An Application of Multicriteria Approach to Compare Economics Sectors: The Case of Sinaloa, Mexico

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Abstract. In this paper, a multicriteria approach for ranking the performance of the economic sectors of the Sinaloa economy is proposed, and the most attractive sectors are identified. To achieve this goal, the software SADAGE was used for solving ranking problems, which require one to rank a set of alternatives - given evaluations in terms of several criteria - in decreasing order of preference. The approach uses the ELECTRE III method to construct a valued outranking relation and then a multiobjective evolutionary algorithm (MOEA) to exploit the relation to obtain a recommendation. The retail and manufacturing sectors were ranked first in all the rankings; the utilities sector was ranked second in all the rankings; the mining sector and the management of companies and enterprises sector were ranked lowest. The results of this application can be useful for investors, business leaders, and policy-makers. This study also contributes to an important, yet relatively new, body of application-based literature that investigates multicriteria decision making that use fuzzy theory and evolutionary multi-objective optimization methods.

Keywords: Multicriteria Decision Analysis, Economic Sectors, Ranking Problem, ELECTRE III, Multiobjective Evolutionary Algorithms.

Introduction

One of the most important requirements for planning the economic development of developing countries is to be able to promote different economic sectors appropriately to contribute most effectively toward solving social, economic and other related problems. (Sudaryanto, 2000).

Firms, industries and entire sectors operating within the Mexican economy have experienced varying degrees of success in coping with the competitive global economic environment. Therefore, investors and policy-makers must assess economic performance in a relatively new context.

In recent years, multicriteria-based methods have been employed to assess the performance of economic sectors and have yielded decision-making implications (e.g., Augusto et al., 2005; Balezentis et al., 2012; Sudaryanto, 2000). However, such applications are still limited in number and scope. This relatively small number of applications is interesting because multicriteria methods can be adapted to the economic and social sciences (Treadwell, 1995).

This study utilizes a multicriteria approach to construct an aggregation model of preferences and then a multiobjective evolutionary algorithm to exploit the model to rank the performance of economic sectors of the Sinaloa, México economy. While the application has practical implications, the method has not yet been sufficiently developed.

This study also contributes to an important, yet relatively new, body of application-based literature that concerns a multicriteria, and multiobjective evolutionary approach to decision-making.

This paper is organized as follows: the second section presents a brief description of the relevant literature concerning the performance of economic sectors. The third section describes a study and focuses on the procedure and method used. The fourth section describes a sensitivity analysis of the final result. The fifth section presents results and a brief discussion. The final section presents concluding comments.

2 Literature Review

Most social, economic, biological and environmental systems are complex in nature; therefore, measuring their performance is a multifaceted and difficult task (Augusto et al., 2005). Thus, economic sectors are not easy to compare. In practice, several approaches can be used to measure the performance of economic systems. These approaches include multiple criteria optimization (Steuer, 1986), multiple criteria decision theory (Keeney and Raiffa, 1993) and multicriteria decision aiding (Roy, 1996). The ELECTRE methods (Roy, 1996) are a group of well-known decision aiding methods. In recent years, a vast number of applications with ELECTRE methods to performance ranking problems were developed (Karagiannidis and Moussiopoulos, 1997; Rogers and Bruen, 1998; Salminen et al., 1998; Teng and Tzeng, 1994; Martel et al., 1988; Beccali et al., 1998; Georgopoulou et al., 1997; Siskos and Hubert, 1983; Blondeau et al., 2002; Colson, 2000; Augusto et al., 2005; Leyva, 2005).

Fuzzy set theory (Zadeh, 1965) is also significant in the social sciences and humanities because it can treat ambiguities, uncertainties, and vagueness that cannot be treated by methods that use crisp values. Balezentis et al. (2012) presented an integrated assessment of Lithuanian economic sectors based on financial ratios and fuzzy Multicriteria Decision Making (MCDM) methods. Three fuzzy MCDM methods were applied in this study: VIKOR (Kaya and Kahraman 2011), TOPSIS (Yu and Hu, 2010), and ARAS (Turskis and Zavadskas, 2010).

Sudaryanto (2000) described the application of a fuzzy multi-attribute decisionmaking model for the empirical identification of the key sectors of the Indonesian economy. Diaz et al (2006) presented a fuzzy clustering approach to identify the key sectors of the Spanish economy. Furthermore, Misiūnas (2010) analyzed the performance of Lithuanian economic sectors using financial analysis. As demonstrated in previous studies (Xidonas and Psarras 2009; Xidonas et al. 2009, 2010), the application of multicriteria methods significantly improves the robustness of financial analysis and business decisions. Balezentis et al (2012) proposed a method of inter-sectoral comparison based on financial indicator analysis that uses multicriteria decision making methods.

