Proposal for an objective binary benchmarking framework that validates each other for comparing MCDM methods through data analytics

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When it comes to choosing the best among multiple alternatives with criteria of different importance, it makes sense to use MCDM (Multi Criteria Decision Making) methods with more than 200 variations. However, because the algorithms of MCDM methods are different, they do not always produce the same best option or the same hierarchical ranking. At this point, it is important how and according to which MCDM methods will be compared, and the lack of an objective evaluation framework still continues. The mathematical robustness of the computational procedures, which are the inputs of MCDM methods, is of course important. But their output dimensions, such as their capacity to generate well-established real-life relationships and rank reversal (RR) performance, must also be taken into account. In this study, we propose for the first time two criteria that confirm each other. For this purpose, the financial performance (FP) of 140 listed manufacturing companies was calculated using 9 different MCDM methods integrated with SWARA (Step-Wise Weight Assessment Ratio Analysis). İn the next stage, the statistical relationship between the MCDM-based FP final results and the simultaneous stock returns of the same companies in the stock market was compared. Finally, for the first time, the RR performance of MCDM methods was revealed with a statistical procedure proposed in this study. According to the findings obtained entirely through data analytics, FUCA (Faire Un Choix Adéquat) and (which is a fairly new method) CRADIS (Compromise Ranking of Alternatives From Distance To Ideal Solution) were determined as the most appropriate methods by the joint agreement of both criteria.

PROPOSAL FOR AN OBJECTIVE BINARY BENCHMARKING FRAMEWORK THAT VALIDATES EACH OTHER FOR COMPARING MCDM METHODS THROUGH DATA ANALYTICS

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Abstract

When it comes to choosing the best among multiple alternatives with criteria of different importance, it makes sense to use MCDM (Multi Criteria Decision Making) methods with more than 200 variations. However, because the algorithms of MCDM methods are different, they do not always produce the same best option or the same hierarchical ranking. At this point, it is important how and according to which MCDM methods will be compared, and the lack of an objective evaluation framework still continues. The mathematical robustness of the computational procedures, which are the inputs of MCDM methods, is of course important. But their output dimensions, such as their capacity to generate well-established real-life relationships and rank reversal (RR) performance, must also be taken into account. In this study, we propose for the first time two criteria that confirm each other. For this purpose, the financial performance (FP) of 140 listed manufacturing companies was calculated using 9 different MCDM methods integrated with SWARA (Step-Wise Weight Assessment Ratio Analysis). İn the next stage, the statistical relationship between the MCDM-based FP final results and the simultaneous stock returns of the same companies in the stock market was compared. Finally, for the first time, the RR performance of MCDM methods was revealed with a statistical procedure proposed in this study. According to the findings obtained entirely through data analytics, FUCA (Faire Un Choix Adéquat) and (which is a fairly new method) CRADIS (Compromise Ranking of Alternatives From Distance To Ideal Solution) were determined as the most appropriate methods by the joint agreement of both criteria.

Key Words: MCDM Benchmarking and Evaluation Methodology, Data Analytics, Rank Reversal, Financial Performance

1. INTRODUCTION

The measurement of financial performance (FP) with an accurate procedure has an important function in improving the decisions of the users of information about the company (e.g., investor, manager, partner, supplier and creditor). Because financial performance is an important indicator that reveals whether a company successfully fulfills its mission or not (Ayhan and Önder, 2021).

42   It is therefore reasonable to use MCDM methods because of their success in considering the
43   multidimensional nature of FP with precision. As a matter of fact, MCDM methods have been
44   preferred as a selection and ranking method in many previous studies and in many different
45   scientific fields (Kabir and Hasin, 2013; Stević et al 1a.,2022; Pala, 2022; Gvozdović et al., 2022;
46   Oral, 2021; Zhang et al., 2022). Of course, a single criterion or ratio is insufficient for an overall
47   assessment of the multidimensional performance of companies. In this sense, MCDM methods
48   take into account the dimensions that express the different purposes of the enterprises and
49   transform them into a single score (Diakoulaki et al., 1995; Zopounidis et al. 2015; Rasoulzadeh
50   and Fallah 2020; Turhan and Aydemir, 2021; Khodadadi-Karimvand and Shirouyehzad 2021; Edu
51   et al., 2021; Baydaş 1a, 2022). Thus, a fair comparison becomes possible for companies.
52   On the other hand, due to the lack of clear consensus, making a valid decision on which MCDM
53   method to choose when measuring companies' FP for a given problem is a challenging issue that
54   is both intriguing and alarming. Although this may seem like an intricate and insoluble problem
55   for methodologists, sensitivity, validation, or robustness analyzes are being developed to better
56   understand the nature of the methods. (Triantaphyllou, 2000). Moreover, the literature currently
57   reports that the number of MCDM methods is more than 200 (Danesh et al., 2017; Cinelli et al.,
58   2022). On the other hand, a more robust, anxiety-reducing, and comforting framework can be
59   suggested compared to a random MCDM selection. Simply put, MCDM methods can be compared
60   based on their ability to relate to real life. This brings to mind the naturally occurring sequences in
61   real life. The share price is an example, and similar rankings can also be used in other scientific
62   fields. It is a known fact that many MCDM types (provided that the same decision matrix and
63   weighting coefficient are used) produce similar rankings at certain scales (Karaoğlan and Şahin,
64   2018). However, MCDM approaches have unique algorithms and therefore MCDM methods may
65   differ in suggesting the 'best alternative'. This situation directly affects the decisions of the decision
66   makers. The factors that differentiate the ranking results of MCDM methods are the normalization
67   type, assumptions, limitations and threshold value, along with different calculation procedures. In
68   addition, this situation affects the general ranking to a certain extent. These features, which make
69   MCDM methods unique, actually facilitate a good comparison. In the past, the most important
70   problem for MCDM selection was the absence of an objective benchmark. But the authors were
71   mostly comparing calculation procedures with MCDM inputs. However, a character analysis based
72   on MCDM outputs can show us a clearer path. In this sense, "price", which establishes a
73   relationship with the FP of the companies simultaneously, can be an anchor criterion. As it is
74   known, the share price of companies is a solid example from real life. The price is formed as a
75   result of the consensus of thousands of stock market investors in the market. In fact, the price
76   phenomenon is a dynamic system that is affected by many factors, similar to financial
77   performance. In other words, although it is represented by a single score (just like MCDM scores),
78   it consists of multiple criteria. While FP is simply a phenomenon that can be controlled by the
79   company, the share price is a dynamic that the company cannot directly control. And there is a
80   simultaneous relationship between these two factors in certain constraints. Moreover, the level of
81   this existing relationship varies according to the ability of MCDM methods (Baydaş 1b, 2022). At
82   this point, the fact that some MCDM methods produce a regular, consistent and strong relationship
83   with the share price shows the special capacity of MCDM methods on a subject. In this study, an
84   "output-based" solution obtained with "data analytics" is proposed as an alternative to a classical
85   "input-based" methodological solution.
86   In this study, we apply two comprehensive analyzes to them to determine the most efficient
87   MCDM method: first, their relationship to real life, and second, their rank reversal (RR)

