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RESEARCH ARTICLE

Multicriteria Decision Model to Support the Evaluation of Common Jurisdiction Violence in the Capital Cities of the States of Mexico

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ABSTRACT The capital cities of the states of the Mexican Republic present a considerable heterogeneity in terms of their level of public security, so their correct characterization is an essential requirement, but not sufficient, for the elaboration of public policies for the prevention of crimes in the common jurisdiction. In this paper, we propose a multicriteria decision model based on the hierarchical ELECTRE III method that assists in how a policy maker can carry out this task. The objective of the work is to measure and compare the incidence of crimes of common jurisdiction in the capital cities of the states of the Mexican Republic. This model compares public security in 31 capital cities, adapting the situation as a multicriteria ranking problem to order the different capitals by their level of public security. The results showed that the model could identify the level of comprehensive public security of a capital city compared to the rest. Similarly, it also shows the disparities of this phenomenon between capital cities in relation to high, medium and low impact crimes.

INDEX TERMS Multicriteria decision analysis, public policies, state capitals cities, crimes of common jurisdiction, hierarchical ELECTRE III method.

I. INTRODUCTION

Common law crimes are understood to be those that directly affect people, that is, crimes in which the effect of the offense falls solely on the person affected by the offender's conduct. The state and municipal police ensure that they prevent and address this type of crime.

The territorial organization of Mexico is defined as a federal state governed in the form of a republic. It is divided into 31 states, where the offices of the state's central government are capital cities and urban centers with strong economic, administrative, social, and cultural components. Each of these capital cities has a different history. Their sociodemographic profile, economic potential, and institutional capacities related to public security differ [1]. However, they share common characteristics, and all suffer to a greater or lesser extent from the scourge of insecurity and violence.

According to [2], "violence has worsened in Mexico in the last decade, and it is currently pervasive in most urban areas" and near the US border [3]. As a result, the year 2020 continued to record a high rate of criminal incidence in the national territory (1,841,188 common law crimes), particularly the increase in intentional homicides (28,830), which have spread to most of the country, resulting in 22.56 deaths for every 100 thousand inhabitants. However, the problem is more concentrated in some states than in the rest of the states; therefore, the Federal Government has identified the most violent territories that concentrate the highest number of murders registered that year [4].

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Measuring and comparing the incidence of common jurisdiction crimes in the capital cities of the states of the Mexican Republic is a complex issue because each capital city needs to be assessed in multiple dimensions or objectives (e.g., strengthening the level of public security in capital cities, increase the level of crime prevention, maximize the use of resources, reduce the response time of security forces, overcome structural and normative restrictions, etc.). On the other hand, the condition of a city is dynamic because the operational circumstances of the crimes might vary, consequently altering the evaluation features; for example, the weight (or relative importance) of each dimension may change over time. For these and other reasons, the dynamism and complexity of common jurisdiction crimes in the capital cities of the Mexican states require that policy makers (PMs) make carefully planned decisions. In this sense, [5] explores the use of a spatio-temporal dashboard to study the crime rate in a Mexican state. In addition, [6] provides a set of policing strategies as a function of criminal complaints in the Brazilian context.

The evaluation of the incidence of common jurisdiction crimes in the capital cities of Mexico is an essential activity in the planning of public security, not only because 17.9 percent of the total population of Mexico resides there, but also because they use a considerable amount of human, economic, and technical resources [7]. Moreover, public security and crime victimization have a direct impact on the quality of life of the population [8], [9], [10]. Due to the magnitude of the problem, there is a need to develop formal procedures for deciding what relative level of public security capital cities have, and what public security planning strategy is best suited for the three levels of government to use in order to achieve their goals [11]. Hence, the central questions of this paper are: how can all the dimensions (seen as decision criteria) be integrated into a model or procedure to assess the relative level of public security in a capital city? What model can policy makers use to establish the best ranking of the capital cities that reflects their relative level of public security and symbolizes the government goals? Which capital cities of the Mexican Republic are the safest and which are the most insecure? Furthermore, what are the dimensions that explain its location in the national ranking?

Only a few specialists have addressed the problem of evaluating the incidence of crime in a set of cities using a multicriteria approach (e.g., [6], [12], [13]). Instead, most have focused on identifying the factors that influence public insecurity in a city and their level of impact using a multidimensional statistical method (e.g., [14], [15], [16]). Among these works, some tend to assess the performance of various factors or schemes through a cost function, this function merges several measures that influence the public security in a city [17]. For example, costs could be calculated according to the perspectives of the victims, government, and society, such as lost productivity, pain and suffering, medical expenses, and the criminal justice system being integrated into cost models [18]. Other researchers evaluate the public security in a city by examining various factors independently, where a specific analysis is performed, factor by factor; for example, crimes such as robbery or homicide, or comparing crime rates between two or more cities [19].

We can observe that the previous approaches do not include all the necessary aspects to evaluate and compare the incidence of common jurisdiction crimes in a group of cities. Note that this problem combines multiple objectives or criteria, some of them in conflict with each other; moreover, goals cannot always be stated in terms of value or utility merged into a value or utility function. Furthermore, occasionally representing an objective in a value or utility criterion can produce a loss of information, especially when it is difficult to measure the consequences of the value or utility (the words factors, attributes, objectives, and criteria are used interchangeably in this paper).

It is difficult to assess the incidence of common jurisdiction crimes in a group of cities by comparing several criteria simultaneously. Consequently, it is crucial to build a procedure that allows a complete evaluation among capital cities. This evaluation must include all the criteria, regardless of the incommensurability between some criteria. Furthermore, the evaluation method must consider the rationality of policy makers, since this procedure implies representing the goals and changes of government at the different levels of government; in this way, the evaluation procedure should elicit the preferences of a certain policy maker in a particular situation.

The problem of ranking the capital cities by their level of public security can be addressed with Multicriteria Decision Analysis (MCDA) methods. Traditionally, the approach to decision-making problems has been carried out mainly with methods based on a single dimension. Given the occurrence of increasingly complex problems, multidimensional approaches have emerged to address these types of problems in a more realistic way. MCDA methods are one of the approaches to address this type of problem [20]. The purpose and scope of MCDA is to support decision makers in solving these types of problems [21], [22].

Multicriteria-based methods have been widely applied to many real-world decision problems including agriculture, environment, finance, education, project selection, personnel, and services. However, as far as we know, the multicriteria approach has not yet been applied to address how to rank the capital cities per their level of public security.

This work aims to recommend an evaluation support model based on a multicriteria approach that determines the best ranking of the capital cities for their level of public security according to the features of each city. The model is presented as an instrument of the public organization that offers an efficient procedure that adds value to the evaluation process. The tool performs a pairwise comparison between a set of capital cities considering all the criteria involved in the evaluation process.

The multicriteria decision analysis tool used to carry out the evaluation and final ranking of the capital cities is the hierarchical ELECTRE III (*h*-ELECTRE III) method [23], [24], which through its criteria hierarchy, outranking, and preference and indifference thresholds concepts make it an acceptable way to be used in situations such as those presented in the study. It should be noted that for the exploitation of the comprehensive fuzzy outranking relation and the partial fuzzy outranking relations related to non-elementary criteria, a multiobjective evolutionary algorithm (MOEA) was used [20], [25]. The result of this MOEA is a ranking (a total preorder of classes of alternatives) of the 31 capital cities with the best public security in decreasing order of evaluation. The study analyzed data generated from the 2020 annual cutoff, available in the databases of the Executive Secretariat of the National Public Security System (SESNSP) and the National Institute of Statistics and Geography (INEGI).

The work is divided into seven additional sections to this one. The second section presents material and methods and incorporates the procedure for designing the decision model. The following section describes the steps to build the multicriteria decision aiding model. The fourth section presents the inter-criterion evaluation and the model presentation. The fifth section presents the results and discussion in the context of the multicriteria ranking problem. The sixth section illustrates the sensibility analysis. The seventh section presents the analysis and discussion of the results in the context of the public security problem. Finally, in the eighth section, the conclusions and potential future work are presented.

II. MATERIALS AND METHODS

In this section, we apply a process for solving problems and building multicriteria decision models improved by [26]. This procedure is based on Simons's decision-making process model, applying the successive refinement technique [27] to resolve MCDA problems. In the subsequent refinement technique, the analyst can return, at any step, from one step back to any other previous step as many times as necessary. This return may or may not indicate the adjustment of successive steps. This succession of actions consists of a recursive procedure, and the return makes it possible to improve the process with better results for the entire process. The system for building multicriteria models is shown in Fig. 1.

