Scaling Issues in MCDM Portfolio Analysis with Additive Aggregation

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Abstract. This paper discusses a typically scaling issue, which can arise in the context of multicriteria (MCDM) portfolio analysis: the portfolio size effect. By analyzing previous application this issue may happen by the impact of an additive aggregation for the standard portfolio construction model. Thus, it has been shown that the scaling issue may arise even when baseline correction procedures are adopted and this paper suggests that additionally to the baseline adjustment, a ratio scale correction may be necessary, depending on the combination of values and constraints considered by the problem.

Keywords: Project portfolio. Portfolio scaling issue. Portfolio size effect. Baseline in portfolio.

1 Introduction

Project portfolio selection problems involve the selection of a set of projects, considering different aspects and taking into account some constraints given by the context, to be undertaken by a company that seeks to optimize the general portfolio value [2].

Optimal portfolios can be readily determined with multi-attribute decision methods that use mathematical programing techniques to construct them [7]. For the decision maker, this simplifies the multi-attribute evaluation task, which has to be performed only on individual items. The number of items is much smaller than the total number of (feasible and efficient) portfolios, and the consequences of individual items might be easier to evaluate. This makes this approach particularly suitable for Decision Support Systems, in the case of portfolio problems [7].

There are plenty of methods from multi-attribute decision making to evaluate the items from a portfolio, such as outranking methods like PROMETHEE [13], Data Envelopment Analysis [5], or additive utility functions [8], that will be the focus of this paper.

In such cases, an additive value function aggregates the projects' attribute-specific performances into an overall project value, and the portfolio value is the sum of those projects' overall values that are included in the portfolio [9]. This method commonly attributes the value of 0, a baseline measurement, to the worst item of a specific criteria analyzed in the portfolio [12].

Clemen and Smith [4] argue that this implicit baseline is often inappropriate and may lead to incorrect recommendations when practitioners assume that not doing a project results in the worst possible score on all attributes. Hence, the authors make some assumption about how to evaluate not doing a project correctly. These baseline corrections have also been examined by Liesiö and Punkka [9].

Even considering the importance of settling an appropriate baseline for the problem, it is extremely necessary to be aware that additive utility functions approach imposes certain requirements on the measurement scales used for the items in a portfolio, which are frequently ignored in existing literature [7] and have considerable impact on the results when they are not taken into account. Also, there are limited computational tools to analyze and specify these issues.

Thus, the purpose of this paper is to make an application adapted from the problem proposed by Clemen and Smith [4] and to show that the major problem it is not to determine a baseline, but perhaps, the scaling issue that exists in additive multicriteria portfolio analysis. Consequently, this paper is not about the baseline specifically and the baseline does not exist in every problem, as explained by [12] and it is not present in this application either.

The numerical application of this research was assessed using a computational tool [3], which makes a MCDM additive portfolio analysis via web for linear intra-criteria value function with sensitivity analysis, using Monte Carlo simulation.

Also, this work is an extension from previous studies mentioned in the text, such as: [1], [6], [7] and [13], which are related to MCDM portfolio analysis in different perspectives and give support for the understanding of the problem presented here.

The paper is structured as follows. Section 2 makes a literature review and some considerations on the baseline problem. Section 3 discusses different scaling issues aspects. In Section 4, a numerical application is presented, and, finally, Section 5 concludes the paper.

2 Literature Review and Considerations on the Baseline Problem

Different papers have discussed about the baseline problem that arose from Clemen and Smith [4] work, who noted that a model of the form

$$\sum_{i=1}^{n} z_i \, v(A_i) \tag{1}$$

where z_i is a binary variable indicating whether item A_i is included in the portfolio ($z_i = 1$ if it is included and $z_i = 0$ if it is not), and $v(A_i)$ is the value of item A_i obtained from the multi-attribute evaluation, implies that the outcome of not performing a project has a utility of zero [4].

In the usual scaling of marginal utility functions, this would mean it is identical to the worst possible outcome. This condition is clearly not always fulfilled, in particular if some attributes refer to negative effects of the items [7]. The authors pointed out that the utility scale should be chosen in a way that zero utility is assigned to the outcome of not doing a project, rather than the worst possible outcome, which implies that some projects have negative marginal utility values indicating that the project worsens outcomes in some attributes [7].