88   performance. Accordingly, we present an objective comparison of nine (including classical,
89   popular, and new) MCDM methods. Between the years 2019-2021, we measured the MCDM-
90   based FP of 10 quarters (a separate performance was measured for each quarter) of 140
91   manufacturing companies from different sectors registered on the Stock Exchange (BIST). We
92   evaluated the relationship between simultaneous price rankings and MCDM. Also, as a second
93   criterion, we propose how to measure the RR performance of MCDM methods for a given problem
94   with a unique robust procedure.
95   In conclusion, we propose two specific and objective evaluation procedures that confirm each
96   other, showing which method is more successful and more capable for decision-makers. We did
97   not base the validity of the analysis results on only one problem, the MCDM method or the
98   weighting method. Unlike many previous studies, this comprehensive study uses 10 different real
99   scenarios, nine different MCDMs, two weighting methods, and more than one hundred alternatives
100   to test the reliability and validity of this procedure.
101   We evaluate that our study will contribute to the literature methodologically and practically by
102   using two objective criteria simultaneously for MCDM comparison and selection, which is a
103   challenging subject. In this study, first of all, BIST manufacturing sector will be calculated using
104   various MCDM methods. In the next step, MCDM methods will be compared according to the
105   correlations between financial performance results and stock returns. To gain a more robust
106   insight, a separate comparison metric will be proposed based on the RR findings produced by the
107   MCDM methods. It is thought that this capacity assessment to be made with these two criteria,
108   which express the relationship and consistency of MCDM methods with real life, can fill an
109   important gap in the literature. In this study, first of all, a comprehensive literature review will be
110   made under various headings. Later, the research methodology will be explained in all its aspects.
111   Findings will be presented next and they will be evaluated in the discussion. Finally, final
112   evaluations will be made in the conclusions section.
113

114   **2. LITERATURE REVIEW**
115   In this section, we will first examine some of the classical views in the literature on rationality on
116   which the concepts of selection, comparison, and capacity for an appropriate MCDM are based.
117   Second, we look at MCDM-based FP measurement and evaluation studies. Next, we will review
118   some recent innovative studies that have addressed the relationship between FP and SR and
119   evaluate this relationship as a capacity indicator for MCDMs. Finally, we review the literature on
120   RR, an MCDM evaluation, and a benchmark.
121

122   **2.1. MCDM Evaluation Methodology**
123   Among the 200+ MCDM methods (Cinelli et al., 2022), there are simple and primitive ones such
124   as SAW (Simple Additive Weighting Method), as well as algorithmically sophisticated methods
125   such as PROMETHEE-2 (Preference Ranking Organization Method for Enrichment Evaluation),
126   VIKOR (VIseKriterijumska Optimizacija I Kompromisno Resenje), or TOPSIS (Technique for
127   Order of Preference by Similarity to Ideal Solution). However, while the MCDM method selection
128   and MCDM evaluation methodology are mostly associated with the sophistication of input-based
129   algorithms, sufficient data analytics have not been conducted regarding the outputs (outcomes)
130   they produce. In this sense, it is not surprising that the existing literature emphasizes that the
131   problem is difficult or has no definitive solution. (Triantaphyllou, 2000). On the other hand, there
132   are many suggestions in the literature about what approach should be adopted when determining
133   any MCDM method. For example, there are some studies claiming that SWOT (Weaknesses,

134   Strengths, Threats and Opportunities) analysis of MCDM methods is vital. The advantages and
135   disadvantages of each of these methods need to be determined. Then, creating new methods that
136   can effectively combine strengths while eliminating weaknesses can increase efficiency
137   (Velasquez and Hester, 2013). Here, strengths and weaknesses are sometimes relative, which can
138   be another problem. On the other hand, comparative analyzes of the methods show that none of
139   the MCDM methods are perfect. For this reason, it has been suggested to apply more than one
140   method to the same problem in order to give a more comprehensive result to the decision makers
141   and it is still widely applied (Mulliner et al., 2016). Although it is unlikely to be validated,
142   combining different methods as an approach can overcome the shortcomings of these methods.
143   There are many problematic issues that complicate the MCDM Evaluation Methodology. The first
144   problem is which of the assumptions based on outranking, value/benefit, and distance should be
145   preferred. Selection of MCDM type, normalization type, weighting technique type, appropriate
146   threshold value, and preference function type is uncertain problem. Purging a method from "rank
147   reversal" and "compensatory" is another important problem. The lack of a standard procedure for
148   sensitivity, robustness, and accuracy analysis can be counted as one of the final problems.
149   Struggles continue intensely to determine an objective and understandable framework procedure
150   on how to choose the most appropriate method (Guarini et al., 2018). Some of the findings are
151   remarkable and can be evaluated. Some "outranking methods" such as PRMOTHEE-2 are less
152   compensatory (one or more criteria suppressing other criteria and distorting fairness), which is a
153   positive feature. On the other hand, compared to its competitors, AHP (Analytic Hierarchy
154   Process) can produce consistency, time and energy problems as it makes many pairwise
155   comparisons with subjective expert opinion. TOPSIS is based on ideal values (pozitive and
156   negative) and it may produce higher rank reversal problem. Many MCDM methods transform and
157   distort information with normalization, which is the most important cause of rank reversal (Wu &
158   Abdul-Nour, 2020). On the other hand, sensitivity analysis, which is claimed to measure
159   robustness for the comparison problem of MCDMs, is proposed. (Haddad et al., 2020). Moreover,
160   it is emphasized that axiomatics for the selection of MCDM methods can be a useful way to
161   improve the decision-making process (Leoneti, 2016). According to some authors, the selection of
162   MCDM can be an erroneous and problematic issue from time to time. And good guidance is
163   essential for its selection. There is a solution point that all previous studies have pointed out
164   insightfully, which is that the necessity of a concrete, clear, and objective evaluation framework is
165   imperative for this problem. (Cinelli et al., (2022).
166   On the other hand, the capacity of MCDM methods to represent real-life scenarios is becoming
167   more important than before (Munier, 2006). Therefore, MCDM methods should be evaluated not
168   only with their potential capacity but also with their capacity to capture real life. MCDM methods
169   that establish a better and more consistent relationship with real-life rankings can be considered
170   successful. Therefore, for MCDM methods, not only their methodological capabilities (calculation
171   procedure) should be evaluated, but also their output-based (results) capabilities. Moreover, it can
172   be said that the rank reversal performance of MCDM methods for a particular problem has not
173   been adequately addressed in a comparative and comprehensive manner.
174
175   **2.2. Financial Performance (FP) and MCDM**
176   Multiple and sometimes contradictory purposes of financial criteria require using the consensus
177   solution of the MCDM paradigm for computation. The idea of reducing FP to a single score with
178   MCDM dates back more than 20 years in the literature.