Finally, evolutionary algorithms are beginning to be used in the outranking approach to address large-scale problems and to mitigate the complexity of some computations in the outranking methods; the complexity is primarily due to the nonlinearity of the formulas used in these methods (Figueira et al., 2010).

3 The Study

3.1 Research Framework A decision-aiding method is only relevant for decision processes that involve decision makers. In this paper, we will focus our attention on the set of activities (steps) occurring within such a setting. Tsoukias (2007) called such a set of activities a "decision aiding process". The ultimate objective of this process is to arrive at a consensus between the decision maker and the analyst. The decision maker has domain knowledge concerning the decision process. In contrast, the analyst has methodological, domain independent knowledge. Given the decision maker's domain knowledge and the analyst's methodological knowledge, the analyst must interpret the decision maker's concerns and knowledge so that he or she can improve his or her perceived position concerning the reference decision process. Such an interpretation ought to be "consensual" (Tsoukias, 2007).

The multicriteria approach utilized in this study combines the logic of outranking models (the ELECTRE III procedure (Roy, 1996)) with multiobjective evolutionary algorithms (MOEA) (Leyva and Aguilera, 2005), aided by the SADAGE Software (Leyva et al., 2008), to solve the ranking problem.

Configuration of the Decision Aid Process. In a systematic decision aid process, there is a continuous flow of activities between the different phases, but at any phase, there may be a return to a previous phase (this is referred to as feedback). The general scheme of the ELECTRE III–MOEA method is schematically represented in Figure 1. A decision aiding process is not a linear process where the stages follow one another. Instead, it should be noted that the procedure is iterative rather than sequential. If the decision maker is unsatisfied with the result at any stage, he or she may return to any step and redo it.

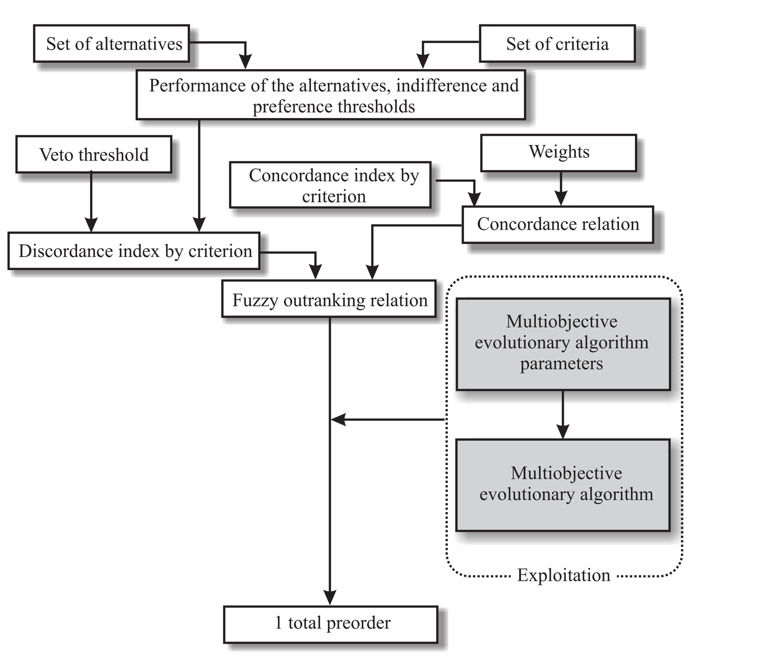

Fig. 1. General scheme of the ELECTRE III-Multiobjective Evolutionary Algorithm

3.2 Data Source

The data used in this study were obtained from a database supplied by The National Institute of Statistics and Geography (Instituto Nacional de Estadística y Geografía, INEGI, http://www.inegi.gob.mx), which performs the economic census in Mexico. The data are part of the 2009 Economic Census.

The objective of the census is to obtain updated and reliable basic statistical data about establishments that manufacture goods, trade merchandise and render services to generate various detailed geographic, sectoral, and thematic economic indicators for Mexico. The classification used for the census is the North American Industry Classification System (NAICS) 2007.

Table 1 presents the dominant economic sectors in Sinaloa, Mexico.