The procedure used in this work consists of three main phases. First, a preliminary stage is operated, in which the main elements of the MCDA problem are addressed, and the Problem Structuring Methods (PSM) [28] are applied to structure the problem. Using the PSM, the analyst has the adequate support to organize the information from the actors of the decision process. It comprises of the following actions: (*i*) Identify the PMs, involving an explanation of who and how many they are; (*ii*) Determine the objectives; (*iii*) Based on the objectives settled in (*ii*), describe measurable, operational and understandable criteria; (*iv*) Distinguish the multicriteria decision problem (choice, sorting, ranking) and define the set of alternatives, and (*v*) Detect the existing

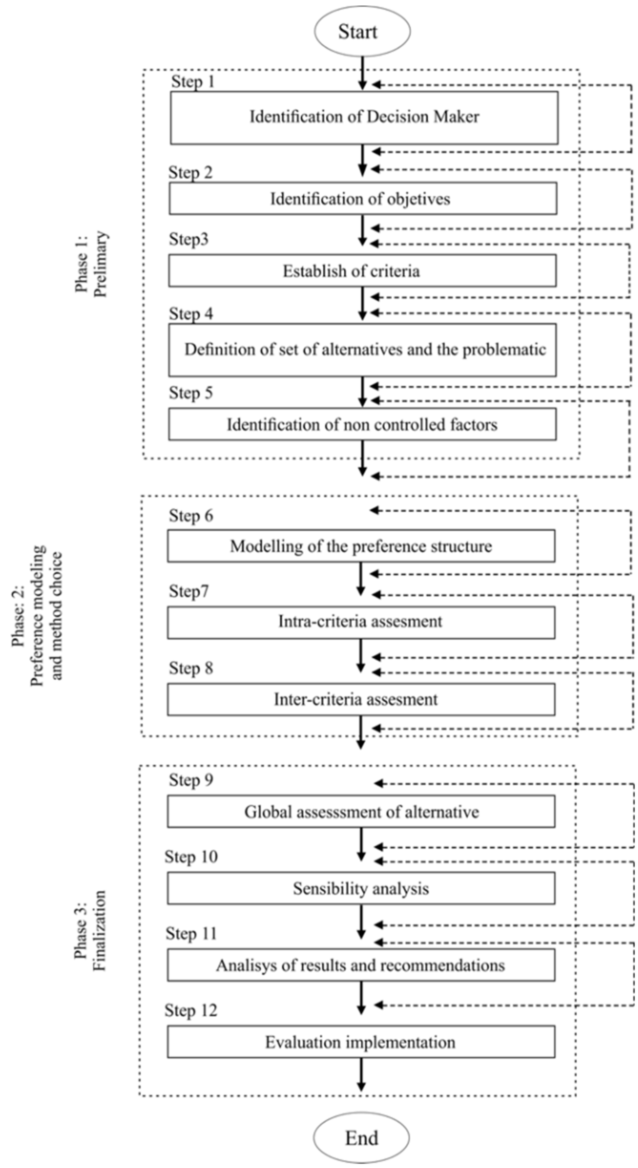


FIGURE 1. Phases and steps for the design of a multicriteria decision model. (Adjusted from [26]).

factors in the multicriteria decision problem that are not under the control of the PMs, and remove them from the design of the multicriteria model.

Preference modeling is conducted in the second phase, and the MCDA method is chosen. It includes (*i*) building the preference structure based on what the PM wants. Here an appropriate multicriteria decision method for the circumstances must be identified. Then, (*ii*) there is an intracriteria assessment, and (*iii*) an inter-criteria assessment. At the end of the second phase, the multicriteria decision model is prepared to be used in the third phase. This is a flexible phase in that the three steps of this phase may be done almost simultaneously, exploring a richer insight process. The output of this phase is an already built MCDA model, which serves as the third phase's entry.

In the third phase, the choice and implementation stages are managed for the final solution of the problem. It begins by (*i*) evaluating the alternatives utilizing the multicriteria method selected in the second phase. Then, (*ii*) the constructed model is examined via a sensibility analysis of some significant parameters. To close, (*iii*) the conclusions based on the results obtained are presented and discussed. Subsequently, suggestions can be made that provide a firm basis for public policy formulation. Finally, it should be considered that it is still feasible to go back and make improvements and modifications to the built model.

III. BUILDING OF THE EVALUATION MODEL

This section presents the essential components related to building the model, which is specified in more detail in the previous section.

A. DESCRIPTION OF THE POLICY MAKER AND OTHER ACTORS

Participation in evaluation is in line with the common principle of active participation of key stakeholders as fundamental to good evaluation practice. The main stakeholders may involve public decision makers, technical evaluators, direct and indirect beneficiaries involved in the public policy under evaluation and representatives of the community [29]. In this work, the decision-making scenario is the capital cities of the states of Mexico, where the public security authority of state and federal governments (State and Federal Secretaries of Public Security) is the main policy maker (PM). The design and implementation of the best tactical security strategies depend on them, and that capital cities have the best level of public security possible. In real operations, the State and Federal Secretaries of Public Security have a team of collaborators in the chain of command that provides them with valuable information for more informed decision-making. Thus, other actors are interconnected to the crime prevention activity in the common jurisdiction. These actors are technical specialists, stakeholders, and analysts. Multicriteria Evaluation Methods aim to recreate the different dimensions of the decision-making problem and the different opinions of the various actors [30].

B. IDENTIFYING OBJECTIVES AND THEIR STRUCTURE

Value-Focused Thinking (VFT) methodology [31] was used to structure the insecurity problem in Mexico's state capital cities. The VFT is a multicriteria methodology used to determine how values can improve decision-making. Per this method, it is crucial to establish the values to understand their relations and roles and make their uses easy. Then, structuring values and developing objectives aids a more profound and precise understanding of what decision makers care about in a specified decision context.

According to [31], an objective is the statement of something one wants to achieve. It is described by three distinct elements: decision context, object, and direction of preference. The VFT constructs an objective hierarchical structure into three primary levels: strategic, fundamental, and means-end objectives [32], [33].

The VFT methodology can be divided into six stages. Here we explain step by step how it was applied to the insecurity problem in Mexico's state capital cities. For that, it was necessary to meet five times with the policy maker. This methodology was used for six months due to the schedule of the policy maker.

1st Stage: Semi-Structured Interviews:

For the application of the VFT methodology, a set of semi-structured interviews was designed. Each interview was designed considering the information we wanted to elicit from the decision maker. The first interview was related to the context of the problem. The application took approximately an hour and a half due to the extension and depth. The subsequent interviews were to validate previous information and obtain new ones generated in tasks done by the policy maker or us, which agreed on each meeting.

2nd Stage: Structuring of the Problem of the Insecurity Problem in Mexico's State Capital Cities:

This section presents the problem more directly and shows how the situation was structured by applying the VFT methodology.

Problem description: During the interview with the policy maker, some interrelated problems were identified. Violence has worsened in Mexico in the last twenty years and is currently pervasive in most urban areas. To such a degree that for the last few years, there has been a high rate of criminal incidence in the national territory. Nevertheless, the problem is focused more on some states of the Mexican republic.

According to the policy maker, measuring and comparing the incidence of crimes in common jurisdictions in the states' capital cities is complex because each capital city needs to be assessed in multiple dimensions.

The capital cities are settled by the 17.9 percent of the total population of Mexico, and these cities are conformed by a considerable volume of human, economic, and technical resources; however, the population's quality of life of these cities is affected by public insecurity.

Due to the magnitude of the public insecurity problem in the capital cities, the policy maker is interested in knowing the relative level of general insecurity that capital cities have, at least concerning the crimes of common jurisdictions. This would help identify the capital cities where there is greater public insecurity and work on designing public policies that help reduce the insecurity problem.

3rd Stage: Identifying and Structuring Objectives:

This stage corresponds to analyzing the obtained information in the second stage to identify and define the policy maker's objectives related to the problem. Here, we identified the fundamental and means-end objectives. Then, we verified their redundancy and relationship to generate a list. After the analysis, we eliminate redundantly and create a hierarchy of primary objectives. This hierarchy was handed over to the policy maker for analysis, modification, or acceptance.

Once we accept the set of objectives and its hierarchy, we define each objective's orientation, maximizing or minimizing. Fig. 2 shows the structure of the objectives based on the VFT approach for the case study.

4th Stage: Measuring the Achievement of Objectives:

From the previous stage, the policy maker set that the overall strategic objective in preventing crimes of the common jurisdiction in the capital cities of Mexico is to rank order the capital cities by their relative level of violence in the common jurisdiction. This strategic objective was divided into two fundamental objectives -strengthening the level of public security in capital cities and increasing the prevention of public insecurity in capital cities - both with means-end objectives. For each means-end objective, it is necessary to specify an attribute to measure the degree to which the objective is achieved.

5th Stage: Quantification of Objectives With a Decision Model:

In this step, with the aid of the policy maker, we made a description of the attributes and the quantification of the objectives for constructing a decision model. These allow us to clarify, discover the objectives and facilitate decision-making. The means-end objectives are stated using criteria expected to be fused with an MCDA method to evaluate the relative degree of public insecurity in the capital cities. These criteria permit all operational elements that influence the evaluation of the relative degree of general security in capital cities to be integrated. Below, we present a brief description of each means-end objective:

Strengthening public security in capital cities potentially involves improving the prevention of crimes of the common jurisdiction so that they achieve significant reductions in their number, which is a relevant aspect of present and future population public security. In addition, some events can increase the population's perception of public security in the capital cities. Some of these events involve minimizing the number of murders and deprivation of liberty, thus centering on decreasing the number of high-impact crimes in the capital cities. An alternative way to expand public security is to minimize crimes of medium and low social impact and reduce robberies of various types and patrimonial crimes. This type of crime creates an environment of insecurity in the population, making it more vulnerable.

Rising crime prevention in capital cities indicates evaluating and choosing effective procedures to ensure better performance indicators of public security activities such as social inequality and schooling of the population. One option is to provide sufficient financial, material, and human resources to combat public insecurity; guaranteeing enough resources to combat public insecurity will allow better planning of activities to prevent crimes in the common jurisdiction. Poor public security is related to a lack of intelligence and material, human, and economic resources. Police training is an alternative indicator that can be measured to achieve a high level of crime prevention that should be maximized, that is, better use of human and economic resources and adequate time to face the commission of crimes under the common jurisdiction intelligently, punish lawbreakers for reducing impunity. Efficient resource exercises progressively influence crime prevention. Finally, it is vital to reduce social inequality, which is a primary concern of the three levels of government. This aspect focuses on generating opportunities for personal development in the entire population.