179 Ertuğrul and Karakaşoğlu (2009) evaluated the FP of 15 cement companies based on 18 criteria
180 and using fuzzy AHP and TOPSIS methods. Wang (2014) evaluated the FPs of three container
181 shipping companies operating in the field of shipping in Taiwan using fuzzy multi-criteria decision
182 making techniques. In his study, Wang (2014) first dealt with 5 periods with 21 ratios divided into
183 clusters and then calculated representative indices from these clusters. Then, these representative
184 indices were used as evaluation criteria, the FPs of the firms were evaluated using the fuzzy
185 TOPSIS method, and then the firms were ranked according to their financial performance. Rezaie
186 et al. (2014) evaluated the FPs of 27 listed companies operating in the cement sector between
187 2008-2009 using 13 ratios. In the study, companies are listed with the VIKOR method. On the
188 other hand, Pineda et al. (2018) developed an integrated model for the performance evaluation of
189 airline companies that uses data mining and MCDM methods together. They evaluated the
190 performance of 12 air companies using 11 criteria divided into four main groups. They used a
191 hybrid model, applying a combination of DRSA, DEMATEL, DANP, and VIKOR methods to
192 rank and identify financial and operational critical factors. Similarly, Yalçın and Ünlü (2018) used
193 the Objective Weighting Method (CRITIC) and Equal Weight (MW) method together in their
194 study to evaluate the initial public offering performance of companies and ranked the firm
195 performances by evaluating them with the VIKOR method. In their studies, 9 ratios were used for
196 16 companies, taking into account the period of 2010-2012. Akgün and Soy Temür (2016) made
197 the 6-year FP evaluation of two airline companies in the BIST transportation sector between 2010
198 and 2015 using the TOPSIS method and then compared the findings. Similarly, Metin et al. (2017)
199 calculated the ratios of 11 energy companies in the BIST according to their financial statements
200 between 2010 and 2015, and then evaluated the FPs of these companies using TOPSIS and
201 MOORA methods. In their study, they concluded that the FPs of companies changed in both
202 methods, but they observed that only three companies had the same performance ranking for both
203 methods. Finally, Özçelik and Küçükçakal (2019) evaluated the FPs of 7 financial leasing and
204 factoring companies traded on the BIST for the period 2009-2016 using the TOPSIS method. In
205 this analysis, they used 6 financial ratios and identified higher performing companies.
206 In MCDM-based FP studies, there is generally a lack of objective justification for choosing and
207 using an MCDM method. Some other remarkable results that we can observe in FP measurement
208 studies based on MCDM can be listed as follows (De Almeida-Filyo et al., 2020): First, the number
209 of studies using MCDM methods is constantly increasing from the past to present. Secondly, while
210 TOPSIS was the most used MCDM method in performance studies, similarly, profitability and
211 risk-based financial criteria were preferred more frequently. Third, FP in general is one of the most
212 studied subjects in finance based on MCDM.
213
214 **2.3. The Relationship between Financial Performance and Stock Return**
215
216 In addition to the above-mentioned case studies in which FP was calculated integrally with MCDM
217 methods, there are few other studies comparing the obtained FP results with price. SR or return on
218 share (return on capital) is defined as the percentage change in price. For instance, Sakarya and
219 Aytekin (2013) used 10 financial ratios to determine the relationship between FP and stock returns
220 (SR) of deposit banks traded in BIST during the period between 2007 and 2011. In this sense, they
221 used PROMETHEE method as one of the MCDM methods and Spearman Rank Correlation as
222 statistical method. On the other hand, Işık (2019) used the Entropy method to determine the
223 weights of financial variables, and applied TOPSIS method to evaluate the performance of the
224 companies in his study, in which he investigated the relationship between SR and the FP of the

225   companies in the BIST 30 Index. He analyzed the relationship between financial performance and
226   stocks by correlation analysis. Baydaş and Pamučar (2022); Baydaş et al. (2022) stated in his study
227   that there is a consistent and continuous relationship between MCDM-based FP and stock return
228   under certain constraints. In other words, some methods stably capture the relationship between
229   two variables better. This shows that methods that capture real life have a special capacity.
230
231   **2.4. Rank Reversal**
232   RR is a phenomenon where the order (rank) of some alternatives in the new scenario is reversed
233   when alternative(s) are added or removed. The reasonable suspect for the RR problem is usually
234   normalization, but not just that (Barzilai and Golany, 2017). Since normalization distorts the
235   original data in the first decision matrix, it violates the principle of independence from irrelevant
236   alternatives (PIIA) (Mufazzal and Muzakkir, 2018). To give an example, in the first case,
237   alternative A is higher in rank than alternative B in an MCDM ranking array. After adding or
238   subtracting a different alternative to the ranking, alternative A falls behind alternative B in the
239   ranking. Such a situation also means that the MCDM method produces an RR problem. In the
240   literature, the issue of RR, which is an important problem related to MCDM methods in many
241   scientific fields, has been researched and proposed solutions (Belton and Gear, 1983; Keshavarz-
242   Ghorabaee et al., 2018; Bączkiewicz et al., 2021; Agrawal, 2021). In general, rank reversal is a
243   valid problem for MCDM methods to some extent.
244   Comparative determination of the RR degree (performance) for MCDM methods for a given
245   problem is an important requirement. The classical approach in this regard consists of observing
246   the results by adding or subtracting an alternative. However, it is also possible to approach the
247   subject more comprehensively and statistically. In their study, Mufazzal and Muzakkir (2018)
248   recommended using the spearman rank correlation, which is a statistical method, to measure RR
249   sensitivity. In this study, the RR degree of MCDM methods was measured objectively with
250   Spearman correlation. The procedure used here is unique. Any MCDM calculations are made first
251   with the available alternatives. Then, as many alternatives as possible are discarded from the
252   system, and MCDM is calculated again with the remaining ones. If the correlation result of the
253   common alternatives in two different MCDM series is one (1), it is said that there is no RR
254   problem. The closer to zero, the greater the RR problem.
255   For example, in this study, half of the 140 alternatives are discarded from the system. The
256   correlation between the two 70 alternatives gives the degree of RR. Note that we are dealing with
257   subtracting alternatives for the first sequence and adding alternatives for the second sequence.
258   Also, the purpose of adding and removing a large number of alternatives here is to stress test an
259   MCDM method to force it to RR error (production) or to measure its RR immunity. This is a
260   procedure that has been proposed and successfully applied for the first time in the literature.
261   Moreover, it will be possible to compare MCDM methods with this objective RR measurement
262   framework.
263
264   **2.4. The Literature Gaps and Suggestions**
265   Our study has potential to fill some gaps in the literature by a more comprehensive analysis
266   procedure. Our suggestions and solutions for these gaps are listed as follows:
267   • It is a difficult and chronic problem to determine which of the MCDM methods is more
268   suitable and which one should be chosen. However, in this study, we made an application
269   with an indirect but practical, undeniable and objective criterion. Accordingly, we preferred
270   only one MCDM method in FP calculation that produces a better statistical correlation with

271   price. For example, some methods provide a low level and some methods provide a high-
272   level relationship between two variables, which we obviously know that they have
273   significant relationship. The different findings of MCDM methods show their success, thus,
274   we can compare different MCDM methods according to their capacity to capture real-life,
275   and then we can choose the most appropriate method.
276 • In this study, we will try to explore for the first time the RR sensitivity of MCDM methods
277   for a particular problem. We will search for valuable clues with MCDM analytics.
278 In the few previous studies using this procedure, the success of certain MCDM methods stands out
279 (Baydaş & Pamucar, 2022). Therefore, this study is aimed to see the big picture better and to reveal
280 the capabilities of different methods. In addition to the methods used in previous studies, some
281 new (e.g. COCOSO and CRADIS), classical (e.g. TOPSIS, VIKOR), and popular (e.g. FUCA and
282 MABAC) methods were used in this study. When a decision maker wants to compare MCDM
283 methods comprehensively, it is undoubtedly logical to use classical, popular, new, as well as all
284 schools ("outranking", utility, value, distance-based, etc.) in the literature. Accordingly, we used
285 representatives of all MCDM types in this study, including the new methods. There are more than
286 200 MCDM methods and the sample of MCDM methods in this study has a very high ability to
287 represent the universe.

