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SELECTION OF SUITABLE DATA NORMALIZATION METHOD TO COMBINE WITH THE CRADIS METHOD FOR MAKING MULTI-CRITERIA DECISION

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Abstract:
Compromise Ranking of Alternatives from Distance to Ideal Solution *(CRADIS)* is a new *MCDM* method (discovered in 2022). It is built on a combination of three well-known methods, including Additive Ratio Assessment *(ARAS)*, Measurement Alternatives and Ranking according to Compromise Solution *(MARCOS)*, and Technique for Order Preference by Similarity to Ideal Solution *(TOPSIS)*. This method has the advantage of being resistant to the rank inversion phenomenon. However, if only the available data normalization *(DN)* method in this method is used, this method will only be usable in some cases. This study investigated the suitability of twelve data normalization methods combined with the *CRADIS* method. The solutions in four cases of four different fields were ranked using these twelve combination methods. Using these methods, the ranked results were compared with those of other *MCDM* methods. Four *DN* methods were appropriate in combination with the *CRADIS* method. The application scope of *CRADIS* method can be extended when using this *DN* method.

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1. INTRODUCTION

Evaluating the solutions is often conducted to find the best solution in every field. The multi-criteria decision-making *(MCDM)* methods are useful tools that can be used to complete this work [1,2]. *CRADIS* method is a *MCDM* method that is formed by combining three methods *ARAS*, *MARCOS*, and *TOPSIS*. This method was only found in 2022 to rank the medical waste incinerators with outstanding advantages, such as minimizing the inversion phenomenon [3]. The third section of this study presents the steps to perform the *CRADIS* method. Although it has only been found for a short time, several studies ranking the solutions in various fields such as in the selection of agricultural machines [4], evaluating the effects of *FDI* (Foreign Direct Investments) on the sustainability of the economic system [5], ranking forty-six countries based on three criteria including energy, environment, and sustainability [6], evaluating the Global innovation index of the countries in the Western Balkans [7]. This method has also been improved into the fuzzy *CRADIS* method for ranking the pear varieties in Serbia [8] and for selecting green suppliers [9].

Thus, the *CRADIS* method has been applied in ranking the solutions in many different fields, although it was only found recently. However, an in-depth study of this method showed that its available *DN* method would not allow it to be used in two cases. The following sections will clarify this content when presenting the steps to follow the CRADIS method.

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With the limitation mentioned above, it is necessary to overcome the limitation of the *CRADIS* method to expand the scope of the application. Overcoming the limitation mentioned above is also a reason why this study was conducted. Overcoming the limitation means finding other *DN* methods that can replace the data normalization method available in the *CRADIS* method. Firstly, an overview of DN methods is required. The investigation was carried out to determine the suitable DN methods combined with the *CRADIS* method, which is the subject of section four.

2. LITERATURE REVIEW

One of the important stages when ranking the solutions is the DN [10,11]. The task of *DN* is to convert the criteria with different dimensional into the same dimensional form [12-15]. However, many studies have shown that using different *DN* methods, the rank of the solutions in MCDM problems could be different [12,16-19].

Table 1 presents twelve *DN* methods that are commonly used in combination with *MCDM* methods [20].

Table 1. Data normalization methods [20]

