Webconferencing	☐

Decisions / Actions agreed and by whom
-Prepare a summary of the project with Background, Aim, Objectives, Methods and Keywords. -Develop a detailed work plan schedule. -Get introduced to the project with some literature.

Date of next meeting
12/05/2021

D.2 June

Supervision Meeting Notes

Taught ☒ Research ☐

Student Name	Nicolas Fernandez Perez					
Student Number	S340374					
Course	Management and Information Systems					
Supervisor	Emanuele Pagone					
Date of Meeting	03/06/2021					
Meeting by	In person	☒	Telephone	☐	Skype / Webconferencing	☐

Decisions / Actions agreed and by whom
-Improve the mind map presented. -Research, deeply understand and present the different methods used to deal with uncertainty in MCDA for the next meeting.

Date of next meeting
10/06/2021

D.3 July

Supervision Meeting Notes

Taught ☒ Research ☐

Student Name	Nicolas Fernandez Perez						
Student Number	S340374						
Course	Management and Information Systems						
Supervisor	Emanuele Pagone						
Date of Meeting	01/07/2021						
Meeting by	In person	☐	Telephone	☐	Skype / Webconferencing	☒	

Decisions / Actions agreed and by whom
-Apply COPRAS and its modification to the case presented. -Detail the differences between conventional COPRAS and its developed adaptation to the case of weighed scenarios.

Date of next meeting
08/07/2021

D.4 August

Supervision Meeting Notes

Taught ☒ Research ☐

Student Name	Nicolas Fernandez Perez					
Student Number	S340374					
Course	Management and Information Systems					
Supervisor	Emanuele Pagone					
Date of Meeting	03/08/2021					
Meeting by	In person	☐	Telephone	☐	Skype / Webconferencing	☒

Decisions / Actions agreed and by whom
-Modify the poster according to the feedback. -Seek another case study in the literature applicable to the method. -Continue the writing of the final thesis.

Date of next meeting
10/08/2021

Appendix E CURES – Letter of approval

12 May 2021

Dear Mr Fernandez Perez ,

Reference: CURES/13249/2021
Title: Criteria Uncertainty in Multiple Criteria Decision Analysis of Sustainable Manufacturing Systems

Thank you for your application to the Cranfield University Research Ethics System (CURES).

We are pleased to inform you your CURES application, reference CURES/13249/2021 **has been reviewed. You may now proceed with the research activities you have sought approval for.**

If you have any queries, please contact CURES Support.

We wish you every success with your project.

Regards,

CURES Team