Morton [12] underscore the criticism of the value function of not doing a project by showing it can lead to a rank reversal and provide a measurement theoretic account of the problem, showing that the problem arises from using evaluating projects on an interval scale whereas to guard against such rank reversals, suggesting that the benefits must be measured on at least a ratio scale.

Liesiö and Punkka [9] presented a baseline value specification technique that admit incomplete preference statements and make it possible to model problems where the decision maker would prefer to implement a project with the least preferred performance level in each attribute. They also show how these results can be used to analyze how sensitive project and portfolio decision recommendations are to variations in the baseline value and provide project decision recommendations in a situation where only incomplete information about the baseline value is available.

de Almeida, Vetschera, and Almeida [7] discuss the effects of different utility scales on the results of multi-attribute portfolio problems. They analyze three effects: the portfolio size effect, the baseline effect and consistency across different aggregation sequences. They also show that these three effects have similar causes related to the use of an interval utility scale, which allows for additive transformation of utilities.

In [6] the problem noted by Mavrotas et al. [10] is analyzed. This problem related to PROMETHEE V method for multi-attribute analysis, which fails to include an item in a portfolio if it has a negative net flow with respect to other items. They pointed out that the model formulated by Mavrotas et al. [10] introduces a bias in favor of large portfolios because the PROMETHEE V method is sensitive to scale transformations, so de Almeida and Vetschera [6] propose to use the c-optimal portfolio concept in order to overcome this issue, which has been applied in [1].

Vetschera and Almeida [13] also explore a new formulation of the PROMETHEE V method and develop several alternative approaches based on the concepts of boundary portfolios and *c*-optimal portfolios.

Even considering the importance given by the baseline problem, it is worthwhile to note that the additive utility functions approach imposes certain requirements on the measurement scales used for the items in a portfolio that should not be ignored, given the different results that can arise from the portfolio size effect, as it will be shown in Section 3 and in the numerical adaptation of the paper.

Therefore, this paper suggests that the major problem it is not to define the baseline, but perhaps, to make an adequate scale transformation that it is appropriate for additive multicriteria portfolio analysis. Nevertheless, if there is a baseline problem in multiattribute portfolio analysis, then it is important not to forget to verify scale requirements.

In addition, the scale transformation pointed out by this paper was applied to the same problem proposed by Clemen and Smith [4] but did not present the portfolio size effect, once the combination of values was not favorable for the case. Thus, a number of instances was generated until find the one showed in Section 4, which kept the value structure considered by [4] and taking into account factual data.

Consequently, it is possible to infer that the portfolio size effect does not happen for all the cases and they will depend on the combination of values and constraints considered by the problem analyzed. Additionally, it is always important to examine the existence of the scale problem and, if it does happen, then one should make the necessary changes to adequate the case.

3 Scaling Issues Aspects

A model of the form (1), previously presented, is not invariant to a linear transformation of the value functions [7]. Though, a transformation of scores is sometimes needed with the aim of avoiding to exclude portfolios with a negative net flow [10]. This can easily be shown, as already pointed out in [6], for the PROMETHEE V and can also be applied for the additive model, through replacing the value function $v(.)$ by a function $w(.) = av(.) + b$:

$$max \sum_{i=1}^{n} z_i\, w(A_i) = \sum_{i=1}^{n} z_i\,(av(A_i) + b) = a \sum_{i=1}^{n} z_i\, v(A_i) + bc \qquad (2)$$

where $c = \sum z_i$ is the number of items contained in the portfolio. Depending on the sign of b, a linear transformation of the original value function will thus lead to a different objective function which favors either large portfolios (for $b > 0$) or small portfolios (for $b < 0$). de Almeida, Vetschera, and Almeida [7] denoted this effect as the *portfolio size effect*.

In [13] the concept of c-optimal portfolios is proposed to overcome the portfolio size effect. By adding the constraint $c = \sum z_i$, problem (1) can be solved for portfolios of a given size c. By varying c, different portfolios are obtained, which then can be compared to each other at the portfolio level using any multi-attribute decision method. Nevertheless, for additive models, the portfolio size effect do not exist if $v(A_i)$ is measured on a ratio scale, which has a fixed zero point and to solve the baseline problem, should be identical to the outcome of not including an item in the portfolio [7].