Method	With j is the *B* form criterion (The bigger the better criteria-BBC)		With j is the *C* form criteria (The smaller the better criteria-SBC)	
DN1	$N_{ij} = \frac{y_{ij}}{max\ y_{ij}}$	(1)	$N_{ij} = \frac{min\ y_{ij}}{y_{ij}}$	(2)
DN2	$N_{ij} = \frac{y_{ij} - min\ y_{ij}}{max\ y_{ij} - min\ y_{ij}}$	(3)	$N_{ij} = \frac{max\ y_{ij} - y_{ij}}{max\ y_{ij} - min\ y_{ij}}$	(4)
DN3	$N_{ij} = \frac{y_{ij}}{\sum_{i=1}^{m} y_{ij}}$	(5)	$N_{ij} = \frac{1/y_{ij}}{\sum_{i=1}^{m} 1/y_{ij}}$	(6)
DN4	$N_{ij} = \frac{y_{ij}}{\sqrt{\sum_{i=1}^{m} (y_{ij})^2}}$	(7)	$N_{ij} = 1 - \frac{y_{ij}}{\sqrt{\sum_{i=1}^{m} (y_{ij})^2}}$	(8)
DN5	$N_{ij} = \frac{ln y_{ij}}{ln(\prod_{i=1}^{m} y_{ij})}$	(9)	$N_{ij} = 1 - \frac{ln y_{ij}}{ln(\prod_{i=1}^{m} y_{ij})}$	(10)
DN6	$N_{ij} = \frac{y_{ij}}{max\ y_{ij}}$	(11)	$N_{ij} = 1 - \frac{y_{ij}}{max\ y_{ij}}$	(12)
DN7	$N_{ij} = 1 - \frac{min\ y_{ij}}{y_{ij}}$	(13)	$N_{ij} = \frac{min\ y_{ij}}{y_{ij}}, if\ j \in C$	(14)
DN8	$N_{ij} = 1 - \left\lvert \frac{max\ y_{ij} - y_{ij}}{max\ y_{ij}} \right\rvert$	(15)	$N_{ij} = 1 - \left\lvert \frac{min\ y_{ij} - y_{ij}}{max\ y_{ij}} \right\rvert$	(16)
DN9	$N_{ij} = \left(\frac{y_{ij}}{max\ y_{ij}} \right)^2$	(17)	$N_{ij} = \left(\frac{y_{ij}}{max\ y_{ij}} \right)^3$	(18)
DN10	$N_{ij} = \frac{100 y_{ij}}{max\ y_{ij}}$	(19)	$N_{ij} = \frac{100 min\ y_{ij}}{y_{ij}}$	(20)
DN11	$N_{ij} = \frac{y_{ij} - \frac{\sum_{i=1}^{m} y_{ij}}{m}}{\sqrt{\frac{\sum_{i=1}^{m} (y_{ij} - \mu_j)^2}{m}}}$	(21)	$N_{ij} = - \frac{y_{ij} - \frac{\sum_{i=1}^{m} y_{ij}}{m}}{\sqrt{\frac{\sum_{i=1}^{m} (y_{ij} - \mu_j)^2}{m}}}$	(22)
DN12	$N_{ij} = 1 - \frac{max y_{ij} - y_{ij}}{\sum_{i=1}^{m} (max y_{ij} - y_{ij})}$	(23)	$N_{ij} = 1 - \frac{y_{ij} - min y_{ij}}{\sum_{i=1}^{m} (y_{ij} - min y_{ij})}$	(24)

As mentioned above, the selection of *DN* methods influenced the ranked results of the solutions. There are usually one or several available *DN* methods for each *MCDM*. However, the available *DN* methods cannot be applied in some cases. For example, if a criterion of type B has a maximum value of zero, then the Eqs. (1), (9), (11), (13), (15), (17), and (19) would be meaningless. In that case, methods *DN1* and *DN5-DN10* cannot be used. In other examples, with the *C*-type criteria, there is a criterion value of zero, then the Eqs. (2), (6), (10), (14), and (20) would be meaningless. It means the methods *DN1*, *DN3*, *DN5*, *DN7*, and *DN10* also cannot be used. In these cases, we should find other *DN* methods that can replace the available ones in *MCDM* methods [18,21]. Therefore, many studies have been conducted to determine whether the *DN* methods are suitable for combining with a particular *MCDM* method.