6th Stage: Creating Solution Alternatives:

Based on the means-end objectives, jointly with the policy maker, in the following sections, we continue with the process of ordering the capital cities in descending order of violence in the common jurisdiction. For this, we first define the hierarchical structure of the criteria [31], [32], [33]

C. DEFINITION OF A COHERENT FAMILY OF ASSESSMENT CRITERIA

We define a hierarchical structure of criteria. The hierarchical structure of a coherent family of criteria with three levels is represented in Fig. 3. Thirty-one capital cities of Mexico, evaluated on twelve elementary criteria placed at the bottom of the hierarchy tree, have been extracted from public databases [4], [34], [35], [36], [37]. The criteria were established considering the proposed goals of the case study, and they fulfill the properties of no redundancy, completeness, and consistency. All the objectives and criteria considered in this case study were derived from the information provided by this PM, whose system of preferences was the only factor in the following classification of crimes.

Table 1 describes the twelve elementary criteria comprised in the multicriteria decision support model. As can be seen in Fig. 3, High Impact Crimes (HIC), Medium Impact Crimes (MIC), Low Impact Crimes (LIC), Resource Application for Public Security (RAPS), and Social Prevention of Violence and Crime (SPVC) are macro-criteria. The first three constitute the macro-criterion related to Strengthening the level of Public Security in Capital Cities (PSCC); these last two compose the macro-criterion associated with Increasing the Prevention of Insecurity in Capital Cities (PPICC). Murders (M), Kidnappings (K), and Women Rapes (WR) are elementary criteria descending from High Impact Crimes; Property Crimes (PC) and Injuries (I) are elementary criteria descending from Medium-Impact Crimes; Common Theft (CT), Bank Robberies (BR), and Other Crimes (OC) are elementary criteria descending from Low Impact Crimes; Performance Strengthening for Public Security (PSPS) is an elementary criterion descending from Resource Application for Public Security; Perception of Insecurity (PI), Unemployment Rate (UR), and Marginalization (MA) are elementary criteria descending from Social Prevention of Violence and Crime. The policy maker with the support of the analyst defined the classification of the macro-criteria HIC, MIC, and LIC.

The criteria represent the means-end objectives, and each elementary criterion has its functional representation. As described in Sec. III-B (Identifying objectives and their structuration), minimizing high-, medium-, and low-impact

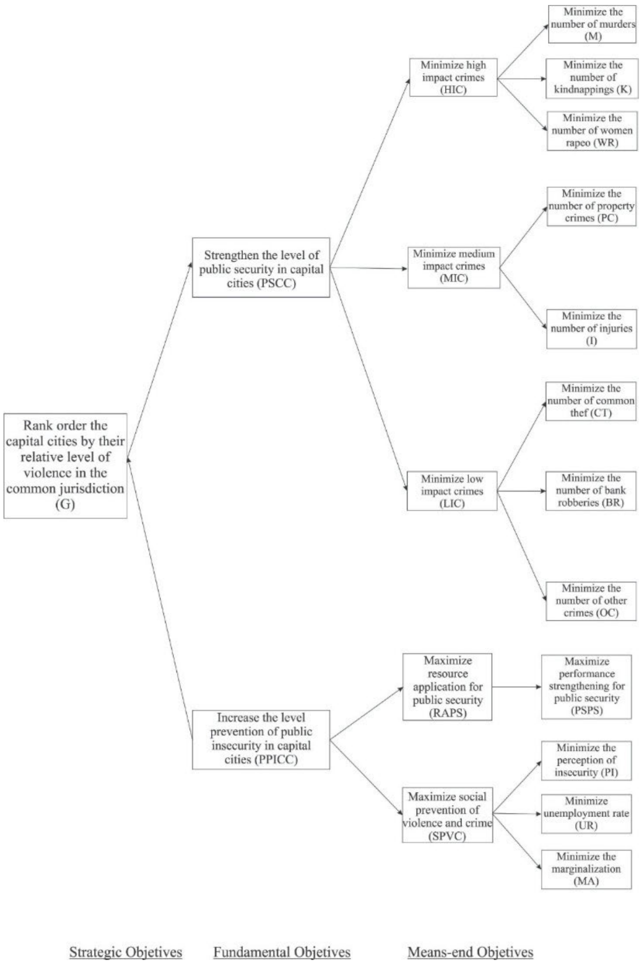


FIGURE 2. Objective hierarchical structure based on the Value-Focused Thinking (VFT) methodology.

crimes is important because this directly influences public security in capital cities. Therefore, a measurement must be made of the elementary criteria that are derived from crimes of high, medium and low impact crimes for public security in capital cities. In addition, important goals were taken to minimize the perception of insecurity, the unemployment rate, marginalization, maximizing performance, and strengthening public security were taken as important goals, which offers a quantitative view of how resources are used efficiently, which directly influences the prevention of violence in the common jurisdiction in the capital cities.

D. DEFINITION OF A STABLE FAMILY OF ALTERNATIVES

The family of alternatives for the multicriteria decision problem is a set of thirty-one (31) members, which denote the capital cities of the states of Mexico. The set of alternatives is stable and global. The alternatives are displayed in Table 2.

Once the criteria and alternatives have been defined, we are ready to measure and compare the incidence of crimes of common jurisdiction in the capitals of the states of the Mexican Republic in 2020 by applying a multicriteria analysis model. This model compares public security in 31 capital cities, adapting as a multicriteria ranking problem to order the different capital cities per their level of public security.

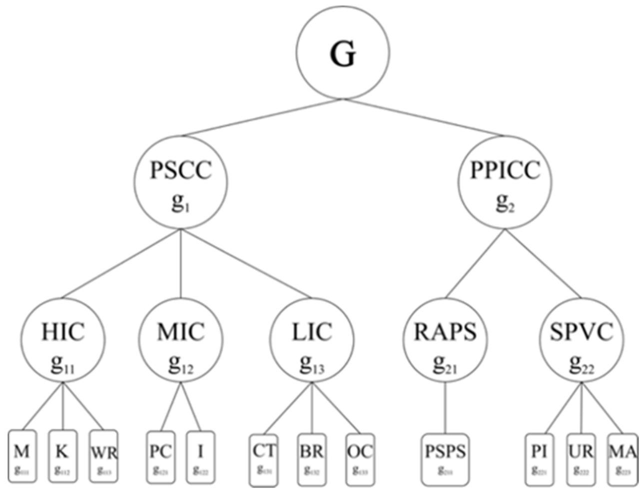


FIGURE 3. The hierarchical structure of criteria considered in the case study.

E. CHOICE OF THE MULTICRITERIA PROCEDURE

A multicriteria evaluation approach was considered acceptable from the perspective of the incidence of crimes of common jurisdiction in the capital cities of the states of the Mexican Republic since it makes possible the evaluation of cities with multiple criteria even if some of them are incommensurables. In this case, multicriteria methods allow evaluating the criteria in their standard features [21].

One advantage of multicriteria decision analysis compared to other evaluation methodologies is that it allows the PMs to incorporate their preferences in the construction of the evaluation model [38]; thus, this allows characterizing the goals of a government while admitting that purposes vary among the three levels of government. Using multicriteria models to rank order the public security level of a capital city and to consider the specific preferences of the PM can generate good results.

A multicriteria approach also enables comparing public security in 31 capital cities, adapting as a multicriteria ranking problem to order the different capital cities by their level of public security. As a result, the multicriteria model can identify the level of comprehensive public security of a capital city compared to the rest. It can also show the disparities of this phenomenon between capital cities concerning high, medium, and low impact crimes.

When choosing a multicriteria method, we must consider at least three characteristics that any adequate analytical method for decision-making must have: (*i*) the analysis performed must be as rational as possible; (*ii*) the method must be sensitive to changes in parameter values; and (*iii*) the method should provide final recommendations. Regarding the first point, in the public security situation, it is not easy for the PM to compare cities in a hierarchy of criteria using trade-offs between the performances expressed by each criterion to

TABLE 1. Description of the elementary criteria.

Code	Elementary criterion name	Description
M	Murders	The rate of murders per hundred thousand inhabitants
K	Kidnappings	The rate of kidnappings per hundred thousand inhabitants
WR	Women Rapes	The rate of women rapes per hundred thousand inhabitants
PC	Property Crimes	The rate of property crimes per hundred thousand inhabitants
I	Injuries	The rate of injuries per hundred thousand inhabitants
CT	Common Theft	The rate of common theft per hundred thousand inhabitants
BR	Bank Robberies	The rate of bank robberies per hundred thousand inhabitants
OC	Other Crimes	The rate of other crimes per hundred thousand inhabitants
PSPS	Performance Strengthening for Public Security	Millions of Mexican pesos invested in equipment, infrastructure, and training of police elements and public security institutions
PI	Perception of Insecurity	The percentage of the population aged 18 and over than in December 2020 felt insecure in their city
UR	Unemployme nt	The percentage of unemployment of the population aged 15 years and over for urban cities with 100,000 inhabitants or more
MA	Marginalizati on	Index that allows differentiating the country's municipalities according to the global impact of the deficiencies suffered by the population because of the lack of access to education, residence in inadequate housing, the perception of insufficient monetary income and those related to residence in localities little

TABLE 2. The capital cities of the states of mexico.