Table 1. Dominant economic sectors in Sinaloa, Mexico

Sector code (alternative)	Economic sector
A_1	21 (212) Mining (except Oil and Gas)
A_2	22 Utilities (Electricity, Water and Gas Distribution to Final Customer)
A_3	23 Construction
A_4	31-33 Manufacturing
A_5	42 Wholesale trade
A_6	44-45 Retail trade
A_7	48-49 Transportation and Warehousing
A_8	51 Information
A_9	52 Finance and Insurance
A_{10}	53 Real Estate and Rental and Leasing
A_{11}	54 Professional, Scientific and Technical services
A_{12}	55 Management of Companies and Enterprises
A_{13}	56 Administrative and Support and Waste Management and Remediation Services
A_{14}	61 Educational services
A_{15}	62 Health Care and Social Assistance
A_{16}	71 Arts, Entertainment, and Recreation
A_{17}	72 Accommodation and Food Services
A_{18}	81 Other Services (except Public Administration)

3.2 Criteria

According to Bouyssou (1990) the criteria family should be legible (containing sufficiently small number of criteria), operational, exhaustive (containing all points of view), monotonic and non-redundant (each criterion should be counted only once). These rules provide a coherent family of criteria. The criteria family used to rank the economic sectors are primarily economic. The criteria used in this study are reported in Table 2. These criteria are designed to capture the multidimensional nature of the performance of the studied sectors. These criteria include the following, where the last six are expressed in millions of Mexican pesos and all are defined with increasing preference direction in Table 2:

- Number of employees
- Remunerations
- Total gross production
- Intermediate consumption
- Gross fixed capital formation
- Gross value added
- Total fixed assets

Table 2. Value of criteria for each economic sector

Sector code (alternative)	Economic sector	Number of employees	Remunerations	Total gross production	Intermediate consumption	Gross fixed capital formation	Gross value added	Total fixed assets
A_1	21 (212) Mining (except Oil and Gas)	1192	64	400	156	83	243	373
A_2	22 Utilities (Electricity, Water and Gas Distribution to Final Customer)	6257	1235	15607	7137	904	8469	39624
A_3	23 Construction	22440	1172	11150	6910	188	4240	2384
A_4	31-33 Manufacturing	58804	2729	35553	24376	824	11176	14478
A_5	42 Wholesale trade	32044	1933	13103	4915	386	8187	5779
A_6	44-45 Retail trade	130186	3031	17728	8625	2344	9103	19588
A_7	48-49 Transportation and Warehousing	22529	976	6708	3396	275	3312	5832
A_8	51 Information	5869	914	7897	4668	407	3229	4618
A_9	52 Finance and Insurance	3906	3471	1329	938	17	390	238
A_{10}	53 Real Estate and Rental and Leasing	6331	198	2473	970	36	1502	1575
A_{11}	54 Professional, Scientific and Technical Services	9710	527	1797	574	42	1223	656
A_{12}	55 Management of Companies and Enterprises	931	0	433	257	3	176	29
A_{13}	56 Administrative and Support and Waste Management and Remediation Services	17789	956	2424	810	288	1613	1423
A_{14}	61 Educational Services	11941	835	2102	498	45	1604	999
A_{15}	62 Health Care and Social Assistance	14461	304	1378	605	32	772	1122
A_{16}	71 Arts, Entertainment, and Recreation	6286	128	1199	558	47	640	1017
A_{17}	72 Accommodation and Food Services	43916	1082	6348	3889	235	2458	4406
A_{18}	81 Other Services (except Public Administration)	32533	663	2890	1422	92	1467	2987

Table 2 reports the values of the criteria for sector. The results in Table 2 underscore the differences that exist among the studied sectors based on the different measures used.

3.4 Procedure and Methodology

Multiple factors motivated the selection of the ELECTRE III method for the assessment of the performance of the economic sectors of Sinaloa, Mexico.

First, Leyva and Aguilera (2005) presented a MOEA to exploit a valued outranking relation, but it is interesting to demonstrate the functionality of the combination of ELECTRE III and MOEA to a real-world application. This method was systematized using the SADAGE software (Leyva et al., 2008), which was used to analyze the problem addressed in this study.

Second, there exist a set of discrete alternatives and a set of economic dimensions that can be easily converted into a set of criteria. Additionally, the problem type addressed in this study can be modeled as a ranking problem. Based on the literature, the ELECTRE family of methods is considered appropriate for addressing a problem type such as the one addressed in this study (see Roy, 1996). This is especially true for the ELECTRE III method.

Third, ELECTRE was originally developed by Roy to incorporate the fuzzy (imprecise and uncertain) nature of decision-making by using thresholds of indifference and preference. This feature is appropriate for solving this problem.

Fourth, the decision maker is required to assign numerical values to the intercriteria parameters associated with the different criteria (Roy, 2006).