To obtain equivalent evaluations of alternatives, the weights must be rescaled as:

$$q_j = k_j \cdot (\overline{x_j} \,/\, \overline{x_j} - \underline{x_j}) \qquad (3)$$

where $\underline{x_j} = \min_i x_{ij}$ is the worst and $\overline{x_j} = \max_i x_{ij}$ is the best outcome in attribute j. k_j represents the weights used in the original model using an interval scale and q_j the weights to be used for a ratio scale.

To see detailed information about this transformation or other topics on the subject, see [7].

Following numerical application shows that this issue may arise, even if baseline corrections are introduced, as already pointed out by Morton [11].

4 Numerical Application with Baseline Correction

The ideas presented in this paper can be seen in an application, which is an adaptation of the one given by Clemen and Smith [4].

It was considered a portfolio of Information Technology projects, which are evaluated according to three criteria: financial contribution, risk and fit, as shown in Table 1. There are eight projects (A – H) to consider. The attribute financial contribution is measured in dollars. Risk reflects the probability that the project will lead to a marketable product [4] and is classified as: safe (least risky projects), probable (intermediate level) and uncertain (riskiest projects). Fit could be a rough measure of an incremental revenue that the project might generate [4] and is scored on a scale from 1 (worst) to 5 (best). The last column lists the necessary days required for each project, in total there is a limit of 2500 person days. The weights presented in the last line are related to an elicitation procedure based on an interval scale and the scores are already normalized in Table 2.

Table 1. Data for example.

Project	**Financial Contribution**	**Risk**	**Fit**	**Days required**
A	392913	Uncertain	5	700
B	227503	Safe	2	400
C	155012	Probable	3	600
D	136712	Uncertain	3	250
E	441713	Uncertain	5	300
F	382780	Probable	3	350
G	202678	Probable	5	600
H	189295	Safe	1	800
Weights	**0,25**	**0,25**	**0,5**	

Table 2. Data for example with normalized scores for each attribute

Project	Financial Contribution	Risk	Fit	Value Score	Days required	Go?
A	0,84	0	1	0,710	700	1
B	0,30	1	0,25	0,449	400	1
C	0,06	0,5	0,5	0,390	600	0
D	0,00	0	0,5	0,250	250	0
E	1,00	0	1	0,750	300	1
F	0,81	0,5	0,5	0,577	350	1
G	0,22	0,5	1	0,679	600	1
H	0,17	1	0	0,293	800	0
Weights	**0,25**	**0,25**	**0,5**			

Applying the additive model, the results indicate a portfolio with projects A, B, E, F and G, for the interval scale. This solution uses a total of 2350 days, 150 less than the total available.

On the other hand, using a ratio scale with the appropriate new set of weights, leads to another portfolio, in which A is replaced by C and D, and this is the correct solution for the problem, based on a multicriteria portfolio analysis. In this case, the interval scale favors a portfolio with size c = 5, while the ratio scale indicates a portfolio with c = 6. Projects C and D require 150 additional days, available in the limit constraint, compared to project A. Thus, the solution uses a total of 2500 days. Besides, these two projects give additional outcomes for risk and fit criteria when compared to project A. The new results are shown in Table 3 and Table 4 shows the comparison between alternatives A, C and D.

Table 3. Results for a ratio scale

Project	Financial Contribution	Risk	Fit	Value Score	Days required	Go?
A	0,89	0	1	0,766	700	0
B	0,52	1	0,4	0,555	400	1
C	0,35	0,5	0,6	0,507	600	1
D	0,31	0	0,6	0,394	250	1
E	1,00	0	1	0,798	300	1
F	0,87	0,5	0,6	0,658	350	1
G	0,46	0,5	1	0,741	600	1
H	0,43	1	0,2	0,429	800	0
Weights	**0,29**	**0,20**	**0,51**			

Table 4. Comparison between alternatives

Project	Financial Contribution	Risk	Fit	Total Value Score
A	0,89	0	1	0,766
C + D	0,66	0,5	1,2	0,901

The interval scale favors portfolios with fewer alternatives, decreasing artificially the actual value of larger portfolios. This application is realistic and similar to any kind of portfolio related to real application, particularly in the domain of information systems and DSS Web [7].