	Capital City	State		Capital City	State
A_1	Acapulco	Guerrero	A_{17}	Morelia	Michoacán
A_2	Aguascalientes	Aguascalientes	A_{18}	Oaxaca	Oaxaca
A_3	Campeche	Campeche	A_{19}	Othón P. Blanco	Quintana Roo
A_4	Centro (Villahermosa)	Tabasco	A_{20}	Pachuca	Hidalgo
A_5	Chihuahua	Chihuahua	A_{21}	Puebla	Puebla
A_6	Colima	Colima	A_{22}	Queretaro	Queretaro
A_7	Cuernavaca	Morelos	A_{23}	Saltillo	Coahuila
A_8	Culiacán	Sinaloa	A_{24}	San Luis Potosí	San Luis Potosí
A_9	Durango	Durango	A_{25}	Tepic	Nayarit
A_{10}	Guadalajara	Jalisco	A_{26}	Tlaxcala	Tlaxcala
A_{11}	León	Guanajuato	A_{27}	Toluca	Estado de México
A_{12}	Hermosillo	Sonora	A_{28}	Tuxtla Gutierrez	Chiapas
A_{13}	La Paz	Baja California Sur	A_{29}	Victoria	Tamaulipas
A_{14}	Merida	Yucatan	A_{30}	Xalapa	Veracruz
A_{15}	Mexicali	Baja California	A_{31}	Zacatecas	Zacatecas
A_{16}	Monterrey	Nuevo León			

generate a comprehensive assessment. Consequently, the problem of evaluating public insecurity in the capital cities can be categorized as non-compensatory (i.e., low scores on non-compensatory criteria cannot be compensated by higher scores on other criteria [39]. Then, out of all of them, outranking methods were chosen as a suitable approach, as they allow for a pairwise comparison of alternatives.

Regarding the second point, different MCDA methods have been developed and applied to solve decision-making problems, where the ELECTRE family stands out [40], [41]. This is especially true for the *h*-ELECTRE III method [23], which is an appealing option. The method offers a direct relationship between the decision maker and the analyst in such a way that the multicriteria model is built by joint agreement between both actors when there exists a hierarchical structure of criteria. The hierarchy helps to decompose complex decision problems into smaller and manageable subtasks and is therefore desirable for illustrative and computational efficiency reasons [24]. It allows not only to reduce the number of criteria contributing to evaluating alternatives from a specific higher-level point of view but also to group criteria into logically consistent sub-families. Also, the PM can express preference information comprehensively and partially, considering preference information concerning a subcriterion at an intermediate level of the hierarchy. Besides, this method utilizes specific parameters such as indifference, preference, veto thresholds, and weights in the criteria to construct the aggregation model of preferences represented as a fuzzy outranking relation. In this way, it is feasible to work with an inaccurate and uncertain estimation of parameters and subjective judgments [42]. This seems pertinent in evaluating a city because criteria such as property crimes, murders, injuries, and kidnappings, might vary over time. Moreover, this variation might be caused due to circumstances such as deficient police surveillance, insufficient application of resources, low intelligence in police operations, and increased poverty in the population, which makes it difficult to accurately estimate the parameters.

Regarding the third characteristic, the final recommendation of the *h*-ELECTRE III is in the form of a ranking of

TABLE 3. Performance matrix of elementary criteria. Primary Source: Executive Secretariat of the National Public Security System (SESNSP) and the National Institute of Statistics and Geography (INEGI) for the year 2020.

	M	K	WR	PC	I	CT	BR	OC	PSPS	PI	UR	MA
A1	51.44	0.77	16.16	155.09	84.02	95.82	0.90	303.76	4852029.08	77.90	4.86	-0.580997
A2	12.96	0.74	22.76	499.37	320.13	499.79	0.00	592.00	3543654.74	48.20	5.87	-1.315320
A3	8.50	0.00	29.92	19.38	16.32	50.33	0.00	56.11	3739178.66	39.90	3.95	-1.144640
A4	36.57	1.02	15.36	222.50	256.14	562.31	0.00	901.40	1304305.02	86.80	7.89	-1.215095
A5	41.06	0.00	33.38	371.77	122.54	132.35	0.21	190.15	1184406.13	60.70	5.42	-1.386087
A6	63.67	1.27	33.11	960.22	369.95	578.17	0.00	1610.34	9382408.51	71.80	4.47	-1.157756
A7	50.73	1.59	32.76	519.98	239.38	838.89	1.59	1119.75	4819910.55	87.70	3.25	-1.246878
A8	60.19	0.30	6.88	99.85	99.75	85.60	1.20	183.45	3023429.63	64.50	2.68	-1.204350
A9	11.18	0.00	20.91	363.44	210.69	350.52	0.15	525.19	3283360.93	43.10	5.41	-1.252476
A10	33.20	0.22	6.64	378.67	139.86	833.70	0.87	847.27	4010045.52	86.20	4.72	-1.341700
A11	47.29	0.06	4.18	285.67	163.61	52.87	0.06	272.66	1878715.15	84.00	6.37	-1.054585
A12	31.94	0.11	12.71	126.03	52.44	85.02	0.00	248.97	3678218.09	68.30	3.60	-1.256742
A13	10.95	0.34	28.06	437.99	240.55	63.30	0.00	549.20	5810534.91	31.80	4.26	-1.101218
A14	6.63	0.00	0.80	224.90	17.49	448.59	0.20	879.89	5407191.03	24.60	3.31	-1.277108
A15	27.34	0.19	20.19	377.60	253.76	222.33	0.10	600.69	2820758.04	63.00	2.40	-1.240347
A16	23.97	0.17	23.88	278.39	88.63	185.74	0.44	315.84	2575565.02	72.90	4.43	-1.332680
A17	60.89	0.94	16.37	290.44	269.01	212.00	0.00	355.22	2674554.99	72.70	3.91	-1.180576
A18	42.44	0.74	30.63	428.48	324.04	260.93	0.37	656.20	7576509.07	71.20	3.36	-0.958452
A19	69.76	0.43	39.80	535.42	224.70	564.10	0.00	1102.94	4261744.74	64.7	4.8	-0.972730
A20	20.68	0.95	34.68	415.49	390.67	1219.73	6.04	1010.40	5638884.76	52.80	3.82	-1.264186
A21	12.23	0.41	15.66	94.73	52.18	368.16	0.00	579.90	1436026.55	82.20	6.69	-1.128401
A22	16.77	0.57	30.39	312.26	272.72	24.20	0.10	233.57	3125284.98	48.30	5.69	-1.247061
A23	8.30	0.45	8.18	170.69	116.60	380.25	0.00	696.51	3039903.54	30.90	5.75	-1.383355
A24	32.90	1.32	29.28	449.50	175.79	23.58	0.00	186.75	2972836.82	87.00	5.03	-1.275415
A25	10.80	0.47	14.32	42.03	18.31	26.53	0.00	29.58	1463451.97	43.10	4.26	-1.213796
A26	11.01	3.00	4.00	54.06	40.04	5564.79	0.00	9328.70	8540487.62	46.00	5.52	-1.280656
A27	18.56	0.77	10.98	337.80	471.99	28.99	0.00	79.51	2701769.30	79.50	5.28	-1.055367
A28	12.08	0.00	12.75	80.94	43.86	84.09	0.00	165.19	2547552.63	72.20	5.92	-1.071436
A29	42.61	0.86	15.73	220.20	108.10	288.54	0.29	497.01	4398690.31	37.00	6.4	-1.257760
A30	16.38	1.23	9.21	310.11	151.47	28.04	0.00	382.98	3670353.93	62.6	4.81	-1.127002
A31	63.50	4.01	17.38	600.24	225.26	2447.75	0.00	6258.40	10007409.18	85.90	4.88	-1.336926

alternatives in descending order of public insecurity, which offers the PM the identification of the capital cities with less public insecurity and an evaluation of the other cities. Furthermore, this ranking provides the PM with greater knowledge about the performance of the cities. Additionally, the PM can obtain a final recommendation for the comprehensive view and recommendations at intermediate hierarchy levels. For additional aspects of the h-ELECTRE III method, please see [23] and [24].

F. INTRA-CRITERION EVALUATION

To meaningfully compare capital cities, the elementary criteria M, K, WR, PC, I, CT, BR, and OC were normalized to calculate each crime rate under the formula:

$$T = \left(\frac{Number\ of\ crimes}{Total\ population} \times 100,000 inhabitants \right)$$

Table 3 presents the normalized performance matrix, which shows the assessment of each capital city on each elementary criterion. Again, each performance was computed under similar conditions, with data from SESNSP and INEGI for 2020.

IV. INTER-CRITERION EVALUATION AND MODEL PRESENTATION

The h-ELECTRE III method aims to produce a comprehensive ranking of alternatives and partial rankings of alternatives for each non-elementary criterion in decreasing order of preferences. h-ELECTRE III constructs the ranking in two phases: (1) the construction of a fuzzy outranking relation among the alternatives, which represents the aggregating model of preferences; and (2) the exploitation of the outranking relation to derive a final recommendation in the form of a raking [43].

TABLE 4. Weights for the non-elementary and elementary criteria using the deck of card.