Fifth, another feature of ELECTRE that distinguishes it from many multicriteria solution methods is that it is fundamentally non-compensatory. This means that good scores on some criteria cannot compensate for a very bad score on a different criterion.

Finally, another feature is that ELECTRE models allow incomparability. Incomparability, which should not be confused with indifference, occurs between some alternatives a and b when there is no clear evidence in favor of some type of preference or indifference.

Two important concepts that underline the ELECTRE approach, thresholds and outranking will now be discussed. Assume that there exist defined criteria g_j, $j=1,2,\dots r$ and a set of alternatives A. Traditional preference modeling assumes that the following two relations hold for the two alternatives $a,b \in A$:

$$aPb \quad (a \text{ is preffered to } b) \quad \Leftrightarrow \quad g(a) > g(b)$$
$$aIb \quad (a \text{ is indifferent to } b) \quad \Leftrightarrow \quad g(a) = g(b)$$

In contrast, the ELECTRE methods introduce the concept of an indifference threshold, q; then, the preference relations are redefined as follows:

$$aPb \quad (a \text{ is preffered to } b) \quad \Leftrightarrow \quad g(a) > g(b) + q$$
$$aIb \quad (a \text{ is indifferent to } b) \quad \Leftrightarrow \quad |g(a) - g(b)| \le q$$

Whereas the introduction of this threshold partially accounts for how a decision maker actually feels when making real comparisons, a problem remains. Namely, there is a point at which a decision maker changes from indifference to strict preference. Conceptually, it is justified to introduce a buffer zone between indifference and strict preference that corresponds to a decision maker hesitating between preference and indifference. This zone of hesitation is referred to as weak preference; it is also a binary relation like P and I above and is modeled by introducing a preference threshold, p. Thus, we have a double threshold model with an additional binary relation Q that measures weak preference:

$$aPb \quad (a \text{ is strongly preffered to } b) \quad \Leftrightarrow \quad g(a) - g(b) > p$$
$$aQb \quad (a \text{ is weakly preffered to } b) \quad \Leftrightarrow \quad q < g(a) - g(b) \le p$$
$$aIb \quad (a \text{ is indifferent to } b \text{; and } b \text{ to } a) \quad \Leftrightarrow \quad |g(a) - g(b)| \le q$$

The choice of thresholds intimately affects whether a particular binary relation holds. Although the choice of appropriate thresholds is not easy, in most realistic decision making situations, there are good reasons for choosing non-zero values for p and q.

Note that we have only considered the simple case where thresholds p and q are constants instead of functions of the values of the criteria; the latter is the case of variable thresholds. While the simplification of using constant thresholds aids the utilization of the ELECTRE method, it may be worth using variable thresholds in cases where criteria with larger values lead to larger indifference and preference thresholds. In this study, a government official acted as the decision maker and the authors of this paper acted as the analyst. Table 3 reports the indifference and preference thresholds for the criteria used in this study. The veto threshold was not considered.

Using thresholds, the ELECTRE method seeks to build an outranking relation S. aSb means that according to the global model of decision-maker preferences, there are good reasons to believe that "a is at least as good as b" or "a is not worse than b". Each pair of alternatives a and b is then tested to check whether the assertion aSb is valid. This yields one of the following four situations: aSb and $not(bSa)$; $not(aSb)$ and bSa; aSb and bSa; $not(aSb)$ and $not(bSa)$.

The third situation corresponds to indifference, whereas the fourth corresponds to incomparability.

Table 3. Indifference (q), and preference (p) threshold values

	Criterion (g_j)	Indifference (q_j)	Preference (p_j)
g_1	Number of employees	6000	14000
g_2	Remunerations	250	400
g_3	Total gross production	200	500
g_4	Intermediate consumption	300	600
g_5	Gross fixed capital formation	200	400
g_6	Gross value added	250	500
g_7	Total fixed assets	1100	2100

The thresholds and weights represent the subjective input provided by the decision maker. Weights used in the non-compensatory ELECTRE model are significantly different from weights used in compensatory decision modeling approaches. Weights in ELECTRE are "coefficients of importance" and, as Vincke (1992) notes, they can be considered votes for each of the criterion "candidates." Roger et al. (2000) reviewed existing weighting schemes for ELECTRE and provided a useful discussion of the weighting concept in ELECTRE. Care also must be taken in determining threshold values, which must relate specifically to each criterion and reflect the preferences of a decision maker. Procedures for choosing appropriate threshold values were addressed by Roger and Bruen (1998). The decision maker was assisted in defining the 7 criteria weights, which are shown in Table 4. Personal Construct Theory (PCT), as suggested by Rogers et al. (2000), was used for the weight definition.