Only *DN2* was suitable when combining the *SAW* method with four *DN* methods (*DN2-DN4* and *DN6*) [22]. Only DN9 is considered suitable when combining the ROV method with eight methods (*DN2-DN4, DN6, DN7, DN9, DN11*, and *DN12)* [23]. Only three methods (*DN1, DN2* and *DN4*) among five methods (*DN1* to *DN5*) were confirmed to be suitable in combining with *MARCOS* method [24]. Only *DN1* in four methods (*DN1* to *DN4*) was found suitable in combining with *VIKOR* method [25]. Only DN3 in five methods (*DN2* to *DN6*) is suitable for combining with the *TOPSIS* method [21]. Both methods *DN3* and *DN4* were suitable for combination with *WISP* method [26]. In six methods from *DN1* to *DN6*, five methods (*DN1-DN4* and *DN6)* were suitable for combining with the *CODAS* method [27]. In the twelve *DN* methods listed in Table 1, only four methods (*DN1*, *DN6*, *DN8*, and *DN11*) are suitable for combination with the *PSI* method [20]. However, several *DN* methods were suitable for combination with many different *MCDM* methods. Such as method *DN2* was confirmed to be suitable to combine with all five methods, including *MABAC*, *COCOSO*, *MAIRCA*, *VIKOR*, and *ROV* methods [28] etc.

Through the results from the above studies, the studies in the determination of the appropriate *DN* methods for combination with an *MCDM* method have attracted the attention of the researchers. Their results show that several *MCDM* methods were suitable for combination with only one *DN* method. Conversely, there are also some *MCDM* methods that may be suitable in combination with some *DN* methods. Determining which *DN* methods is considered to be appropriate when combining with the *CRADIS* method will be a contribution to this research direction. This contribution is even more significant when it solves the limitation of the *CRADIS* method.

3. CARDIS METHOD

The *CARDIS* method in ranking the solutions is conducted by the following steps [3]:

Step 1: With *m* solutions to be ranked according to *n* criteria, a matrix that is called a decision matrix is formed by Eq. (25).

$$A = \begin{bmatrix} y_{11} & y_{12} & \cdots & y_{1n} \\ y_{21} & y_{22} & \ddots & y_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ y_{m1} & y_{m2} & \cdots & y_{mn} \end{bmatrix} \tag{25}$$

Step 2: Normalize data according to *DN1* method (Eq. (1) and (2)).

However, from the two Eq. (1) and (2), it seems that Eq. (1) will be meaningless if, among the *B* form criteria, for a certain criterion, its maximum value is equal zero. Eq. (2) also becomes meaningless if among the *C* form criteria, in some criteria, one or several criteria have the value zero. When either of these situations occurs, obviously, the method *DN1* is not applicable. That means we could not use the *CRADIS* method. For this reason, we need to identify other *DNMs* that can be substituted for the *DN1* method under similar situations.

Step 3: Calculating the normalization values when considering the criteria weights by Eq. (26).

$$v_{\text{i}} = n_{ij} \cdot w_j \tag{26}$$

where, w_j is the *j* criterion weight.

Step 4: Determining the absolute best and worst solutions.

- If *j* is the BBC.

$$t_i = max v_{ij} \tag{27}$$

- If *j* the SBC.

$$t_{ai} = min v_{ij} \tag{28}$$

Step 5: Calculating the difference in comparing to the absolute best and absolute worst solutions.

$$d^+ = t_i - v_{ij} \tag{29}$$

$$d^- = v_{ij} - t_{ai} \tag{30}$$

Step 6: Calculating the values S^+ and S^- by Eq. (31) and Eq. (31).

$$S^+ = \sum_{j=1}^{n} d^+ \tag{31}$$

$$S^- = \sum_{j=1}^{n} d^- \tag{32}$$

Step 7. Calculating the values K_i^+ and K_i^- by Eq. (33) and Eq. (34).

$$K_i^+ = \frac{S_0^+}{S_i^+} \tag{33}$$

$$K_i^- = \frac{S_i^-}{S_0^-} \tag{34}$$

where $S_0^+ = min\ (S_i^+)$ and $S_0^- = max\ (S_i^-)$, with $i = 1 \div m$.