HIC				MIC			LIC				RAPS		SPVC		
0.398				0.149			0.156				0.056		0.241		
M	K	WR		PC	I		CT	BR	OC		PSPS		PI	UR	MA
0.142	0.135	0.121		0.113	0.036		0.049	0.1	0.007		0.056		0.078	0.071	0.092

In the h-ELECTRE III method, given a non-elementary criterion $g_r \in G$, a partial outranking relation is a binary relation $S_r \subseteq A \times A$, such that aS_rb means "a is at least as good as b concerning criterion g_r." Each pair of a and b alternatives is then verified to test if the affirmation aS_rb is valid or not.

For each elementary criterion $g_t \in G^L$, a weight meaning its relative importance within the family of elementary criteria is symbolized by w_t. The weights are assumed to be positive and normalized, that is, $w_t > 0$ for each $g_t \in G^L$ and $\sum_{g_t \in G^L} w_t = 1$. Table 4 presents the particular weight given to each non-elementary and elementary criterion. The deck of card technique was used to obtain the weights of the subcriteria of each non-elementary criterion [24], [44].

For each elementary criterion $g_t \in G^L$, the indifference q_t, preference p_t, and veto v_t thresholds should be specified. The indifference threshold is the maximum difference between the performances of alternatives a and b on g_t that is compatible with their indifference on g_t; the preference threshold is the minimum difference between the performances of a and b on g_t that is compatible with the preference of one over the other on g_t; the veto threshold represents the minimum difference between the performances of b over a on g_t that is incompatible with the outranking of a over b on any criterion g_r from which g_t descends, that is, $g_t \in G(g_r)$. For consistency purposes, $v_t > p_t \geq q_t \geq 0$. Table 5 presents the indifference and preference thresholds for each criterion. In this work, the veto threshold v_t is zero for all the criteria. Take for example the comparison of cities A_1 and A_{29} from the perspective of the Murder criterion; in this case, $g_M(A_1) = 51.4$ and $g_M(A_{29}) = 42.61$ (see Table 3). Since $q_M = 6.558$ and $p_M = 9.837$ (see Table 5), then $q_M < |g_M(A_1) - g_M(A_{29})| = 8.79 \leq p_M$. Therefore, A_1 is weakly preferred to A_{29} from the perspective of the Murder criterion; that is, $(A_1, A_{29}) \in C(A_1 Q_M A_{29})$.

For each pair of alternatives $a, b \in A$, such that $g_t(a) \geq g_t(b)$ for all $g_t \in G(g_r)$, three preference relations can be defined:

Per-Criterion Indifference Relation

Alternatives a and b are indifferent according to criterion g_t, represented by aI_tb, whenever $|g_t(a) - g_t(b)| \leq q_t$. Let $C(aIb)$ denote the subset of criteria such that aI_tb.

Per-Criterion Strict Preference Relation

Alternative a is strictly preferred to b according to the criterion g_t, represented by aP_tb, whenever $g_t(a) - g_t(b) > p_t$. Let $C(aPb)$ denote the subfamily of criteria such that aP_tb.

Per-Criterion Weak Preference Relation

Alternative a is weakly preferred to b according to the criterion g_t, represented by aQ_tb, whenever $q_t < g_t(a) - g_t(b) \leq p_t$. Let $C(aQb)$ denote the subfamily of criteria such that aQ_tb.

These binary relations can be grouped into one partial outranking relation S_t comprising the three situations $S_t = P_t \cup Q_t \cup I_t$, where aS_tb (a outranks b) means that "a is at least as good as b" on criterion g_t.

For the construction of a partial outranking relation, aS_rb, the h-ELECTRE III method takes into account a concordance principle, which requires that a majority of elementary subcriteria, after considering their relative importance, are in favor of the assertion "alternative a outranks alternative b," and a non-discordance principle, which implies that within the minority of elementary subcriteria, which do not support the argument, none of them strongly opposes the statement.

They are modeled with a comprehensive concordance index and per-elementary criterion discordance indices. These two indices are then joined to determine a credibility degree about the relation "a outranks b." We accept that all elementary subcriterion $g_t \in G(g_r)$ is increasingly monotonous with respect to preference.

h-ELECTRE III defines a concordance index $c_r(a, b)$ for each pair of alternatives $(a, b) \in A \times A$ which means a sufficiently powerful coalition of concordant criteria that supports "a outranks b." The power of each elementary criterion $g_t \in G(g_r)$ is given by its *weight*, w_t. That is, the power of the concordant coalition is provided by the criteria in favor of the affirmation "a outranks b" plus a proportion of the power of those criteria for which "b is weakly preferred to a." This view can be modeled through the following *partial concordance index* for each non-elementary criterion $g_r \in G$:

$$c_r(a, b) = \sum_{g_t \in G(g_r) \wedge g_t \in C(a\{I,Q,P\}b)} w_t + \sum_{g_t \in G(g_r) \wedge g_t \in C(bQa)} \varphi w_t \tag{1}$$

where

$$\varphi_t = \frac{p_t - [g_t(b) - g_t(a)]}{p_t - q_t} \in [0, 1]$$

assuming that the weights of elementary subcriteria sum up to one, i.e., $\sum_{g_t \in G^L} w_t = 1$.

Observe that $c_r(a, b) \in [0, W_r]$ where $W_r = \sum_{g_t \in G(g_r)} w_t$ and $c_r(a, b) = 0$ if $g_t(a) + p_t \leq g_t(b)$, for all $g_t \in G(g_r)$

TABLE 5. Indifference and preference thresholds.

Code	Elementary criterion name	Indifference threshold (q)	Preference threshold (p)
M	Murders	6.558	9.837
K	Kidnappings	0.153	0.229
WR	Women Rapes	3.551	5.326
PC	Property Crimes	51.819	77.729
I	Injuries	33.725	50.588
CT	Common Theft	91.471	137.207
BR	Bank Robberies	0.049	0.748
OC	Other Crimes	124.461	186.691
PSPS	Performance Strengthening for Public Security	429561.5	644342.3
PI	Perception of Insecurity	6.32	9.48
UR	Unemployment	0.336	0.504
MA	Marginalization	0.029	0.044

(b is strictly preferred to a on all elementary subcriteria descending from g_r), and $c_r(a, b) = W_r$ if $g_t(a) + q_t \geq g_t(b)$, for all $g_t \in G(g_r)$ (a outranks b on all elementary subcriteria descending from g_r). When $r = 0, c(a, b) \in [0, 1]$ because $G(g) = G^L$ and thus $W = 1$.

The idea of non-discordance indicates that there is no minority coalition of elementary criteria powerful enough to contradict the statement that "a outranks b." The opposing power of the elementary criterion $g_t \in G(g_r)$ uses the *veto threshold*, v_t. This view can be modeled through an *elementary criterion discordance index* for each elementary criterion g_t of the form:

$$d_t(a, b) = \begin{cases} 1, & if g_t(b) - g_t(a) \geq v_t, \\ \frac{[g_t(b)-g_t(a)]-p_t}{v_t-p_t} & if p_t < g_t(b) - g_t(a) < v_t, \\ 0, & if g_t(b) - g_t(a) \leq p_t. \end{cases} \quad (2)$$

The final step is to merge these two indices to produce a *partial credibility index* $\sigma_r(a, b)(0 \leq \sigma_r(a, b) \leq 1)$ for each non-elementary criterion g_r, which measures the degree of outranking between a and b. A way of modeling it is with the following expression:

$$\sigma_r(a, b) = c_r(a, b) \prod_{g_t \in G(g_r)} T_t(a, b) \quad (3)$$

where

$$T_t(a, b) = \begin{cases} \frac{1-d_t(a,b)}{1-c_r(a,b)} if d_t(a, b) > c_r(a, b), \\ 1 otherwise. \end{cases}$$

This formula assumes that if the strength of the partial concordance exceeds that of the elementary discordance, then the partial concordance value should not be modified. Otherwise, we must question the affirmation aS_rb and adjust $c_r(a, b)$ according to the above equation. Hence, we have constructed

TABLE 6. Objective values, number of classes (# Classes), and overall inconsistencies of the top ten solutions with lower numbers of inconsistencies returned by all algorithm's runs at termination in the context of the general criterion.

Solution	λ	# Inconsistences intra-classes	# Inconsistences inter-classes	Sum of Inconsistences	# Classes
1	0.56	42	35	79	5
2	0.56	35	38	73	10
3	0.57	13	57	70	11
4	0.58	14	56	70	12
5	0.58	15	52	67	11
6	0.59	22	49	71	9
7	0.59	19	50	69	11
8	0.59	16	53	69	10
9	0.59	23	53	76	9
10	0.59	18	58	76	10

a partial fuzzy outranking relation $S_A^{\sigma_r}$ defined on $A \times A$; this means that each ordered pair $(a, b) \in A \times A$ is associated with a real number $\sigma_r(a, b)(0 \leq \sigma_r(a, b) \leq W_r)$ that shows the degree of strength of the arguments favouring the crisp outranking aS_rb.

This completes the creation of the multicriteria outranking model. The next phase in the multicriteria outranking approach is to exploit the model and obtain a final partial preorder of alternatives from the fuzzy outranking relation $S_A^{\sigma_r}$ for each non-elementary criterion g_r. Our exploitation approach applies a heuristic method based on the multiobjective evolutionary algorithm (MOEA) proposed by Leyva et al. [25] called RP^2-NSGA-II+H. Finally, the derived ranking is compared with the ranking obtained from the distillation algorithm for the h-ELECTRE III. The reader can consult the details of this procedure in [24].

V. RESULTS AND DISCUSSIONS IN THE CONTEXT OF THE MULTICRITERIA RANKING PROBLEM

This section presents the results obtained by the multicriteria evaluation model described above. We discuss the results at two levels of the criteria hierarchy: the level of the overall criterion and the level of the macro-criterion PSCC.