Table 4. Criteria weights

	g_1	g_2	g_3	g_4	g_5	g_6	g_7	RtG	RtG + 1	Final Weight
g_1	-----	O	X	O	X	O	O	2	3	1.07
g_2	X	-----	X	O	X	X	O	4	5	1.79
g_3	O	O	------	O	X	O	O	1	2	0.71
g_4	X	X	X	------	X	X	O	5	6	2.14
g_5	O	O	O	O	------	O	O	0	1	0.36
g_6	X	O	X	O	X	------	O	3	4	1.43
g_7	X	X	X	X	X	X	------	6	7	2.50
							Total	21	28	10.00

Notes:
1. $RtG \leftarrow RtG + 1$ to account for criterion 5.
2. For every cell ij {X,E,O} signifies that criterion g_i is {more, equal, less} important than criterion g_j
3. The weight for every criterion g_i is obtained by dividing $RtG_i + 1$ by the total.

The input data used in the calculations are the values presented in Table 2 (the performances of the alternatives). All compared alternatives and criteria have been used in the calculation. Information about the preferences of the decision maker – namely, the values of the indifference and preference thresholds for each criterion and the values of the relative importance of the criteria – are presented in Table 3 and Table 4. The values of the relative importance of the criteria indicate that the total fixed assets (g_7) and the intermediate consumption (g_4) criteria are most important to the decision maker.

The computation has been performed on the input data (Table 2) and on the information about the preferences of the decision maker (Table 3 and Table 4) using the ELECTRE III method. According to the additional information noted above, we applied ELECTRE III to construct a valued outranking relation, which has been omitted for the lack of space.

This concludes the construction of the outranking model. The next step in the outranking approach is to exploit the model and produce a ranking of alternatives from the valued outranking relation. Our approach for exploitation is to use a multiobjective evolutionary algorithm–based heuristic method, which is explained in the work by Leyva and Aguilera (2005).

The valued outranking relation was processed using the MOEA to derive the final ranking and systematized using the SADAGE software. The MOEA used the following parameters: the number of generations was set to 10,000; the population size was set to 40; the crossover probability was 0.85; and the mutation probability was 0.35. The restricted Pareto front, $PF^{restricted}_{known}$, that was determined and the associated final set of solutions returned by the MOEA at termination, $P^{restricted}_{known}$, are presented in Table 5. u, f, and λ are the objective functions of the MOEA.

Table 5. Restricted Pareto front found and the associated individuals of the solutions space