288   ## 3. RESERCH METHODOLOGY

289

290 In this study, in which new objective criteria are proposed for the 'methodology for evaluating
291 MCDM methods', which is a rather complicated subject, 'MCDM analytics' has been conducted in
292 order to obtain valuable useful information from the 'data sets'. In this study, we first measured
293 the financial performance (FP) of 140 manufacturing companies traded in the BIST using MCDM
294 methods. FP was measured with nine MCDM methods, which are COCOSO, CRADIS, CODAS,
295 COPRAS, ELECTRE-3, FUCA, MABAC, TOPSIS, and VIKOR. Since there is no complete
296 agreement on which one should be used in the calculation of VIKOR, we added the S-R and Q
297 derivatives/components separately to the results. We have seen that its derivatives have different
298 capacities. SWARA, a subjective method, and CRITIC, an objective method, were used separately
299 for criterion weighting. Here, as readers can guess, we sought a valid answer to the question of
300 whether 'objective dynamic' or 'subjective static' methods are more successful when determining
301 the weight coefficient as a separate main purpose. Next, the 'Spearman Rank Correlation analysis
302 was applied to reveal which MCDM method establishes the current statistical relationship between
303 price (stock return/capital gain) and FP. As a second MCDM evaluation method, we followed an
304 innovative procedure and objectively proved the Rank Reversal (RR) performance of 9 MCDM
305 methods with findings in ten different real scenarios.

306

307   ### 3.1. Performance Metrics
308 Information about the FP measurement criteria and their calculation details are explained below
309 and shown in table-1. The ultimate goal of the firms in the stock market is to maximize the share
310 price and hence the firm value. In general, performance indicators that can establish a close
311 relationship with the share price in every period are not many and they are generally some basic
312 and vital metrics based on risk, value generation, and profitability. Moreover, they are not static
313 but change-based (Baydaş and Pamucar, 2022).
314   *Altman-Z Score*
315 The original use of the Altman-Z score was actually to determine and evaluate the degree of
316 closeness of a firm to bankruptcy, which has been used frequently for more than half a century. As

317   used in this study, its increase or decrease (change) value generally includes a linear and significant
318   relationship with SR. (Carton, 2004). The Altman-Z score is actually a very important risk
319   indicator that can also measure financial success. As it is a benefit-oriented criterion, higher values
320   are always expected for this indicator.
321   *ROE (Net Profit/Equity)*
322   ROE, defined as the ratio of net profit to equity, is one of the most classic and successful metrics
323   for a firm that focuses on the efficiency of profits per se. It is frequently used and recommended
324   to evaluate FP (Bodie et al., 2018). Its change value is usually in a linear and meaningful
325   relationship with price.
326   *MV/BV (Market Value/Book Value)*
327   It can be expressed as the ratio of market value to equity. It expresses the equivalent of the
328   accounting book value as the market value (Stewart, 2013). This is a result of pricing equity in the
329   market. High market pricing of book value by investors means there are high positive earnings
330   expectations for that stock.
331   *MVA margin*
332   MVA Margin is the ratio of MVA (Market Value Added) to net sales. MVA is a classic value-
333   based measure for assessing FP. MVA Margin is a benefit-oriented criterion derived from MVA
334   (Stewart, 2013). In other words, the MVA Margin measures the value created or eroded by net
335   sales. It gives an important insight into the company in general, whether sales translate into value.

336   **Table 1:** Calculation Details of the Criteria Used in the Study

337

338   **3.2 MCDM Methods**

339

340   In this study, 9 MCDM methods were calculated for 140 companies and 10 separate quarters. First
341   of all, financial performance results based on MCDM were evaluated to show the relationship with
342   stock returns. Then, for the Rank Reversal performance calculation, in addition to the current
343   MCDM results for the 140 companies at hand, the financial performance was calculated again with
344   MCDM methods for 70 companies. Spearman correlation results between 70 common companies
345   in the two lists were compared for the RR level. Therefore, since a total of 180 MCDM calculations
346   were made, it was not possible to show their results in the article or in the appendices (because it
347   took up too many pages). Brief descriptive explanations of MCDM methods are given below. Due
348   to a large number of methods, the steps related to the calculation steps of the formulas are presented
349   as tables in the Supplementary files. Brief descriptive explanations of MCDM methods are given
350   below. Due to a large number of methods, the steps related to the calculation steps of the formulas
351   are presented as tables in the Supplementary files. Table 2 shows the names, descriptions and
352   references of the MCDM and weighting methods used in this Study.

353

354   **Table 2:** Methods used in this Study

355

356   **3.3. Weighting Method**
357   In order to understand which one is more efficient as a weighting method, both objective and
358   subjective methods were preferred in this study. These are SWARA (Step-Wise Weight
359   Assessment Ratio Analysis) and CRITIC (Criteria Importance Through Inter Criteria Correlation)
360   whose information is given in the table above. SWARA is a relatively new criterion weighting
361   method compared to the classical others, which is a widely used weighting technique. It is also a

362 subjective method as it recommends getting an expert opinion. SWARA was preferred in this study
363 because it better reflects the expert opinion and provides a broad perspective. Basically, value-
364 based ratios should have a higher weighting coefficient than accounting-based ratios. SWARA is
365 a method that has the capacity to consider this situation. In addition to SWARA, CRITIC weighting
366 methods were also calculated in our study and all final results were compared to gain further
367 insight.

368
369

370   **4. FINDINGS AND DISCUSSIONS**
371   **4.1. Data Set and Experimental Design**
372 In order to measure financial performance with MCDM methods, 140 manufacturing companies
373 operating in the manufacturing sector in the Turkish BIST were taken into account and four
374 different performance indicators belonging to these companies were determined as decision
375 criteria. The performances of these companies in 10 quarters (2019-2021) were taken as the subject
376 of the study. MCDM-based financial performance (FP) of companies (for each quarter) was
377 calculated separately. The financial data of the companies were taken through FİNNET
378 Commercial data software. COCOSO, CRADIS, CODAS, COPRAS, ELECTRE-3, FUCA,
379 MABAC, TOPSIS and VIKOR (S,R,Q) methods were used as MCDM methods to measure the
380 performance of the companies. Then the relationship of MCDM results with SR (stock return) was
381 obtained by Spearman rank correlation coefficient for each base period.

382
383   The steps of the experimental process of the study are explained below and summarized in
384 Figure 1.
385   *First Stage*: It includes the steps consisting of the determination of the criteria, the creation
386 of the first decision matrix, which is the basis for the calculations, data normalization and MCDM
387 calculations.
388   *Second Stage*: In the second stage, the final results of the MCDM methods are evaluated.
389 MCDM methods are compared in terms of their relation to SR and RR performance. Spearman
390 Correlation Analysis is used for both of these criteria. In addition, two different weighting methods
391 are compared.
392   *Third Stage*: In the third stage, the evaluation methodology is applied meticulously.
393 Ultimately, the best companies are determined for each quarter. For this, first, an MCDM must be
394 selected from among the alternatives. For MCDM selection, methods that show joint success in
395 both criteria are examined. In addition, it is determined which of the weighting methods will be
396 decided. Thus, based on the appropriate method, the best company is selected and recommended
397 to the decision maker. A stock selection recommendation is beyond our scope here because our
398 purpose is purely methodological. But users can also use the methodology here as a partial
399 dimension of fundamental analysis. The flow chart of this study is shown below.
400   **Figure 1:** Flowchart of the Study

401
402

403 **4.2. FINDINGS**

404

405   **4.2.1. Determination Of Weighting Coefficient for MCDM Based FP Criteria**
406 In fact, although the classical static ratios give an idea, a general evaluation of the change ratios of
407 the overall financial performance of the companies and a stock-focused FP is a good guide for us.