A. COMPUTATIONS WITH THE RP^2-NSGA-II+H ALGORITHM IN THE CONTEXT OF THE OVERALL CRITERION

To find the most favorable solutions, $S_A^{\sigma_r}$ was processed using the RP^2-NSGA-II+H procedure. We performed the RP^2-NSGA-II+H procedure ten times with the following parameters: number of generations = 500, population size = 200, crossover probability = 0.8, lambda's value range = [0.51, 0.60]. The mutation operator automatically deduces the mutation probability.

We ordered all the solutions obtained at the end of the ten algorithm performances according to their number of inconsistencies to select the final solution. Table 6 presents the top ten solutions with the lowest number of inconsistencies.

From Table 6, we selected solution #6 because it gave one of the fewer classes and inconsistencies. Therefore, Fig. 4 illustrates the decoded representation as a ranking of classes of the individual associated with solution #6 and a table specifying the class to which each alternative belongs.

Capital cities were grouped into nine different ordered classes: $C_1, C_2, \ldots, C_9$. From Fig. 4, it can be seen that when capital cities are compared within classes, they differ from other capital cities in their degree of public security. For example, capital cities in the "C_9", "C_7", and "C_6" classes present relatively lower levels of public security in comparison with the first classes in the ranking: "C_8", and "C_3". On the other hand, capital cities in the same class present a similar level of public security. Appropriate granularity in the classes allows us to better differentiate the correct level of public safety between two capital cities, which is valuable for many state and federal government social policy agendas.

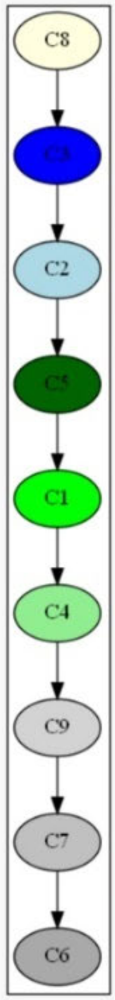
The results suggest that Mérida, belonging to the first class C_8, is the city best evaluated according to the incidence of crimes of common jurisdiction and sociodemographic information. We can perceive the facility of the RP2-NSGA-II+H to identify classes of alternatives that are indifferent to each other. A specialist, stakeholder, and/or analyst on public security could use these results to obtain an adequate representation of the relative level of public security in Mexico's capital cities.

B. RESULT COMPARISON BETWEEN THE RP2-NSGA-II+H ALGORITHM AND THE DISTILLATION PROCEDURE

We compare the accuracy of the ranking given by the RP^2-NSGA-II+H algorithm and the distillation algorithm, the original ranking procedure of ELECTRE III, in relation to the aggregation of PM's model of preferences represented by a fuzzy outranking relation. The generation of the ranking with the distillation procedure was performed using the Diviz software (see [45]).

The RP^2-NSGA-II+H algorithm proposed a ranking with nine classes, while the distillation procedure suggested a ranking with 16 classes. Both rankings are different in several classes, and the rank of the cities appears different if grouped by adjacent cities, as indicated in Table 7. For example, the cities in the first rank of the RP^2-NSGA-II+H's ranking do not correspond to those that are in the first rank of the distillation's ranking. RP^2-NSGA-II+H evaluates the city $A_{14} \in C_8$, corresponding to Merida as the most preferred city in the ranking. In contrast, distillation's ranking evaluates the cities$A_3, A_{12} \in C_1$, corresponding to the cities of Campeche and Hermosillo, as the most preferred cities in the ranking. Both rankings disagree on the best cities (i.e., the capital cities with the lowest level of public insecurity).

At the bottom of the rankings, both algorithms disagree with respect to the most insecure cities, which are the cities in



Alternative	Ranking Country	Class
A_{14}	Mérida	C8
A_3	Campeche	C3
A_{12}	Hermosillo	C3
A_{13}	La Paz	C3
A_{23}	Saltillo	C3
A_{25}	Tepic	C3
A_{26}	Tlaxcala	C3
A_{28}	Tuxtla Gutiérrez	C3
A_2	Aguascalientes	C2
A_8	Culiacan	C2
A_9	Durango	C2
A_{15}	Mexicali	C2
A_{16}	Monterrey	C2
A_{21}	Puebla	C2
A_{22}	Queretaro	C2
A_{27}	Toluca	C2
A_{30}	Xalapa	C2
A_5	Chihuahua	C5
A_{10}	Guadalajara	C5
A_{11}	León	C5
A_1	Acapulco	C1
A_{17}	Morelia	C1
A_4	Centro	C4
A_{20}	Pachuca	C4
A_{29}	Victoria	C4
A_{18}	Oaxaca	C9
A_{24}	San Luis Potosí	C9
A_7	Cuernavaca	C7
A_6	Colima	C6
A_{19}	Othón P. Blanco	C6
A_{31}	Zacatecas	C6

FIGURE 4. Left: Decoded representation as a ranking of alternatives of the associated individual of solution #6 in Table 6. Right: Table specifying the class each capital city belongs to according to the RP2-NSGA-II+H procedure.

classes C_9, C_7 and C_6 of the RP^2-NSGA-II+H's ranking and those in classes C_{14}, C_{15} and C_{16} of the distillation's result. Compared by rank, the cities in C_9, C_7 and $C_6$are different from the cities in C_{14}, C_{15} and C_{16}, except only for A_{18} (rank 7 in RP^2-NSGA-II+H, rank 14 in distillation procedure).

On top of that, both rankings look completely different by groups of classes; the high granularity in the ranking

TABLE 7. Ranking of classes of alternatives for the MOEA and distillation methods.

<table>
<tr><th colspan="3">MOEA</th><th colspan="3">DISTILATION</th></tr>
<tr><th>RANK</th><th>CLASS</th><th>ID</th><th>RANK</th><th>CLASS</th><th>ID</th></tr>
<tr><td>1</td><td>C8</td><td>A14</td><td>1</td><td>C1</td><td>A12, A3</td></tr>
<tr><td rowspan="3">2</td><td rowspan="3">C3</td><td rowspan="3">A3, A12, A13, A23, A25, A26, A28</td><td>2</td><td>C2</td><td>A14, A25</td></tr>
<tr><td>3</td><td>C3</td><td>A23, A26</td></tr>
<tr><td>4</td><td>C4</td><td>A28</td></tr>
<tr><td rowspan="5">3</td><td rowspan="5">C2</td><td rowspan="5">A2, A8, A9, A15, A16, A21, A22, A27, A30</td><td>5</td><td>C5</td><td>A8, A9</td></tr>
<tr><td>6</td><td>C6</td><td>A13, A16</td></tr>
<tr><td>7</td><td>C7</td><td>A15</td></tr>
<tr><td>8</td><td>C8</td><td>A10, A29, A30</td></tr>
<tr><td>9</td><td>C9</td><td>A2, A22</td></tr>
<tr><td rowspan="2">4</td><td rowspan="2">C5</td><td rowspan="2">A5, A10, A11</td><td>10</td><td>C10</td><td>A17, A21, A5</td></tr>
<tr><td>11</td><td>C11</td><td>A11, A27</td></tr>
<tr><td>5</td><td>C1</td><td>A1, A17</td><td>12</td><td>C12</td><td>A1, A24</td></tr>
<tr><td>6</td><td>C4</td><td>A4, A20, A29</td><td>13</td><td>C13</td><td>A31, A4</td></tr>
<tr><td>7</td><td>C9</td><td>A18, A24</td><td>14</td><td>C14</td><td>A18, A19, A20</td></tr>
<tr><td>8</td><td>C7</td><td>A7</td><td>15</td><td>C15</td><td>A6</td></tr>
<tr><td>9</td><td>C6</td><td>A6, A19, A31</td><td>16</td><td>C16</td><td>A7</td></tr>
</table>

TABLE 8. Objective values, number of classes (# Classes), and overall inconsistencies of the top ten solutions with lower numbers of inconsistencies returned by all algorithm run at termination in the context of the macro-criterion PSCC.

Solution	λ	# Inconsistences intra-classes	# Inconsistences inter-classes	Sum of Inconsistences	# Classes
1	0.6	48	31	79	6
2	0.6	29	38	67	9
3	0.6	2	61	63	17
4	0.6	23	41	64	10
5	0.6	1	66	67	21
6	0.6	20	42	62	11
7	0.6	15	44	59	12
8	0.6	13	45	58	13
9	0.6	53	30	83	7
10	0.6	48	31	79	6

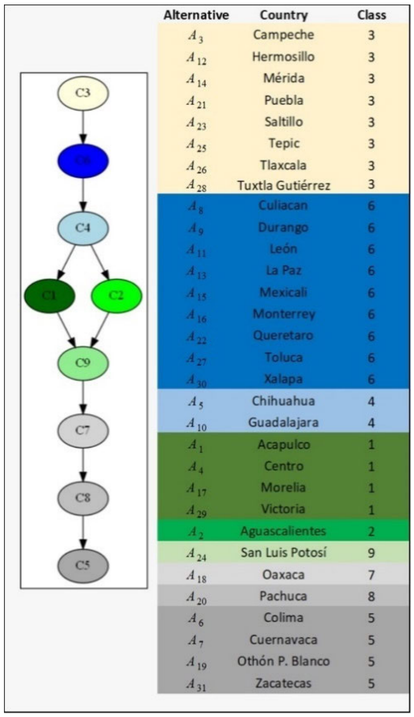


FIGURE 5. Left: Decoded representation as a ranking of classes of cities of the associated individual of solution #2. Right: Table indicating the class each capital city belongs to according to the RP^2-NSGA-II+H algorithm. All in the context of the macro-criterion PSCC.

recommended by the distillation procedure produces more inconsistencies than the low granularity classes of the RP^2-NSGA-II+H method. For example, the RP^2-NSGA-II+H's ranking has an overall inconsistency rate of 7%, while the distillation's ranking has an overall inconsistency rate of 24%, 17% more inconsistency than the RP^2-NSGA-II+H's recommendation.