Ranking	$\tilde{p}_1$	$\tilde{p}_2$	$\tilde{p}_3$	$\tilde{p}_4$	$\tilde{p}_5$	$\tilde{p}_6$	$\tilde{p}_7$	$\tilde{p}_8$	$\tilde{p}_9$	$\tilde{p}_{10}$	$\tilde{p}_{11}$	$\tilde{p}_{12}$	$\tilde{p}_{13}$	$\tilde{p}_{14}$	$\tilde{p}_{15}$	$\tilde{p}_{16}$
1	A_6	A_4	A_4	A_6	A_6	A_6	A_2	A_4	A_2	A_6	A_6	A_4	A_6	A_6	A_4	A_{17}
2	A_4	A_6	A_6	A_4	A_5	A_4	A_6	A_2	A_4	A_4	A_4	A_5	A_5	A_8	A_6	A_6
3	A_2	A_2	A_2	A_2	A_4	A_5	A_4	A_6	A_6	A_2	A_2	A_3	A_8	A_7	A_2	A_{13}
4	A_5	A_5	A_5	A_5	A_2	A_3	A_5	A_5	A_5	A_5	A_{17}	A_6	A_4	A_4	A_8	A_4
5	A_3	A_3	A_3	A_3	A_3	A_2	A_3	A_3	A_7	A_3	A_5	A_2	A_2	A_2	A_5	A_{14}
6	A_8	A_8	A_8	A_8	A_8	A_7	A_8	A_8	A_3	A_8	A_3	A_8	A_3	A_{18}	A_1	A_{11}
7	A_7	A_7	A_7	A_7	A_7	A_8	A_7	A_7	A_8	A_7	A_8	A_7	A_7	A_5	A_3	A_2
8	A_{17}	A_{17}	A_{17}	A_{17}	A_{17}	A_{17}	A_{17}	A_{17}	A_{17}	A_{17}	A_7	A_{17}	A_{17}	A_3	A_7	A_{10}
9	A_{18}	A_{18}	A_{18}	A_{18}	A_{18}	A_{18}	A_{18}	A_{13}	A_{18}	A_{13}	A_{18}	A_{18}	A_{18}	A_{17}	A_{17}	A_{15}
10	A_{13}	A_{13}	A_{13}	A_{13}	A_{13}	A_{13}	A_{13}	A_{18}	A_{13}	A_{18}	A_{13}	A_{13}	A_{11}	A_{13}	A_{18}	A_5
11	A_{14}	A_{14}	A_{14}	A_{14}	A_{14}	A_{14}	A_{11}	A_{14}	A_{14}	A_{15}	A_{14}	A_{14}	A_{13}	A_{14}	A_{13}	A_3
12	A_{11}	A_{11}	A_{11}	A_{11}	A_{11}	A_{11}	A_{14}	A_{11}	A_{11}	A_{14}	A_{11}	A_{11}	A_{14}	A_{11}	A_{14}	A_8
13	A_{10}	A_{10}	A_{10}	A_{10}	A_{10}	A_{10}	A_{10}	A_{10}	A_{10}	A_{11}	A_{10}	A_{10}	A_{10}	A_{10}	A_{11}	A_7
14	A_{15}	A_{15}	A_{15}	A_{15}	A_{15}	A_{15}	A_{15}	A_{15}	A_{15}	A_{10}	A_{15}	A_{15}	A_{15}	A_{15}	A_{10}	A_{18}
15	A_9	A_9	A_9	A_9	A_9	A_9	A_9	A_9	A_9	A_9	A_9	A_9	A_9	A_9	A_{15}	A_9
16	A_{16}	A_{16}	A_{16}	A_{16}	A_{16}	A_{16}	A_{16}	A_{16}	A_{16}	A_{16}	A_{16}	A_{16}	A_{16}	A_{16}	A_9	A_{16}
17	A_{12}	A_{12}	A_{12}	A_{12}	A_{12}	A_{12}	A_{12}	A_{12}	A_{12}	A_{12}	A_{12}	A_{12}	A_{12}	A_{12}	A_{16}	A_{12}
18	A_1	A_1	A_1	A_1	A_1	A_1	A_1	A_1	A_1	A_1	A_1	A_1	A_1	A_1	A_{12}	A_1
u	0	0	0	1	2	2	2	3	3	3	4	4	6	11	12	36
f	0	1	2	3	0	1	2	0	1	3	2	3	3	1	1	3
λ	0.56960	0.63880	0.71870	0.73780	0.57000	0.63960	0.71880	0.57000	0.63990	0.73880	0.72000	0.73960	0.73990	0.64000	0.64000	0.74000
fitness	37.00851	37.00851	37.00851	37.00851	37.00851	37.00851	37.00851	37.00851	37.00851	37.00851	37.00851	37.00851	34.30998	18.71453	17.15499	5.718329

Table 6 shows the number $T(i,j)$, $(1 \le i, j \le m)$, of times (i.e., the position frequencies) that an alternative was found at a certain place in the ranking of the individual $\tilde{p}_i$ associated with the members of the final restricted Pareto front. Based on Table 6, we found a compromise solution using the following procedure: because the ranking of the alternatives is of significant importance, the number of times that an alternative is found at a certain place in the ranking is weighted according to the importance of the alternatives to be ranked. Then, we calculate the weighted sum $\sum_{i=1} w_i T(i,j)$, $j=1,2,\dots,m$. Finally, we obtain a succession in decreasing order of preference generated in this manner and a recommendation for the decision maker.

Table 6. The number of times that an alternative was found at a certain place in the ranking

Weight w_i	Rank	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}	A_{11}	A_{12}	A_{13}	A_{14}	A_{15}	A_{16}	A_{17}	A_{18}
18	1	0	2	0	5	0	8	0	0	0	0	0	0	0	0	0	0	1	0
17	2	0	1	0	6	3	5	0	1	0	0	0	0	0	0	0	0	0	0
16	3	0	7	1	2	1	2	1	1	0	0	0	0	1	0	0	0	0	0
15	4	0	1	1	3	8	1	0	1	0	0	0	0	0	0	0	0	1	0
14	5	0	4	8	0	2	0	1	0	0	0	0	0	1	0	0	0	0	0
13	6	1	0	3	0	0	0	1	9	0	0	1	0	0	0	0	0	0	1
12	7	0	1	1	0	1	0	0	3	0	0	0	0	0	0	0	0	0	0
11	8	0	0	1	0	0	0	2	0	0	1	0	0	0	0	0	0	12	0
10	9	0	0	0	0	0	0	0	0	0	0	0	0	2	0	1	0	2	11
9	10	0	0	0	0	1	0	0	0	0	0	1	0	11	0	0	0	0	3
8	11	0	0	1	0	0	0	0	0	0	0	1	0	2	11	1	0	0	0
7	12	0	0	0	0	0	0	0	1	0	0	11	0	0	4	0	0	0	0
6	13	0	0	0	0	0	0	1	0	0	13	2	0	0	0	0	0	0	0
5	14	0	0	0	0	0	0	0	0	0	2	0	0	0	0	13	0	0	1
4	15	0	0	0	0	0	0	0	0	15	0	0	0	0	0	1	0	0	0
3	16	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	15	0	0
2	17	0	0	0	0	0	0	0	0	0	0	0	15	0	0	0	1	0	0
1	18	15	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
$\sum_{i=1}^{m} w_i T(i,j)$		28	248	213	269	236	276	191	208	63	99	119	31	151	130	87	47	185	155
Minimum λ: 0.5696																			