Step 8. Calculate the values of Q_i by Eq. (35). Ranking the solutions (the solution with the maximum value of Q_i is the best solution).

$$Q_i = \frac{K_i^+ + K_i^-}{2} \tag{35}$$

4. SELECTION OF THE SUITABLE DNM FOR COMBINATION WITH CRADIS METHOD

As analyzed in the third section of this paper, in some cases we cannot use the *DN1* method to normalize the data. Then the *CRADIS* method will not be used. This section will conduct a survey to find the possible data normalization methods to replace the *DN1* method in combination with the *CRADIS* method. This section will use the *CRADIS* method in five different examples. In the first example, all the criteria are type *C*. In the second example, all criteria are type *B*. In the third example, the criteria number in type *C* is more than the number of criteria in type *B*. In example four, the number of *B*-type criteria is greater than the number of *C*-type criteria. In each example, when using the *CRADIS* method, the ranked results of the solution were also compared to results when using the other methods. With four examples, selecting examples with the different types of criteria aims to obtain the most general conclusions. After performing the four examples, it was determined which *DN* methods are considered suitable for incorporation with the *CRADIS* method, and then example five is performed. In example five, a set of numbers was intentionally created where some *DN* method was not used (including *DN1*). The alternative *DN* methods will be used. This work is conducted to confirm the appropriateness of new *DN* methods in replacing the *DN1* method when combined with the *CRADIS* method.

4.1. Example 1

Table 2 presents the data of seventeen different solutions of the metal drilling process [29,30]. Six C-type criteria were used in this example including *C1* - machining time (s), *C2* - the height of the burr on the drilling surface at the incut direction of the tool (mm), *C3* - height burr in the exit direction of the tool (mm), *C4* - the burr thickness on the drilling surface in the incut direction of the tool (mm), *C5* - the burr thickness in the exit direction of the tool (mm), and *C6* – the roughness of surface (μm).

Table 2. Data of example 1 [29,30]

Weight	0.3	0.1	0.1	0.1	0.1	0.3
No.	C1	C2	C3	C4	C5	C6
S1	14.03	0.051	0.058	0.105	0.21	0.479
S2	7.59	0.053	0.058	0.155	0.245	1.211
S3	7.34	0.035	0.06	0.165	0.215	0.916
S4	4.06	0.033	0.075	0.18	0.215	0.535
S5	5.4	0.048	0.078	0.25	0.195	0.601
S6	5.5	0.05	0.084	0.185	0.185	0.703
S7	2.81	0.033	0.058	0.185	0.185	0.466
S8	2.62	0.028	0.048	0.2	0.19	0.577
S9	2.88	0.028	0.05	0.18	0.15	0.417
S10	2.75	0.043	0.051	0.23	0.195	0.675
S11	2.84	0.043	0.055	0.165	0.205	0.418
S12	1.59	0.028	0.074	0.145	0.17	0.601
S13	1.88	0.038	0.064	0.185	0.175	0.563
S14	3.44	0.049	0.066	0.19	0.185	0.391
S15	2.04	0.023	0.059	0.16	0.18	0.493
S16	2.1	0.043	0.05	0.235	0.185	0.675
S17	1.25	0.04	0.049	0.44	0.19	0.65