408 In order to make a fair comparison, common criterion weighting coefficients for MCDM methods
409 should be obtained. For this reason, SWARA, which is one of the subjective techniques, and the
410 CRITIC method, which is an objective method, were used in this study, which was made with the
411 contributions of 3 experts. According to the analysis findings, SWARA was adopted in all
412 assessments, as the SWARA method (as will be proved later) is obviously and dominantly better
413 than the CRITIC method. Calculation Results for the SWARA Criterion Weighting coefficient are
414 as follows: Altman-Z Score 0.163; ROE 0.163; MV/BV is 0.245, MVA Margin is 0.428. CRITIC
415 weighting coefficients, which is an objective method, are shown in Table-4 below. In fact, another
416 invisible main purpose of this study is to make a comparison for objective and subjective methods.
417   **Table 3:** CRITIC Criteria Weighting Results

419 It should be noted here that the SWARA method is static/single for all periods and the CRITIC
420 method is dynamic/variable.

422   **4.2.2. Comparison of the Calculated MCDM Methods and Analysis Findings of the**
423 **Suggested Evaluation Methodology**
424 Recently, some researchers, who have been making MCDM calculations with financial-based data,
425 are interested in finding the most appropriate MDCM method by using the relationship between
426 FP and SR as a tool. It may be possible for an MCDM method that better models real life to better
427 capture SR rankings. At this point, the statistical relationship between FP and SR rankings
428 calculated by Spearman's Rank Correlation method can be evaluated. For comparison, 9 new,
429 classical and popular MCDM methods were compared statistically with SR separately. The final
430 spearman rho correlation coefficient results obtained with this approach are shown in table 5 and
431 table 6 below.
432   **Table 4:** Rho Coefficients Showing the Relationship Between SR Rankings and SWARA

433   Integrated MCDM Rankings

434 FUCA is able to produce a better relationship to real life compared to other methods and has more
435 consistent success in most quarters and averages. Table 6 below confirms that FUCA is the winner
436 in all the remaining periods except for one period, according to the rho results. While VIKOR's Q
437 ranking results are very good, R and S results are not so good. When these three results are
438 averaged, VIKOR is not in the top three. The top three successful methods in terms of sequencing
439 performance are FUCA, CoCoSo, and CRADIS methods. It is seen that ELECTRE-3 and
440 COPRAS are in last place. The fact that COPRAS is first in the ninth quarter and third in the
441 seventh quarter, but generally second to last, shows how volatile this method is. We consider that
442 the results will be more positive when an appropriate normalization selection and some minor
443 computational improvements are made to this method. We have similar thoughts about CODAS.
444 Despite the volatile nature of financial data, the very stable and consistent performance of the
445 MABAC method is admirable and remarkable. Although TOPSIS is the most widely adopted and
446 popular method in MCDM history, its performance is mediocre.
447   **Table 5:** Rho Performance Ranking of SWARA-based MCDM results

449 It is clear how variable the quarterly ranking results are for methods other than FUCA and
450 MABAC. It is a matter of curiosity whether the successful performance of FUCA and the new
451 methods CoCoSo and CRADIS will also be valid for the other evaluation criteria, RR. Table 7

452 below shows the Rank Reversal (RR) sensitivity analysis results of MCDM methods in each
453 quarter and the general mean. In this study, a very innovative and practical procedure was
454 determined. We suggest a more objective assessment than classical RR measures, as we know that
455 RR sensitivity is a serious consistency issue that can distort rankings. In classical measures, an
456 alternative is added and subtracted, and then it is observed by checking the individual alternatives
457 whether the consistency in the ranking is impaired. However, such a measurement does not allow
458 us to make a general conclusion about an MCDM method, so the final results are somewhat
459 random. Moreover, individual control is a weak evaluation from a statistical point of view. In this
460 study, we performed the RR sensitivity multiple times (10 times) for 10 quartiles. Moreover, we
461 operated this for 9 different methods. Moreover, we ultimately did not observe the alternatives and
462 instead performed the Spearman correlation analysis. We continue to explain the procedure
463 through our example. RR can be measured logically and objectively through Spearman Rank
464 correlation. (Mufazzal and Muzakkir, 2018) We already have the final ranking results of all
465 MCDM methods for 140 companies from previous analyses. Then, in order to calculate the RR,
466 we divided 140 firms in the middle (we divide them in alphabetical order to be fair) and again
467 made the MCDM calculations using the same decision matrix and weight coefficients of the first
468 seventy firms. Then, we compared the MCDM results of 70 companies in the first list with the 70
469 companies in the second list with Spearman correlation analysis. Here, the correlation results will
470 produce values between 0-1. If the result is close to 1(one), it means that there is no RR problem
471 at all. If the result is close to 0 (zero), it means that the RR problem increases. Notice that we
472 subtract alternatives according to the first list and add alternatives according to the second list.
473 Adding and removing as many alternatives as possible will produce more reliable and valid results
474 for an MCDM method as it is almost a stress test. Users can also run a separate RR test for the
475 second list, which we recommend.
476
477 **Table 6**: Rank Reversal level produced by SWARA-based MCDM Rankings
478

479 According to the results of Table 7 above, the method with the best performance according to RR,
480 another MCDM evaluation criterion, is FUCA (as before). The RR Analysis findings show that,
481 in general, MCDM methods produce very low RR problems, the results are close to each other,
482 but the presence of RR is present. It is noteworthy that the CRADIS, MABAC and S methods have
483 the same degree of RR on average. Rarely in some quarters, some MCDM methods produced no
484 RR at all. For VIKOR, while the Q method was prominent in the previous analysis, the S order
485 was more successful in this analysis. There are 6 different quarters where the R method produces
486 no RRs, but the others have low average performance because they produce high RRs. In parallel
487 with the previous analysis, we observed that the performance of the derivatives of the VIKOR
488 method is volatile here as well. We continue to think that minor computational improvements
489 (revisions) are critical for VIKOR, which has a high potential. It is clear that TOPSIS, the most
490 popular method, performed mediocrely in this analysis as well as before. COPRAS clearly stands
491 out as the MCDM method that is exposed to the highest degree of RR problems. In both analyses,
492 the performance of the CODAS, COPRAS, and ELECTRE-3 methods is low. If it is accepted that
493 the RR problem is caused by normalization, it is recommended to use different normalization types
494 for these methods.
495
496 **Table 7**: Ranking of SWARA-based MCDM methods by Rank Reversal performance

497

498 According to the MCDM RR ranking performance findings in table 8 above, the performance of
499 the new methods CoCoSo and CRADIS, as well as FUCA, are the best. In the previous analysis,
500 CRADIS was in the top three and continued its success here as well. When we make an evaluation
501 based on the two criteria, the most successful methods are CRADIS and FUCA. It is not possible
502 for these objective results, which we evaluated with two criteria for 10 different real-life scenarios,
503 to be coincidental. It has also caught the reader's attention that we have run all analyzes based on
504 the SWARA weighting method, which is a subjective method from the beginning. In fact, an
505 objective method, CRITIC, was also used as an alternative in this study. But SWARA is obviously
506 more successful when it comes to its relation to real life. This can be clearly seen in the table
507 below. These findings show that it is critical to consult experts in the field to determine the weight
508 coefficient. Table-9 below shows the Relationship between SR Rankings and CRITIC-based
509 MCDM Rankings.