Table 6 suggests the following final ranking:

$$A_6 \succ A_4 \succ A_2 \succ A_5 \succ A_3 \succ A_8 \succ A_7 \succ A_{17} \succ A_{18} \succ A_{13} \succ A_{14}, A_{11} \succ A_{10} \succ A_{15} \succ A_9 \succ A_{16} \succ A_{12} \succ A_1 \tag{1}$$

The above multicriteria method was performed 50 times using the SADAGE software with the same data (performance matrix, inter-criteria parameters and MOEA parameters) to produce 50 rankings. Then, using the same procedure as in the above paragraph, we calculated the number $T(i,j)$, $(1 \le i, j \le m)$, of times (i.e., the position frequencies) that an alternative was found at a certain place in the 50 rankings, which are shown in Table 7.

Table 7. The number of times that an alternative was found at a certain place in the 50 rankings

Weight w_i	Rank	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}	A_{11}	A_{12}	A_{13}	A_{14}	A_{15}	A_{16}	A_{17}	A_{18}
18	1	0	0	0	24	0	26	0	0	0	0	0	0	0	0	0	0	0	0
17	2	0	0	0	26	0	24	0	0	0	0	0	0	0	0	0	0	0	0
16	3	0	44	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0
15	4	0	6	1	0	43	0	0	0	0	0	0	0	0	0	0	0	0	0
14	5	0	0	46	0	1	0	0	2	0	0	0	0	0	0	0	0	1	0
13	6	0	0	2	0	0	0	7	37	0	0	0	0	0	0	0	0	4	0
12	7	0	0	1	0	0	0	27	7	0	0	0	0	0	0	0	0	15	0
11	8	0	0	0	0	0	0	15	4	0	0	0	0	0	0	0	0	27	4
10	9	0	0	0	0	0	0	1	0	0	1	0	0	7	2	0	0	3	36
9	10	0	0	0	0	0	0	0	0	0	12	7	0	11	10	1	0	0	9
8	11	0	0	0	0	0	0	0	0	4	7	9	0	19	8	2	0	0	1
7	12	0	0	0	0	0	0	0	0	6	16	7	0	8	11	2	0	0	0
6	13	0	0	0	0	0	0	0	0	6	5	11	0	3	11	12	2	0	0
5	14	0	0	0	0	0	0	0	0	10	4	8	2	2	7	11	6	0	0
4	15	8	0	0	0	0	0	0	0	11	2	4	2	0	1	10	12	0	0
3	16	4	0	0	0	0	0	0	0	9	3	3	10	0	0	8	13	0	0
2	17	16	0	0	0	0	0	0	0	4	0	1	19	0	0	3	7	0	0
1	18	22	0	0	0	0	0	0	0	0	0	0	17	0	0	1	10	0	0
$\sum_{i=1}^{m} w_i T(i,j)$		98	794	697	874	755	876	590	637	239	353	317	103	405	356	237	153	573	493
Minimum λ: 0.5016																			

Table 7 suggests the following final ranking:

$$\{A_6 \succ A_4\} \succ A_2 \succ A_5 \succ A_3 \succ A_8 \succ A_7 \succ A_{17} \succ A_{18} \succ A_{13} \succ \{A_{14}, A_{10}\} \succ A_{11} \succ \{A_9, A_{15}\} \succ A_{16} \succ \{A_{12}, A_1\} \tag{2}$$

4 Sensitivity Analysis of the Final Result

In most cases, arriving at the final ordering accepted by the decision maker does not conclude the decision aiding process. The analyst can additionally propose performing a sensitivity analysis. Examples of employing a sensitivity analysis have also been presented elsewhere (Briggs et al., 1990; Goicoechea et al., 1982; Rios Insua and French, 1991, Leyva 2005).