Table 3. Ranked results of example 1

No.	CRADIS												TOPSIS	COPRAS	FUCA
	DN1	DN2	DN3	DN4	DN5	DN6	DN7	DN8	DN9	DN10	DN11	DN12			
S1	13	16	13	16	17	16	13	16	2	13	16	16	17	17	13
S2	17	17	17	17	2	17	17	17	1	17	17	17	16	16	17
S3	16	15	16	15	7	15	16	15	4	16	15	15	15	15	15
S4	12	12	12	12	12	11	12	11	7	12	12	12	12	12	11
S5	14	13	14	13	11	13	14	13	5	14	13	13	13	13	14
S6	15	14	15	14	10	14	15	14	3	15	14	14	14	14	16
S7	7	3	7	4	13	3	7	3	14	7	3	3	5	6	4
S8	9	4	8	7	8	5	9	5	15	9	4	5	7	7	6
S9	2	1	4	2	15	1	2	1	17	2	1	1	2	2	2
S10	11	11	11	11	5	12	11	12	8	11	10	11	10	11	12
S11	5	6	6	5	14	6	5	6	11	5	6	4	6	5	7
S12	4	5	2	3	4	4	4	4	12	4	5	6	4	3	3
S13	6	7	5	6	6	7	6	7	13	6	7	7	3	4	5
S14	8	8	9	8	16	8	8	8	9	8	8	8	8	8	9
S15	1	2	3	1	9	2	1	2	16	1	2	2	1	1	1
S16	10	9	10	9	3	9	10	9	10	10	9	9	9	9	10
S17	3	10	1	10	1	10	3	10	6	3	11	10	11	10	8

The weight values of the criteria are also presented in the first row of Table 2. Before this study, two methods including *TOPSIS* and *COPRAS* were used to select the best solution [30]. The *FUCA* method was also used to select the best option [29].

The implementation steps of the *CRADIS* method described in section 3 were used to rank the solutions in this example. In which, twelve different data normalization methods (presented in section 2) were used respectively. The ranked results in this case and when using *TOPSIS*, *COPRAS*, and *FUCA* methods [29,30] were summarized in Table 3.

The results in Table 3 show that when using the *CRADIS* method, the ranking results of the solutions are different corresponding to different normalization methods. This is consistent with the found statement in references [31-34]. Of seventeen considered solutions, S15 was the best as determined by the *TOPSIS*, *COPRAS* [30], and *FUCA* methods [29].

Thus, in this case, the *CRADIS* method only combined with *DN1, DN4, DN7*, and *DN10* to obtain the same results (*S15* is the best solution). It means that only *DN1, DN4, DN7*, and *DN10* are suitable for combining with the *CRADIS* method in this example. When observing the data in Table 3, another interesting thing is that the ranking results of the solutions are the same when using methods *DN1, DN7*, and *DN10*.

4.2. Example 2

In this example, seven solutions for the human resource of a textile company in Turkey were ranked [35]. In order to analyze each solution, five *B* form criteria including work experience (*C1)*, foreign language ability (*C2)*, problem-solving ability (*C3)*, communication ability (*C4)*, and group work ability (*C5)*, were applied. The evaluation scores for each criterion in each alternative and the weight of each criterion are summarized in Table 4 [35]. Before this study, two methods, *CODAS* and *PSI,* were also used to rank the solutions in this case [35].

Table 4. Data of example 2 [35]

Weight	0.257	0.129	0.214	0.196	0.204
Criteria	C1	C2	C3	C4	C5
S1	2	110	3	2	3
S2	5	100	5	3	3
S3	3	90	4	5	2
S4	10	80	3	4	4
S5	4	85	2	4	5
S6	8	80	3	4	4
S7	5	95	2	4	3

Table 5 presents the ranking results of the solutions when using the *CRADIS* method corresponding to twelve different data normalization methods. The ranking results of the solutions by two methods, *CODAS* and *PSI*, were also summarized in this table.

The data in Table 5 shows:

- The ranking results of the solutions when combining CRADIS with eleven *DN* methods (*DN1, DN2, DN3, DN4, DN5, DN6, DN8, DN9, DN10, DN11*, and *DN12*) are completely identical and the same with the case using *CODAS* or *PSI* methods.

- When using the *DN7* data normalization method, the ranking results of the solutions also have a very high degree of similarity compared to when using other data normalization methods. Specifically, there is only a difference between the ranking results in the two solutions including *S3* and *S7*.

- All twelve data normalization methods showed that the best and worst solutions were *S4* and *S1*, *respectively*.

Thus, in this case, it seems that all twelve data normalization methods are considered to be suitable to be combined with the *CRADIS* method.