C. COMPUTATIONS WITH THE RP^2-NSGA-II+H ALGORITHM IN THE CONTEXT OF THE MACROCRITERION PSCC

The following discussion is in the context of the macro-criterion related to Strengthening Public Security in Capital Cities (PSCC). Here, we also run the MOEA ten times with the same parameters mentioned above. The results are shown in Table 8.

We have chosen solution #2 because it showed one of the fewer classes and inconsistencies. Fig. 5 presents the decoded representation as a ranking of classes of the individual related to solution #2 and a table indicating the belonging class (for the MOEA's result) of each of the alternatives.

We can observe from figures 4 and 5 that the global ranking and the ranking derived from the macro-criterion related to Strengthening the level of Public Security in Capital Cities (PSCC) are slightly different. For example, in the global ranking, $A_{14} \in C_8$ (Merida city) is the only

TABLE 9. Effect of variations in criteria weights and variations in the values of the final result.

Range of changes of specific parameters	Changes made to parameter values	Final ranking after having made the changes in the parameters
Change of relative importance (weights) values (w) for two or more criteria at the same time	M: $w_M = 0.132$ WR: $w_{WR} = 0.131$	$\{A_3, A_{12}, A_{14}, A_{23}, A_{25}, A_{26}, A_{28}\} \succcurlyeq \{A_2, A_5, A_8, A_9, A_{10}, A_{11}, A_{13}, A_{15}, A_{16}, A_{21}, A_{22}, A_{27}, A_{30}\} \succcurlyeq \{A_1\}$ R $\{A_4, A_{17}, A_{29}\}$ R $\{A_{18}\} \succcurlyeq \{A_{20}\} \succcurlyeq \{A_{24}\} \succcurlyeq \{A_7\} \succcurlyeq \{A_6, A_{19}, A_{31}\}$
	K: $w_K = 0.125$ I: $w_I = 0.045$	$\{A_3, A_{12}, A_{13}, A_{14}, A_{23}, A_{25}, A_{26}, A_{28}\} \succcurlyeq \{A_2, A_8, A_9, A_{10}, A_{15}, A_{16}, A_{21}, A_{22}, A_{27}, A_{30}\} \succcurlyeq \{A_1, A_5, A_{11}, A_{17}, A_{29}\} \succcurlyeq \{A_4, A_{24}\}$ R $\{A_{18}\}$ R $\{A_{20}\} \succcurlyeq \{A_7\} \succcurlyeq \{A_6, A_{19}, A_{31}\}$
	WR: $w_{WR} = 0.116$ K: $w_K = 0.140$	$\{A_3, A_{14}\} \succcurlyeq \{A_{12}, A_{13}, A_{23}, A_{25}, A_{26}, A_{28}\} \succcurlyeq \{A_2, A_9, A_{15}, A_{16}, A_{21}, A_{22}, A_{27}, A_{30}\} \succcurlyeq \{A_5, A_8, A_{10}, A_{11}\} \succcurlyeq \{A_1, A_{17}\} \succcurlyeq \{A_4, A_{20}, A_{29}\} \succcurlyeq \{A_{18}, A_{24}\} \succcurlyeq \{A_7\} \succcurlyeq \{A_6, A_{19}, A_{31}\}$
	PC: $w_{PC} = 0.108$ MA: $w_{MA} = 0.097$	$\{A_{14}\} \succcurlyeq \{A_3, A_{12}, A_{23}, A_{25}, A_{26}, A_{28}\} \succcurlyeq \{A_{13}\} \succcurlyeq \{A_2, A_8, A_9, A_{15}, A_{16}, A_{21}, A_{22}, A_{27}, A_{30}\} \succcurlyeq \{A_5, A_{10}, A_{11}\} \succcurlyeq \{A_1, A_4, A_{17}, A_{20}, A_{29}\} \succcurlyeq \{A_7, A_{18}, A_{24}\} \succcurlyeq \{A_6, A_{19}, A_{31}\}$
	I: $w_I = 0.031$ BR: $w_{BR} = 0.105$	$\{A_{14}\} \succcurlyeq \{A_3, A_{12}, A_{13}, A_{23}, A_{25}, A_{26}, A_{28}\} \succcurlyeq \{A_2, A_8, A_9, A_{15}, A_{16}, A_{21}, A_{22}, A_{27}, A_{30}\} \succcurlyeq \{A_5, A_{10}, A_{11}\} \succcurlyeq \{A_1, A_{17}\} \succcurlyeq \{A_4, A_{20}, A_{29}\} \succcurlyeq \{A_{18}, A_{24}, A_7\} \succcurlyeq \{A_6, A_{19}, A_{31}\}$
	M: $w_M = 0.138$ PC: $w_{PC} = 0.115$ OC: $w_{OC} = 0.009$	$\{A_3, A_{12}, A_{13}, A_{14}, A_{23}, A_{25}, A_{26}, A_{28}\} \succcurlyeq \{A_2, A_8, A_9, A_{15}, A_{16}, A_{21}, A_{22}, A_{27}, A_{30}\} \succcurlyeq \{A_5, A_{10}, A_{11}\} \succcurlyeq \{A_1, A_4, A_{17}, A_{20}, A_{29}\} \succcurlyeq \{A_{18}, A_{24}\} \succcurlyeq \{A_7\} \succcurlyeq \{A_6, A_{19}, A_{31}\}$
	BR: $w_{BR} = 0.096$ PI: $w_{PI} = 0.080$ PC: $w_{PC} = 0.115$	$\{A_2, A_3, A_5, A_{10}, A_{11}, A_{12}, A_{13}, A_{14}, A_{23}, A_{25}, A_{26}, A_{28}\} \succcurlyeq \{A_8, A_9, A_{15}, A_{16}, A_{21}, A_{22}, A_{27}, A_{30}\} \succcurlyeq \{A_1, A_4, A_{17}, A_{20}, A_{29}\} \succcurlyeq \{A_{18}, A_{24}\} \succcurlyeq \{A_7\} \succcurlyeq \{A_6, A_{19}, A_{31}\}$

city in the first rank of the ranking, while the ranking related to PSCC, A_{14} shares the first position in the ranking with the alternatives $\{A_3, A_{12}, A_{21}, A_{23}, A_{25}, A_{26}, A_{28}\}$. On the contrary, when observing the last place in both rankings, they contain practically the same alternatives. This is a normal thing to happen. To derive the overall ranking, we are using the full performance matrix (31 alternatives and 12 elementary criteria), while in the second case, we are using a partial performance matrix (31 alternatives and eight elementary criteria; here, we are using fewer elementary criteria, i.e., only the elementary criteria related to the macro-criteria PSCC). Clearly, it affects the pairwise comparison of alternatives.

VI. SENSITIVITY ANALYSIS OF THE FINAL RECOMMENDATION

The results of the sensitivity analysis are presented in Tables 9 and 10 (The arrangement of the original parameter values is found in Table 5). Of the 14 changes made in total, most of the evaluation presented in Figure 4 regarding the relative level of public security in Mexico's capital cities was retained. Therefore, it is inferred that in the range of parameter changes handled in this analysis, the sensitivity of the result (ranking) was considered irrelevant. The results of the sensitivity analysis show rankings that are slightly different from the one presented in Figure 4. Generally, the positions of the cities within the classes are interchanged, and in some

TABLE 10. Influence of variations in criteria thresholds and variations in the values of the final result.