A sensitivity analysis is used to characterize the influence of changing the values of parameters, which consist of information about the decision maker's preferences (the various methods use different parameters to reflect the decision maker's preferences), on the final result. Sensitivity analysis is useful for interpreting results that have been achieved by modifying the values of the appropriate parameters reflecting the decision maker's preferences and in estimating the influence of the modifications on the final result. The decision maker supplies a range of values that he considers still consistent with his preferences.

Using this input, the range of sensitivity analysis is defined. The analysis considers the following types of changes in the parameters:

- changes in the values of the relative importance (w) of a single criterion,
- simultaneous changes in the values of the relative importance (w) of multiple criteria,
- changes of the values for threshold functions, which include the thresholds of indifference (q) and preference (p), for a single criterion, and
- simultaneous changes of the values for the thresholds of indifference (q) and preference (p) for multiple criteria.

The results of the sensitivity analysis performed, which depend on the allowed range of values for the selected parameters that describe the decision maker's preferences, are not presented in this paper for lack of space.

Changing the values of the relative importance of a criterion, w, had the least influence on the final order of alternatives. Of the 17 cases in which changes were introduced, in the majority of the cases, the final result typically preserved the final ranking selected by the decision maker (but the alternatives were not always in the same rank). For the ranges of changes in the values of parameters suggested by the decision maker, the sensitivity of the final result (the ranking) was insignificant.

The final ranking, shown in (2), was still achieved when the values of relative importance (w) were changed for both a single criterion and for multiple criteria simultaneously. Basing on the sensitivity analysis, we conclude the following: the decision maker can accept a different final ranking when the influence of the parameter changes on the final result can be justified and when the result changes only slightly compared with the final ranking accepted by the decision maker before the sensitivity analysis was performed. Performing a sensitivity analysis ends the decision aiding process.

5 Results and Discussion

Table 7 presents a summary of the results of this study. Based on these results and the proposed final ranking given in (2), we find the following:

- the retail trade (A_6) and manufacturing (A_4) sectors were consistently ranked first;
- the utilities sector (A_2) was ranked second;
- the wholesale trade sector (A_5) was consistently ranked third;
- the mining sector (A_1) and the management of companies and enterprises sector (A_{12}) were consistently ranked at the bottom of the ranking;
- the art, entertainment, and recreation sector (A_{16}) was consistently ranked in one of the lowest positions, just above the A_1 and A_{12} sectors; and
- the remaining sectors were consistently ranked in the middle.

Based on these results, the retail trade and manufacturing sectors are the most attractive for potential investors. The weak performance of the mining sector may be attributed to the lack of technological innovations and infrastructure investment. However, in the last 5 years, there has been an important revival of this sector, which is primarily due to direct foreign investment. In contrast, the weak performance of the management of companies and enterprises sector may be attributed to the centralized economic activity in some Mexican states. Thus, private and public policy initiatives aimed at improving the performance of these subsectors are needed.

The art, entertainment, and recreation sector ranks low in terms of its attractiveness to investors because of the lack of infrastructure investment and the violent crime and public insecurity in Sinaloa in the last 10 years. Business innovations and policymaking linked with the federal government of Mexico are needed to stop the deterioration of this sector. In the middle of the ranking, we find a large set of economic sectors. These sectors present stable investment opportunities.

6 Concluding Comments

The aim of this study was to offer a novel procedure for integrated assessment and comparison of Sinaloa economic sectors using a Multicriteria Decision Aiding Approach. The proposed procedure for multicriteria comparison of economic sectors uses the ELECTRE III method to construct a valued outranking relation and then a multiobjective evolutionary algorithm (MOEA) to exploit it to obtain a ranking of the economic sectors in decreasing order of performance. The results suggested that the best-performing sector is the retail sector. Furthermore, enterprises operating in the sectors of manufacturing industries, wholesale trade, utilities, and construction work more efficiently than an average Sinaloa enterprise. In contrast, the mining sector; the arts, entertainment and recreation sector; and the management of companies and enterprises sector were ranked below the average alternative.

The multicriteria method utilized in this study to rank the Sinaloa economic sectors is both practical and adequate. The proposed multicriteria assessment framework can provide a rationale for interested stakeholders, including government institutions and policy-makers; investors, financial institutions, and businessmen; employees and trade unions; and clients and suppliers related to certain sectors.

The application presented in this study underscores the applicability of multiobjective evolutionary algorithms to real-life business problems in a multicriteria decisional context. Thus, this study contributes to a growing body of application-based knowledge, which was until very recently the exclusive domain of engineering and the natural sciences.

7 References

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