These results from the numerical application of this paper were easily assessed using a computational tool [3], which makes a MCDM additive portfolio analysis via web for linear intra-criteria value function with sensitivity analysis, using Monte Carlo simulation.

The program is divided into eight parts: the main page of the system; the input data part; a page that shows the consequences matrix, constraints, parameters and weights from the problem; an option to transform or not the input weights, depending on if they were obtained in an elicitation context of ratio scale or interval scale; an option page of not transforming the input weights or an option page when transforming the input weights; the sensitivity analysis part; and, finally, the results from the sensitivity analysis.

A few parts from the program are shown next.

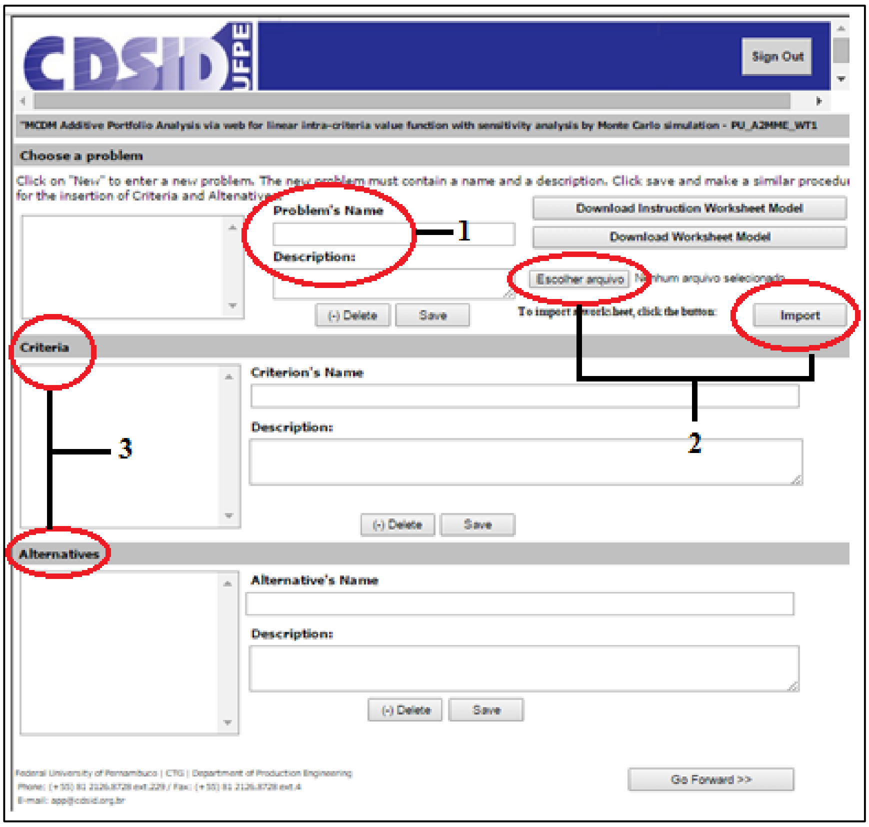

Fig. 1. Input data page.

In the input data page, the user can choose a problem, put its name and make a description (1 from Figure 1) of the problem. It is possible to choose a file and import a worksheet (2 from Figure 1), according to the worksheet model from the system, and there is the description from the criteria and alternatives (3 from Figure 1), that shows up automatically when the worksheet is imported.