510

511   **Table 8:** Rho Coefficients of Different CRITIC based MCDM Rankings with SR Rankings

512
513

514 It can be better seen in the table 10 below that the CRITIC method weakens its relationship with
515 the SR for any MCDM method. It is quite remarkable here that FUCA is less affected by the weight
516 coefficient. The SWARA method is more successful when we take the period averages as a basis.
517   **Table 9**: Comparison of CRITIC and SWARA methods

518

519 **4.3. DISCUSSIONS**

520 As is known, the methodology for evaluating MCDM methods is one of the most difficult and
521 intricate issues. Because it is still not clear which MCDM method is superior and on what basis it
522 was chosen. Even small objective steps to be taken in this regard are of great value. Original
523 findings about the characteristics of MCDM methods will be instructive. Some previous recent
524 authors (Baydaş and Pamucar, 2022) suggested that a stock return could be used as a reference for
525 financial data. In this study, we add another one to this criterion, which is Rank Reversal. Rank
526 Reversal is actually a previously well-known concept, but in no study has it been calculated as
527 reliably and comprehensively as the statistical procedure here. In this study, we can say that we
528 have taken a comprehensive inventory of Rank Reversal performance for MCDM methods (for
529 financial data). With data analytics, large-scale data has been transformed into very useful
530 information for the user. On the other hand, the fact that both criteria produce similar results at the
531 same time confirms the accuracy of this study. The following figure 6 supports the idea that the
532 two criteria we recommend to methodologists for evaluating MCDM methods should be used
533 simultaneously. In other words, if the following figure 6 is carefully examined, it shows that both
534 methods act in parallel, that is, successful, mediocre, and unsuccessful methods in both methods
535 are similar to a certain extent.
536
537   **Figure 2**: Similarity of MCDM benchmarking tools

538

539 The analysis findings of this study prove that in general (for both criteria) FUCA and CRADIS
540 methods for financial data are stable to success, TOPSIS mediocre, VIKOR volatile, and
541 COPRAS, CODAS, ELECTRE underperforming. Moreover, this study shows that SWARA,
542 which is a subjective weighting technique, is clearly more successful than the CRITIC method,
543 which is an objective technique.

544

545   *Limitations in the Study*
546 The MCDM evaluation criteria proposed here are general and can be easily used for ranking
547 problems in any scientific field. However, the comparative results obtained are mostly valid for
548 financial data. MCDM methods either use some normalization techniques such as Sum, Min-Max,
549 Max, and Vector or may work without normalization like some 'outranking' methods. Since
550 financial data is quite volatile (skewness-kurtosis is variable), periodic normalization methods do
551 not always show the same performance. Therefore, data in other fields may result in the success
552 of another MCDM result. For example, for financial data, FUCA may perform best, while for
553 economic data, CODAS may perform best. Data type and structure is the most important limitation
554 of this study. Firm data, normalization type, quarters, MCDM methods, weighting methods, and
555 some threshold values used in this study are other limitations of this study. Although many
556 methods and data types are used extensively in this study to overcome the limitations of the
557 problem, the problems explained here should be considered as a limitation.

558

559

560   **5. CONCLUSIONS**
561 Choosing the best among the multi-criteria alternatives is a classic MCDM problem in the selection
562 of a high-performing firm, as in other areas of expertise. However, the literature states that it is a
563 mystery as to which MCDM method should be preferred among the 200 methods. Even the
564 smallest indirect development can be considered a very important step in this regard. Although it
565 is a complex and insoluble problem in theory, the results of applied data analytics of financial
566 markets show us that the situation is promising. In fact, the relationship between FP (financial
567 performance based on MCDM) and SR (share return), which is defined as the success status of
568 companies, promises a special and natural solution in this regard. As it is known, these two
569 dynamic systems have simultaneous and meaningful relationships. Therefore, the success of a few
570 MCDM methods that ensure this relationship at the highest level and sustainably cannot be a
571 coincidence. While classical studies focus on the mathematical theoretical background of the
572 subject, this study shows that real-life data analytics can offer solutions from a different
573 perspective. According to the data of the manufacturers traded in BIST in Turkey, our findings
574 show that the FUCA and CRADIS method (with these constraints and data conditions) is a more
575 suitable method than the other 5 popular methods. Because these methods have a better-established
576 relationship with real-life rankings. Moreover, the RR (rank reversal) performance of these
577 methods (when we approach the subject for the first time with a statistical procedure proposed in
578 this study) is better.
579 Unlike previous studies, very wide time periods, alternatives, and comparisons of MCDM methods
580 and MCDM have been comprehensively discussed in the analysis without leaving any room for
581 coincidence. This study proposes two different frameworks simultaneously for the comparison,
582 evaluation, and selection of MCDM methods, which is its original and innovative approach. The
583 model framework in this study assists the robustness, sensitivity, and validation analysis frequently
584 used in the MCDM evaluation methodology. The proposal of this study can also help develop any
585 MCDM method. Because with the help of this procedure, new and efficient MCDM algorithms

586 can be developed. Therefore, in our opinion, our study proposes robust, original, and objective
587 criteria for the comparison, selection, and development of MCDM methods.
588 Recommendations for Future Researchers
589 As practiced in this study, if researchers can find a real-life anchor or a relevant sequencing
590 sequence, they can apply the MCDM capacity assessment model in their field of scientific
591 expertise. Moreover, the RR criterion is more universal and can be easily used in all fields of
592 science. In addition to the MCDM selection, algorithm, normalization, threshold, and preference
593 function selection can also be made through the model here. Since the MCDM evaluation criteria
594 proposed here are objective, they can also be used as a validation tool in the production of a new
595 MCDM. Finally, we also recommend users compare fuzzy-based data and net/exact values with
596 these criteria.

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Figure 1

Flowchart of the Study
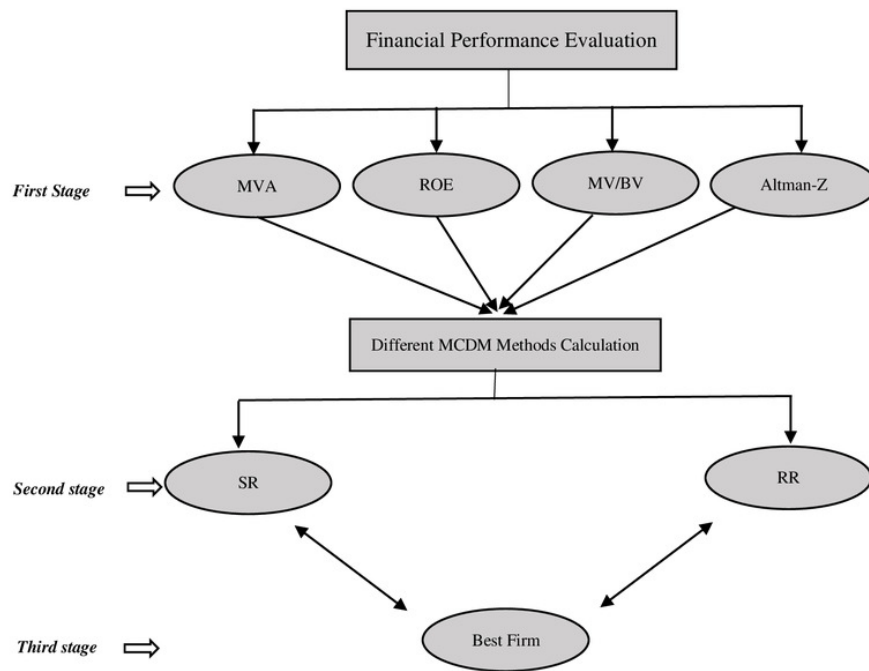
Figure 2

Similarity of MCDM benchmarking tools
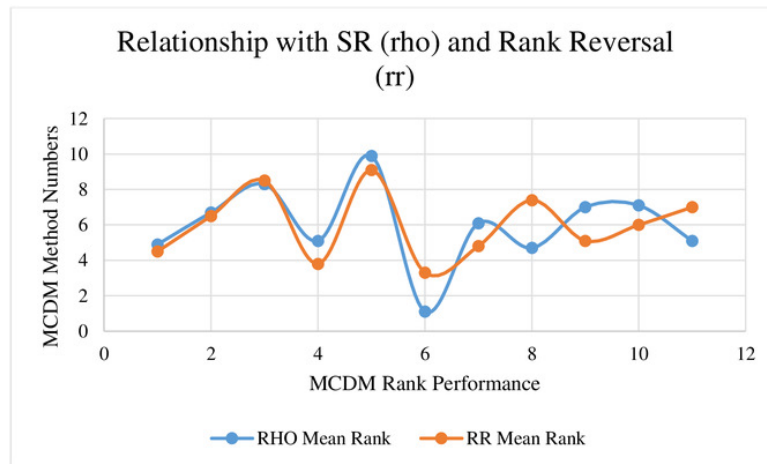
Figure 2: Similarity of MCDM benchmarking tools