Table 5. Ranking the solutions of example 2

No.	CRADIS												CODAS	PSI
	DN1	DN2	DN3	DN4	DN5	DN6	DN7	DN8	DN9	DN10	DN11	DN12		
S1	7	7	7	7	7	7	7	7	7	7	7	7	7	7
S2	3	3	3	3	3	3	3	3	3	3	3	3	3	3
S3	5	5	5	5	5	5	6	5	5	5	5	5	5	5
S4	1	1	1	1	1	1	1	1	1	1	1	1	1	1
S5	4	4	4	4	4	4	4	4	4	4	4	4	4	4
S6	2	2	2	2	2	2	2	2	2	2	2	2	2	2
S7	6	6	6	6	6	6	5	6	6	6	6	6	6	6

4.3. Example 3

This example was performed to rank six different solutions for a medical waste incinerator. The sixteen criteria used to evaluate each solution with their weights are summarized in Table 6 [3].

In which, *C9*, *C10*, *C13*, and *C14* are four criteria in the form of *B*, the remaining twelve criteria are in the form of *C*. The determination of the best solution in this case was also conducted using the methods *MARCOS*, Multi-Attributive Border Approximation area Comparison (*MABAC*), *SAW*, *ARAS*, *WASPAS*, *TOPSIS*, and using the combination of *CRADIS* with *DN1* method [3].

A combination of *CRADIS* with eleven other data normalization methods (*DN2* to *DN12*) was used to rank the solutions with the ranked results as summarized in Table 7.

The data in Table 7 shows that:

The combination of *CRADIS* with ten data normalization methods including *DN1, DN2, DN3, DN4, DN6, DN7, DN8, DN10, DN11*, and *DN12* shows the same best solution using the six other *MCDM* methods. Interestingly, the ranking results of these ten combinations are the same as those when using four methods, including *MARCOS*, *MABAC*, *SAW*, and *WASPAS*. In summary, ten methods, including *DN1, DN2, DN3, DN4, DN6, DN7, DN8, DN10, DN11*, and *DN12* are considered suitable to be combined with the *CRADIS* method in this case.

Table 6. Data of example 3 [3]

Weight	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625
No.	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
S1	1.82	1.59	2.62	2.62	4.31	3.30	2.29	3.30	4.31	5.31	2.29	1.26	0.36	30.00	10.00	5.02
S2	1.82	1.59	2.62	2.62	3.63	3.30	2.29	3.30	4.31	6.00	2.29	1.26	0.54	40.00	11.50	6.26
S3	2.88	2.62	3.30	3.00	4.64	3.91	2.52	3.91	3.30	6.00	3.30	1.44	0.75	50.00	12.50	8.97
S4	1.82	1.59	2.62	3.17	3.63	3.30	2.29	3.30	4.31	6.00	3.30	2.00	0.57	65.00	17.50	8.79
S5	3.11	3.00	3.91	4.00	5.00	4.58	3.30	4.00	2.29	5.00	3.91	2.88	1.35	100.00	16.50	11.68
S6	2.88	2.29	3.63	3.63	5.00	4.31	3.30	4.31	2.88	6.00	4.31	2.29	1.20	100.00	15.50	12.90

Table 7. Ranking the solutions of example 3

No.	MARCOS	MABAC	SAW	ARAS	WASPAS	TOPSIS	CRADIS											
							DN1	DN2	DN3	DN4	DN5	DN6	DN7	DN8	DN9	DN10	DN11	DN12
S1	2	2	2	2	2	2	2	2	2	2	1	2	2	2	6	2	2	2
S2	1	1	1	1	1	1	1	1	1	1	2	1	1	1	5	1	1	1
S3	4	4	4	5	4	6	4	4	4	4	4	4	4	4	3	4	4	4
S4	3	3	3	3	3	3	3	3	3	3	3	3	3	3	4	3	3	3
S5	6	6	6	6	6	5	6	6	6	6	6	6	6	6	1	6	6	6
S6	5	5	5	4	5	4	5	5	5	5	5	5	5	5	2	5	5	5

4.4. Example 4

Data from about fourteen office climate solutions were used in this example [36]. Each solution is described by six criteria. Four type *B* criteria include *C1* (air volume per capita), *C2* (relative humidity), *C3* (air temperature), and *C4* (lighting levels during working hours). The two *C*-type criteria include *C5* (air flow rate) and *C6* (dewpoint). The data on the criteria and their weights are summarized in Table 8.