Range of changes of specific parameters	Changes made to parameter values	Final ranking after having made the changes in the parameters
Change of values in the thresholds q and p in a single criterion	M: $q_M = 6.65, p_M = 9.88$	$\{A_2, A_3, A_8, A_9, A_{12}, A_{13}, A_{14}, A_{23}, A_{25}, A_{26}, A_{28}\} \succcurlyeq \{A_5, A_{10}, A_{11}, A_{15}, A_{16}, A_{21}, A_{22}, A_{27}, A_{30}\} \succcurlyeq \{A_1, A_{17}\} \succcurlyeq \{A_4, A_{20}, A_{29}\} \succcurlyeq \{A_7, A_{18}, A_{24}\} \succcurlyeq \{A_6, A_{19}, A_{31}\}$
	K: $q_K = 0.158, p_K = 0.233$	$\{A_3, A_{12}, A_{13}, A_{14}, A_{23}, A_{25}, A_{26}, A_{28}\} \succcurlyeq \{A_2, A_8, A_9, A_{15}, A_{16}, A_{21}, A_{22}, A_{27}, A_{30}\} \succcurlyeq \{A_5, A_{10}, A_{11}\} \succcurlyeq \{A_1, A_{17}\} \succcurlyeq \{A_4, A_{20}, A_{29}\} \succcurlyeq \{A_{18}, A_{24}\} \succcurlyeq \{A_7\} \succcurlyeq \{A_6, A_{19}, A_{31}\}$
	I: $q_I = 34.50, p_I = 51.50$	$\{A_2, A_3, A_8, A_9, A_{12}, A_{13}, A_{14}, A_{23}, A_{25}, A_{26}, A_{28}\} \succcurlyeq \{A_{15}, A_{16}, A_{21}, A_{22}, A_{27}, A_{30}\} \succcurlyeq \{A_5, A_{10}, A_{11}\} \succcurlyeq \{A_1, A_{17}\} \succcurlyeq \{A_4, A_{20}, A_{29}\} \succcurlyeq \{A_{18}, A_{24}\} \succcurlyeq \{A_7\} \succcurlyeq \{A_6, A_{19}, A_{31}\}$
	MA: $q_{MA} = 0.032, p_{MA} = 0.046$	$\{A_2, A_3, A_{12}, A_{13}, A_{14}, A_{23}, A_{25}, A_{26}, A_{28}\} \succcurlyeq \{A_8, A_9, A_{15}, A_{16}, A_{21}, A_{22}, A_{27}, A_{30}\} \succcurlyeq \{A_1, A_5, A_{10}, A_{11}\} \succcurlyeq \{A_7, A_{17}\} \succcurlyeq \{A_4, A_{20}, A_{29}\} \succcurlyeq \{A_{18}, A_{24}\} \succcurlyeq \{A_6, A_{19}, A_{31}\}$
	OC: $q_{OC} = 120, p_{OC} = 150$	$\{A_2, A_3, A_8, A_9, A_{12}, A_{13}, A_{14}, A_{23}, A_{25}, A_{26}, A_{28}\} \succcurlyeq \{A_{15}, A_{16}, A_{21}, A_{22}, A_{27}, A_{30}\} \succcurlyeq \{A_1, A_5, A_{10}, A_{11}, A_{17}\} \succcurlyeq \{A_4, A_{20}, A_{29}\} \succcurlyeq \{A_7, A_{18}, A_{24}\} \succcurlyeq \{A_6, A_{19}, A_{31}\}$
Change of values in the thresholds q and p for two or three criteria simultaneously	$M: q_M = 6.6, p_M = 9.7$ $PC: q_{PC} = 53, p_{PC} = 78$ $PI: q_{PI} = 6.6, p_{PI} = 9.7$	$\{A_{14}\} \succcurlyeq \{A_3, A_{12}, A_{13}, A_{14}, A_{23}, A_{25}, A_{26}, A_{28}\} \succcurlyeq \{A_2, A_8, A_9, A_{21}, A_{30}\} \succcurlyeq \{A_{15}, A_{16}, A_{22}, A_{27}\} \succcurlyeq \{A_5, A_{10}, A_{11}\} \succcurlyeq \{A_1, A_4, A_{17}, A_{18}\} \succcurlyeq \{A_{20}, A_{29}\} \succcurlyeq \{A_{24}\} \succcurlyeq \{A_7\} \succcurlyeq \{A_6, A_{19}, A_{31}\}$
	$WR: q_{WR} = 3.60, p_{WR} = 5.4$ $OC: q_{OC} = 125, p_{OC} = 185$	$\{A_{14}\} \succcurlyeq \{A_2, A_3, A_8, A_9, A_{12}, A_{13}, A_{14}, A_{23}, A_{25}, A_{26}, A_{28}\} \succcurlyeq \{A_{15}, A_{16}, A_{21}, A_{22}, A_{27}, A_{30}\} \succcurlyeq \{A_1, A_5, A_{10}, A_{11}\} \succcurlyeq \{A_{17}\} \succcurlyeq \{A_4, A_{18}, A_{20}, A_{29}\} \succcurlyeq \{A_{24}\}\ R\ \{A_7\} \succcurlyeq \{A_6, A_{19}, A_{31}\}$

TABLE 11. Partial analysis of results (cities with highest public security) Source: own made.

	M	K	WR	PC	I	CT	BR	OC	PSPS	PI	UR	MA
A_3	8.50	0.00	29.92	19.38	16.32	50.33	0.00	56.11	3739178.66	39.90	3.95	-1.144640
A_{12}	31.94	0.11	12.71	126.03	52.44	85.02	0.00	248.97	3678218.09	68.30	3.60	-1.256742
A_{13}	10.95	0.34	28.06	437.99	240.55	63.30	0.00	549.20	5810534.91	31.80	4.26	-1.101218
A_{14}	6.63	0.00	0.80	224.90	17.49	448.59	0.20	879.89	5407191.03	24.60	3.31	-1.277108
A_{23}	8.30	0.45	8.18	170.69	116.60	380.25	0.00	696.51	3039903.54	30.90	5.75	-1.383355
A_{25}	10.80	0.47	14.32	42.03	18.31	26.53	0.00	29.58	1463451.97	43.10	4.26	-1.213796
A_{26}	11.01	3.00	4.00	54.06	40.04	5564.79	0.00	9328.70	8540487.62	46.00	5.52	-1.280656
A_{28}	12.08	0.00	12.75	80.94	43.86	84.09	0.00	165.19	2547552.63	72.20	5.92	-1.071436
Average	30.85	0.73	19.26	311.71	179.35	535.71	0.403	992.4	4044166.8	62.82	4.80	-1.18
Weight	0.142	0.135	0.121	0.113	0.036	0.049	0.1	0.007	0.056	0.078	0.071	0.092

cases —less frequent— they go from one class to another immediately higher (favourable) or lower (unfavourable).

VII. ANALYSIS AND DISCUSSION OF THE RESULTS IN THE CONTEXT OF PUBLIC SECURITY PROBLEM

The cities that belong to the classes with the highest relative public security, Mérida (A_{14}), Tepic (A_{25}), Campeche (A_3), Hermosillo (A_{12}), La Paz ($A_{13}A_{13}$), Saltillo (A_{23}), Tlaxcala (A_{26}), and Tuxtla Gutiérrez (A_{28}), present a better performance in the most important decision criteria. These criteria descend from the non-elementary criterion of high-impact crimes. Most of these cities are characterized by giving security indicators in all criteria below the average (see Table 11).

TABLE 12. Partial analysis of the results (capital cities with lowest public security) Source: own made.

	M	K	WR	PC	I	CT	BR	OC	PSPS	PI	UR	MA
A_6	63.67	1.27	33.11	960.22	369.95	578.17	0.00	1610.34	9382408.51	71.80	4.47	-1.157756
A_7	50.73	1.59	32.76	519.98	239.38	838.89	1.59	1119.75	4819910.55	87.70	3.25	-1.246878
A_{19}	69.76	0.43	39.80	535.42	224.70	564.10	0.00	1102.94	4261744.74	64.7	4.8	-0.972730
A_{31}	63.50	4.01	17.38	600.24	225.26	2447.75	0.00	6258.40	10007409.18	85.90	4.88	-1.336926
Average	30.85	0.73	19.26	311.71	179.35	535.71	0.403	992.4	4044166.8	62.82	4.80	-1.18
Weight	0.142	0.135	0.121	0.113	0.036	0.049	0.1	0.007	0.056	0.078	0.071	0.092

On the other hand, the results show that the state capitals Cuernavaca, Colima, Zacatecas, and Othon P. Blanco belong to the class with the highest crime rate. The common characteristic of these cities is the low evaluation obtained by the alternatives in the criteria considered most important by the policy maker, such as murders, kidnappings, and rapes of women. As a result, they present, in this class, values above the average, as explained in Table 12. With these results, it can be affirmed that these cities with these characteristics belong to the class with high levels of insecurity.

VIII. CONCLUSION AND FUTURE RESEARCH

This paper aims to develop of a multicriteria decision model based on the hierarchical ELECTRE III (h-ELECTRE III) method. This model operates as a procedure that supports the evaluation of the level of public security of the capital cities of the Mexican Republic.

The objective of this work was to present an objective and structured method for the comparison of the levels of public security of the capital cities of the states of the Mexican Republic and thus select priority capital cities for the application of public policies and specific programs for the attention of the most insecure populations. In this paper, we comprehensively compare capital cities and use a set of representative public security, economic, and sociodemographic indicators found in the literature.

The use of multicriteria decision analysis methodologies to solve complex decision-making problems is linked to governance tasks. In this case study, the h-ELECTRE III method was applied to analyze and compare the levels of public safety in the capitals of the states of the Mexican Republic. The recommendation derived from this method is based on rational decision-making and leaves aside biases that can distort the results obtained. One of the reasons for the success was the structuring of the problem of comparing the levels of public security in the capitals of the states.

Comparing the level of public safety in the capitals of the states of the Mexican Republic can help policy makers of these cities to have a comprehensive perception of the level of public security in comparison with the rest of the capital cities. In the same way, it also aims to inform and sensitize the political and academic sectors of the entity about the disparities of this phenomenon between capital cities.

The limitations of the work are related to the elicitation of the values of its parameters. As is well known, ELECTRE-based methods require the definition of several parameter values whose meaning can be difficult for the decision maker to understand (López et al., 2022). Furthermore, ensuring that the defined parameter values effectively reflect the decision model/policy of the decision maker is an arduous work. However, there are published works that address the problem of obtaining the values of the parameters for the h-ELECTRE-III method [46], and such works can be used complementary to the present work in order to solve this limitation.

In future work, we will aim to carry out a comparative analysis of the levels of public security in the capital cities of the Mexican Republic over time.

DECLARATION OF CONFLICTING INTERESTS

The author(s) declared no potential conflicts of interest with respect to the research, authorship and/or publication of this article.

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