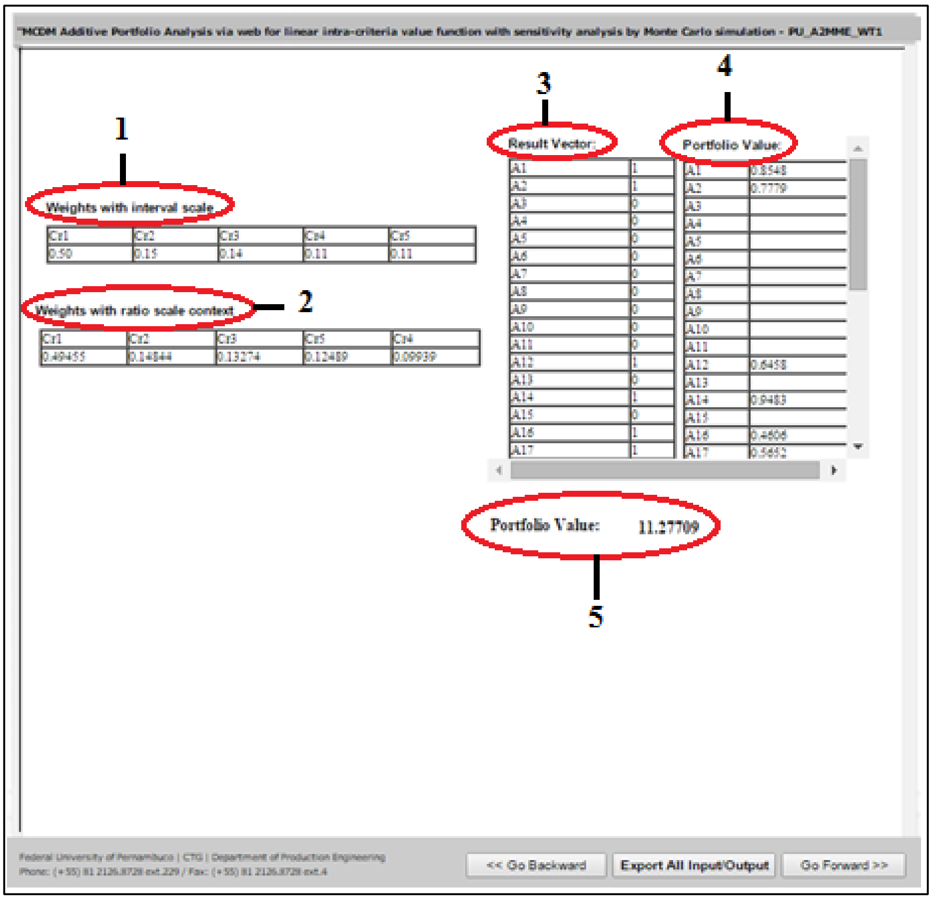

Fig. 2. Option page of transforming the input weights.

The option page of transforming the weights shows a comparison between the weights with interval scale (1 from Figure 2) and the weights obtained with a ratio scale (2 from Figure 2), both of them for each criteria. (3 from Figure 2), (4 from Figure 2), (5 from Figure 2) are the results vector for each alternative, the alternatives portfolio value and the overall portfolio value, respectively.

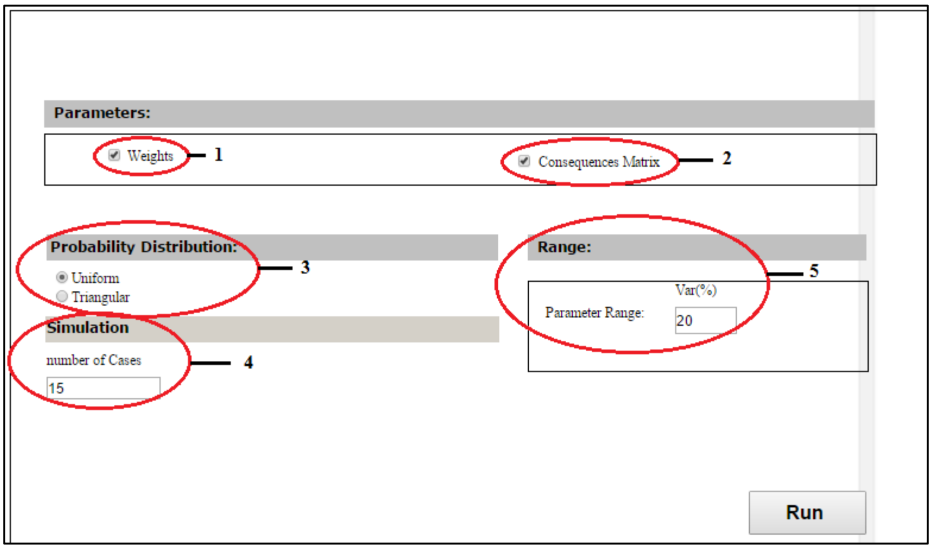

Fig. 3. Sensitivity analysis page

Figure 3 shows the sensitivity analysis page. Here, the user can choose the parameters, weights (1 from Figure 3) and consequences matrix (2 from Figure 3), the probability distribution (3 from Figure 3), uniform or triangular, the number of cases (4 from Figure 3) and the range (5 from Figure 3).