In this example, the combination of the *CRADIS* method with twelve *DN* methods will be used to rank the solutions. Previously, this task was also performed using the *CODAS* method [36]. Table 9 summarizes the ranked results of the solutions with different methods in example 4.

The results from Table 9 show that the ranked results were completely coincident when CRADIS combined with five methods, including *DN1*, *DN3, DN4*, *DN6*, and *DN8*.

Table 8. Data of example 4 [36]

Weight	1/6	1/6	1/6	1/6	1/6	1/6
Criteria	C1	C2	C3	C4	C5	C6
S1	7.6	46	18	390	0.1	11
S2	5.5	32	21	360	0.05	11
S3	5.3	32	21	290	0.05	11
S4	5.7	37	19	270	0.05	9
S5	4.2	38	19	240	0.1	8
S6	4.4	38	19	260	0.1	8
S7	3.9	42	16	270	0.1	5
S8	7.9	44	20	400	0.05	6
S9	8.1	44	20	380	0.05	6
S10	4.5	46	18	320	0.1	7
S11	5.7	48	20	320	0.05	11
S12	5.2	48	20	310	0.05	11
S13	7.1	49	19	280	0.1	12
S14	6.9	50	16	250	0.05	10

When *CRADIS* combined with ten methods including *DN1, DN2, DN3, DN4, DN6, DN7, DN8, DN10, DN11*, and *DN12*, *S8,* the best solution was determined to be the same. This result was the same as the case using the *CODAS* method. In summary, these ten data normalization methods were deemed suitable for combination with the *CRADIS* method in this example.

Through the above four examples, we have confirmed the appropriateness of the data normalization methods when combined with the *CRADIS* method in each case and the results were summarized in Table 10. In which the cell with a check mark represents appropriateness, whereas the blank cell shows the non-conformity.

Thus, in all considered cases, the *CRADIS* method is suitable to combine with only four *DN* methods, including *DN1, DN4, DN7*, and *DN10*. With verifying the suitability when combining *DN4* with the *CRADIS* method, the application scope of the *CRADIS* method will be more extensive than its original version (the original version uses the *DN1* method). The example below is performed to verify this problem.

Table 9. Ranking the solutions of example 4

No.	CRADIS												CODAS
	DN1	DN2	DN3	DN4	DN5	DN6	DN7	DN8	DN9	DN10	DN11	DN12	
S1	3	3	3	3	3	3	3	3	1	10	11	10	3
S2	8	7	8	8	5	8	7	8	11	7	8	7	6
S3	11	10	11	11	7	11	11	11	12	9	9	8	9
S4	10	11	10	10	6	10	10	10	14	4	4	5	10
S5	13	13	13	13	10	13	13	13	7	13	13	13	14
S6	12	12	12	12	9	12	12	12	6	12	12	12	13
S7	14	14	14	14	11	14	14	14	10	8	7	9	12
S8	1	1	1	1	2	1	1	1	3	1	1	1	1
S9	2	2	2	2	1	2	2	2	4	2	2	2	2
S10	9	8	9	9	8	9	9	9	5	11	10	11	11
S11	5	4	5	5	4	5	4	5	8	3	3	3	4
S12	6	6	6	6	14	6	6	6	9	6	5	4	7
S13	4	5	4	4	12	4	5	4	2	14	14	14	8
S14	7	9	7	7	13	7	8	7	13	5	6	6	5

Table 10. Summary of the suitability of the data normalization methods in combination with the CRADIS method

Example	DN1	DN2	DN3	DN4	DN5	DN6	DN7	DN8	DN9	DN10	DN11	DN12
1	√			√			√			√		
2	√	√	√	√	√	√	√	√	√	√	√	√
3	√	√	√	√		√	√	√		√	√	√
4	√	√	√	√		√	√	√		√	√	√

4.5. Example 5

Considering a case where it is necessary to rank four solutions *S1*, *S2*, *S3*, and *S4*. Each solution consists of four criteria, in which *C1* and *C2* are two criteria of type *B*, *C3* and *C4* are two criteria of type *C*, as shown in Table 11.