Calculation Details of the Criteria Used in the Study

1   **Table 1:** Calculation Details of the Criteria Used in the Study

Ratio	Calculation	Formula No.	References
MV/BV	Marketing Value/Equity	(1)	Stewart (2013)
ROE	Net Profit / Equity Value	(2)	Bodie vd. (2018)
MVA margin	(MVt - Inv. Cap. t-1) / Sales t-1	(3)	Stewart (2013)
ALTMAN-Z Score	1.2A + 1.4B + 3.3C + 0.6D + 1.0E A= Working Capital/Total Assets B= Retained Profits/Total Assets C= Earnings Before Interest and Tax/Total Assets D= Market Value of Assets/Total Liabilities E= Sales/Total Assets	(4)	Carton, (2004)
Stock Return	(Current Stock Price - Previous Period Base Price) / Base Price (5)		Carton and Hofer (2006)

Methods used in this Study

MCDM Methods	Explanation	References
COCOSO	The proposed approach is based on an integrated simple additive weighting and exponentially weighted product model. Recommended as a summary of reconciliation solutions.	Yazdani et al., 2018; Badi et al., 2022; Torkayesh et al., 2021
CRADIS	The philosophy of the CRADIS method is to determine the deviations of the alternatives from the ideal and anti-ideal solution. It can be said that this method is a combination of steps drawn from ARAS, MARCOS and TOPSIS methods.	Puška et al., 2022; Puška and Stojanović, 2022
CODAS	Since the overall performance of an alternative in CODAS is measured by its distance from the negative ideal point (NIS), each pair of alternatives is compared. In this method, the first criterion used in the superiority of alternatives to each other is the Euclidean distance and taxi distance of the alternatives considered from the negative ideal.	Wang et al., 2020
COPRAS	In this method, how useful or unhelpful an alternative is compared to other alternatives is defined as a percentage. The higher the priority of the analyzed alternative, the higher the degree of utility. Thus, the degree of utility is determined by comparing each alternative with the most efficient alternative.	Zavadskas&Kaklauskas, 1996; Wang et al., 2020; Tripathi et al. 2022; Ecer, 2021
FUCA	This method is based on ranking the alternatives for each criterion. The first row has the best value, while the last row (n) is assigned the worst value. Then, the weighted sum of the values for each solution point is calculated and the solution with the smallest total value is the best-chosen solution.	Mendoza et al., 2011; Wang and Rangaiah 2017; Baydaş and Pamucar, 2022; Do, 2022.
ELECTREIII	Using the satisfaction and dissatisfaction criteria at the same time, ELECTRE-3 also has both incompatibility and compatibility indices. Therefore, it can be considered as a method of listing the bilateral relations between alternatives.	Wang and Rangaiah ,2017
TOPSIS	In the TOPSIS method developed by Hwang and Yoon, the best alternative chosen is also the closest to the positive ideal solution and the farthest to the negative ideal solution. This method, based on vector distance and ideal values, is the most widely adopted classical method in various fields and in the nearly half-century history of MCDM.	Çınar, 2004; DeAlmeida-Filyo et al., 2020.
MABAC	The descriptive definition for MABAC, one of the most popular methods in the last decade, is the distance of each non-dominant solution from the target's boundary zoom area.	Pamučar and Ćirović, 2015; Wang et al., 2020).
VIKOR	A popular and sophisticated method, VIKOR is based on consensus and ranking assumptions. For this purpose, a multi-criteria ranking index is created over the alternatives and their closeness to the ideal solution is calculated and compared. It is a recommended method in situations where compromise solutions must be used to solve problems effectively and efficiently, especially in scenarios where conflict and incompatibility occur.	Wang and Rangaiah 2017)
Weighting Method		
SWARA	It is based on ranking the criteria in decreasing order of importance by the decision maker (the first criterion is the most important, the last criterion is the least important).	Keršulienė et al. (2010); (Wang et al., 2020); (Stević et. al. 1-b, 2022).
CRITIC	CRITIC is an objective method that takes into account the standard deviation of the criteria and the dependence (correlation) between them.	Diakoulaki et al. (1995)

CRITIC Criteria Weighting Results

Table 3: CRITIC Criteria Weighting Results

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
	2019/03	2019/06	2019/09	2019/12	2020/03	2020/06	2020/09	2020/12	2021/03	2021/06
ALTMAN-Z Score	0.194	0.176	0.171	0.245	0.231	0.183	0.173	0.205	0.210	0.156
ROE	0.306	0.325	0.354	0.252	0.190	0.302	0.343	0.375	0.286	0.461
MV/BV	0.333	0.249	0.300	0.226	0.182	0.330	0.270	0.249	0.200	0.187
MVA margin	0.167	0.249	0.179	0.276	0.397	0.185	0.213	0.171	0.304	0.196

Rho Coefficients Showing the Relationship Between SR Rankings and SWARA Integrated
MCDM Rankings

1   **Table 4:** Rho Coefficients Showing the Relationship Between SR Rankings and SWARA

2   Integrated MCDM Rankings

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	
	2019/03	2019/06	2019/09	2019/12	2020/03	2020/06	2020/09	2020/12	2021/03	2021/06	MEAN
FUCA	0.503	0.479	0.487	0.697	0.673	0.717	0.852	0.861	0.58	0.672	0.652
Q (VIKOR)	0.432	0.392	0.449	0.525	0.475	0.6	0.697	0.794	0.351	0.571	0.528
TOPSIS	0.395	0.391	0.367	0.382	0.592	0.471	0.613	0.846	0.564	0.646	0.526
COCOSO	0.374	0.421	0.309	0.503	0.484	0.599	0.671	0.611	0.361	0.638	0.497
MABAC	0.366	0.421	0.294	0.469	0.488	0.54	0.642	0.724	0.361	0.638	0.494
S (VIKOR)	0.366	0.421	0.294	0.469	0.488	0.54	0.642	0.724	0.361	0.638	0.494
CRADIS	0.366	0.421	0.294	0.469	0.488	0.54	0.642	0.724	0.361	0.638	0.494
R (VIKOR)	0.299	0.227	0.458	0.56	0.367	0.554	0.667	0.698	0.25	0.42	0.45
CODAS	0.2	0.435	0.409	0.192	0.572	0.056	0.512	0.853	0.487	0.495	0.421
COPRAS	0.3	0.099	0.011	0.281	0.094	0.089	0.682	0.618	0.81	0.527	0.351
ELC3	0.123	0.357	0.241	0.318	0.308	0.339	0.324	0.607	0.087	0.541	0.324