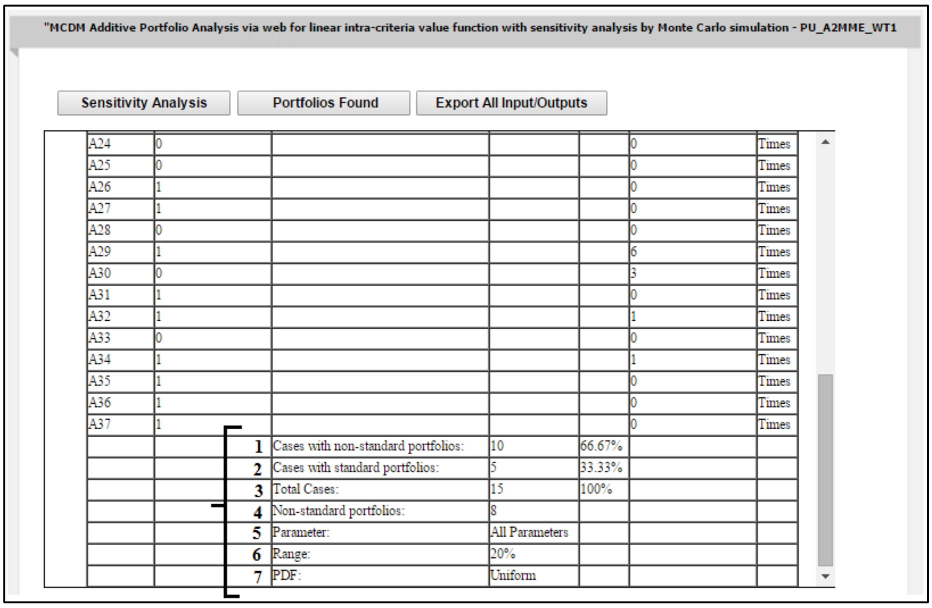

Fig. 4. Page of results from the sensitivity analysis

Figure 4 shows the page of results from the sensitivity analysis, in which there are the cases with non-standard portfolios (1 from Figure 4), the cases with standard portfolios (2 from Figure 4), the total cases (3 from Figure 4), the number of non-standard portfolios (4 from Figure 4), the parameters (5 from Figure 4), the range (6 from Figure 4) and, finally, the chosen probability distribution (7 from Figure 4).

The system also offers the possibility of exporting all input/output from the problem to a Microsoft Excel Worksheet, if the user needs.

5 Conclusions

In this paper, it was discussed a typically scaling issue which can arise in the context of multi-attribute portfolio problems: the portfolio size effect that additive changes in the utility of items create a bias in portfolio evaluation which depends on the number of items in the portfolio. It was shown, by a numerical application adapted from the problem proposed by Clemen and Smith [4], that this issue is caused by the impact of an additive utility transformation on the standard portfolio construction model.

Even considering the importance given by the baseline problem in different papers, this paper pointed out that it is valuable to note that the additive utility functions approach imposes certain requirements on the measurement scales used for the items in a portfolio that should not be ignored, given the different results that can arise from the portfolio size effect. That is, the baseline correction may not be enough to avoid this problem.

Therefore, this paper suggests that additionally to the baseline adjustment, a ratio scale correction may be necessary, depending on the combination of values and constraints considered by the problem, since the portfolio size effect may occur in additive multicriteria portfolio analysis.

In addition, this work is an extension from previous studies mentioned in the text, such as: [1], [6], [7] and [13], which are related to MCDM portfolio analysis in different perspectives and give support for the understanding of the problem presented here.

Also, it is essential to understand that this paper is not about the baseline specifically and the baseline does not exist in every problem, as explained by [12] and it is not present in this application either, as pointed out before.

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