Table 11. Data of example 5

Weight	0.25	0.25	0.25	0.25
No.	C1	C2	C3	C4
S1	-7	6	0	12
S2	-6	7	1	8
S3	0	5	3	9
S4	-2	2	2	7

The data in this table are intentionally created. Specifically, as follows:

- The value of *C1* at *S3* is zero, so the two Eqs. (1) and (19) are meaningless, which means that *DN1* and *DN10* cannot be applied.

- The value of *C3* at *S1* is zero, so the three Eqs. (2), (14), and (20) are meaningless, which means that *DN1, DN7,* and *DN10* also cannot be applied.

Thus, in four methods, *DN1, DN4, DN7*, and *DN10*, only *DN4* is applicable in this case. Using DN4 to combine with the CRADIS method to rank the solutions, assuming the four criteria weights are equal to 0.25.

Three other *MCDM* methods, including *TOPSIS*, Multi-Objective Optimization based on of Ratio Analysis (*MOORA*), and Proximity Indexed Value (*PIV*), were also used to rank the solutions in this case. Note that *DN4* is also the available data normalization method in the three methods *TOPSIS*, *MOORA*, and *PIV*. The ranking results of the solutions are summarized in Table 12.

Table 12. Ranking the solutions of example 5

No.	TOPSIS	MOORA	PIV	CRADIS + N4
S1	2	3	3	2
S2	1	1	1	1
S3	4	2	2	3
S4	3	4	4	4

The ranking results of the solutions in Table 12 show that the combination of *CRADIS* and *DN4* also determines the best solution when using the other three methods. In addition, this combination also shows the same worst solution as when using *MOORA* and *PIV* methods. This means that *DN4* was verified to be successful in combination with *CRADIS* method.

Thus, the contribution of this study is the identification of four methods (DN1, DN4, DN7, and DN10) to be suitable to combine with the CARDIS method. With this contribution, the application scope of the *CRADIS* method was extended. These applications were not available in their original version. The results from example number five are an illustration of this statement. It means that the limitation of the *CRADIS* method has been overcome.

5. CONCLUSION

In some cases, the *CRADIS* method will be unusable if only its available data normalization method (*DN1* method) is used. The case that *DN1* is unusable is when the criteria of type *B* with the largest value of a random criterion is zero or when criteria of type *C* have a value that equals zero. Determining other data normalization methods that can replace the *DN1* method will remove this limitation. Some conclusions can be drawn as follows:

1. Four *DN* methods including *DN1, DN4, DN7*, and *DN10* were suitable in combining with the *CRADIS* method. The combination of the *CRADIS* method and these four *DN* methods consistently determines the best solution in *MCDM*.

2. When *DN1* is unusable, we can use *DN4* instead with the same accuracy for the results of ranking the solutions.

3. When *DN1, DN4, DN7* and *DN10* were combined with the *CRADIS* method, the best solution was consistently determined to be the same. However, in each surveyed case, only one weight set of the criteria was used. The sensitivity analysis toward the best alternative when the weight of the criteria changes is a necessary thing to do. The Spearman's rank correlation coefficients can be used to complete this work [37,38];

4. Currently, the *DN* formulas can not be applied to qualitative criteria (colors, hobbies etc.). That is when the *CRADIS* method is unusable. Improving the *CRADIS* method to rank the alternatives, in this case, is what need to be done in the future.

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