Rho Performance Ranking of SWARA-based MCDM results

Table 5: Rho Performance Ranking of SWARA-based MCDM results

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Rank Mean
FUCA	1	1	1	1	1	1	1	1	2	1	1.1
Q	2	7	3	3	8	2	2	4	9	7	4.7
COCOSO	4	3	6	4	7	3	4	10	5	3	4.9
CRADIS	5	4	7	5	4	5	6	5	6	4	5.1
TOPSIS	3	8	5	8	2	8	9	3	3	2	5.1
MABAC	6	5	8	6	5	6	7	6	7	5	6.1
CODAS	10	2	4	11	3	11	10	2	4	10	6.7
R	9	10	2	2	9	4	5	8	10	11	7
S	7	6	9	7	6	7	8	7	8	6	7.1
COPRAS	8	11	11	10	11	10	3	9	1	9	8.3
ELC3	11	9	10	9	10	9	11	11	11	8	9.9

Rho Performance Ranking of SWARA-based MCDM results

Table 6: Rank Reversal level produced by SWARA-based MCDM Rankings

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	*Mean*
FUCA	0.994	0.998	0.997	0.999	0.994	0.984	0.996	0.998	0.997	0.998	0.995
CRADIS	0.995	0.997	1	0.983	0.969	0.987	0.987	0.976	0.942	0.976	0.981
MABAC	0.995	0.997	1	0.983	0.969	0.987	0.987	0.976	0.942	0.976	0.981
S	0.995	0.997	1	0.983	0.969	0.987	0.987	0.976	0.942	0.976	0.981
COCOSO	0.995	0.998	1	0.967	0.987	0.959	0.969	0.977	0.92	0.976	0.974
TOPSIS	0.938	0.978	0.976	0.968	0.99	0.958	0.911	0.923	0.98	0.994	0.961
Q	0.906	0.996	1	0.971	0.982	0.944	0.901	0.867	0.992	0.959	0.951
CODAS	0.993	0.982	0.999	0.999	0.857	0.994	0.974	0.875	0.84	0.994	0.950
ELECTRE3	0.966	0.985	0.995	0.929	0.91	0.947	0.915	0.877	0.857	0.901	0.928
R	0.495	1	1	1	1	1	0.647	0.639	1	0.906	0.868
COPRAS	0.267	0.097	0.902	0.956	0.984	0.998	0.471	0.934	0.867	0.909	0.738

Ranking of SWARA-based MCDM methods by Rank Reversal performance

1   **Table 7**: Ranking of SWARA-based MCDM methods by Rank Reversal performance

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	RR Mean
FUCA	5	3	8	3	2	7	1	1	2	1	3.3
CRADIS	2	4	2	4	7	4	2	3	5	5	3.8
COCOSO	1	2	1	9	4	8	6	2	8	4	4.5
MABAC	3	5	3	5	8	5	3	4	6	6	4.8
R	10	1	5	1	1	1	10	11	1	10	5.1
S	4	6	6	6	9	6	4	5	7	7	6
CODAS	6	9	7	2	11	3	5	9	11	2	6.5
TOPSIS	8	10	10	8	3	9	8	7	4	3	7
Q	9	7	4	7	6	11	9	10	3	8	7.4
COPRAS	11	11	11	10	5	2	11	6	9	9	8.5
ELECTRE3	7	8	9	11	10	10	7	8	10	11	9.1

Ranking of SWARA-based MCDM methods by Rank Reversal performance

1   **Table 8:** Rho Coefficients of Different CRITIC based MCDM Rankings with SR Rankings

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Rho Mean
COCOSO	0.278	0.362	0.266	0.423	0.435	0.458	0.46	0.414	0.232	0.521	0.384
CODAS	0.134	0.453	0.309	0.157	0.416	0.03	0.214	0.851	0.357	0.535	0.345
COPRAS	0.369	0.02	0.107	0.215	0.02	0.131	0.481	0.752	0.795	0.228	0.311
CRADIS	0.271	0.369	0.237	0.379	0.432	0.375	0.413	0.473	0.179	0.526	0.365
ELECTRE3	0.134	0.282	0.207	0.269	0.275	0.274	0.215	0.41	0.025	0.454	0.254
FUCA	0.455	0.505	0.406	0.64	0.599	0.561	0.78	0.744	0.501	0.653	0.584
MABAC	0.271	0.369	0.237	0.379	0.432	0.375	0.413	0.473	0.179	0.526	0.365
Q	0.588	0.284	0.373	0.457	0.463	0.597	0.724	0.237	0.179	0.43	0.433
R	0.739	0.215	0.388	0.54	0.366	0.635	0.783	0.028	0.254	0.3	0.424
S	0.271	0.369	0.237	0.379	0.432	0.375	0.413	0.473	0.179	0.526	0.365
TOPSIS	0.218	0.306	0.228	0.286	0.436	0.199	0.242	0.552	0.287	0.452	0.320

Comparison of CRITIC and SWARA methods

Table 9: Comparison of CRITIC and SWARA methods

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Rho Mean
FUCA-SW	0.503	0.479	0.487	0.697	0.673	0.717	0.852	0.861	0.58	0.672	0.652
FUCA-C	0.455	0.505	0.406	0.64	0.599	0.561	0.78	0.744	0.501	0.653	0.584
Q-SW	0.432	0.392	0.449	0.525	0.475	0.6	0.697	0.794	0.351	0.571	0.528
TOPSIS-SW	0.395	0.391	0.367	0.382	0.592	0.471	0.613	0.846	0.564	0.646	0.526
COCOSO-SW	0.374	0.421	0.309	0.503	0.484	0.599	0.671	0.611	0.361	0.638	0.497
CRADIS-SW	0.366	0.421	0.294	0.469	0.488	0.54	0.642	0.724	0.361	0.638	0.494
MABAC-SW	0.366	0.421	0.294	0.469	0.488	0.54	0.642	0.724	0.361	0.638	0.494
S-SW	0.366	0.421	0.294	0.469	0.488	0.54	0.642	0.724	0.361	0.638	0.494
R-SW	0.299	0.227	0.458	0.56	0.367	0.554	0.667	0.698	0.25	0.42	0.45
Q-CR	0.588	0.284	0.373	0.457	0.463	0.597	0.724	0.237	0.179	0.43	0.433
R-CR	0.739	0.215	0.388	0.54	0.366	0.635	0.783	0.028	0.254	0.3	0.424
CODAS-SW	0.2	0.435	0.409	0.192	0.572	0.056	0.512	0.853	0.487	0.495	0.421
COCOSO-CR	0.278	0.362	0.266	0.423	0.435	0.458	0.46	0.414	0.232	0.521	0.384
CRADIS-CR	0.271	0.369	0.237	0.379	0.432	0.375	0.413	0.473	0.179	0.526	0.365
MABAC-CR	0.271	0.369	0.237	0.379	0.432	0.375	0.413	0.473	0.179	0.526	0.365
S-CR	0.271	0.369	0.237	0.379	0.432	0.375	0.413	0.473	0.179	0.526	0.365
COPRAS-SW	0.3	0.099	0.011	0.281	0.094	0.089	0.682	0.618	0.81	0.527	0.351
CODAS-CR	0.134	0.453	0.309	0.157	0.416	0.03	0.214	0.851	0.357	0.535	0.345
ELC3-SW	0.123	0.357	0.241	0.318	0.308	0.339	0.324	0.607	0.087	0.541	0.324
TOPSIS-CR	0.218	0.306	0.228	0.286	0.436	0.199	0.242	0.552	0.287	0.452	0.320
COPRAS-CR	0.369	0.02	0.107	0.215	0.02	0.131	0.481	0.752	0.795	0.228	0.311
ELECTRE3-CR	0.134	0.282	0.207	0.269	0.275	0.274	0.215	0.41	0.025	0.454	0.254