Dynamics of Open Innovation in Small- and Medium-Sized Enterprises: A Metacognitive Approach

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***Abstract*—Open innovation (OI) is clearly becoming increasingly important to organizations. Studying its impacts has become a challenge as assessing OI possible effects on not only performance but also processes, time, and people is difficult and complex. To move beyond these barriers, this article develops a metacognitive framework that combines cognitive mapping—supported by the strategic options development and analysis approach—and the decision-making trial and evaluation laboratory technique. This dual methodology facilitates analyses of specific OI-related impacts on small- or medium-sized enterprises (SMEs). The data were collected from SME managers and entrepreneurs who agreed to participate in an expert panel in face-to-face group meetings. The findings include that the methodologies used facilitate the identification and understanding of cause-and-effect relationships among OI determinants in SMEs, and were validated by the participants and a project manager at COTEC Portugal—*Associação Empresarial para a Inovação* (Business Association for Innovation). This organization is a leading think-and-action network for advancing technology diffusion and business innovation cooperation. The contributions and limitations of the proposed methodology are also analyzed.**

***Index Terms*—Cognitive mapping, decision-making trial and evaluation laboratory (DEMATEL), decision support, multiple-criteria decision analysis (MCDA), open innovation (OI), small and medium-sized enterprise (SME), strategic options development and analysis (SODA).**

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I. Introduction

SINCE the beginning of the twentieth century, innovation has been discussed by many authors connected to different sectors of economic activity. The traditional approach to innovation entailed a focus on fluctuations in supply and demand chains but, despite the business opportunities it created, this tactic did not encourage technological change [1], [2]. The capitalist model thus began to shift toward a fresh perspective on new technologies, concepts, processes, ideas, and people, generating a novel management model [3].

Technological diffusion worldwide has had a strong impact on economic systems. Organizations have undergone structural changes to adapt to a newly expanded world that provides a better, more interactive and open approach. Part of this innovative process is the relationships established with universities, including private or public partnerships with consumers, suppliers, and other agents related to distribution channels. The terms "research" and "growth" have been replaced by "connectivity" and "development" [1]–[4].

According to Silva *et al.* [5], closed innovation is not the most efficient strategy to increase competitiveness since research and development (R&D) processes require quite extensive financial and time investments for most organizations. This obstacle is particularly real for small- and medium-sized enterprises (SMEs). Collaborative innovation is a more attainable goal because, with private and/or public partnerships, the risk is shared, making organizations more competitive [6]–[10]. Open innovation (OI) thus creates a co-creation dynamic [11], uniting various elements in order to produce mutually valued outcomes.

In addition, the development of information and communication technologies has also facilitated global market development networks that present new challenges for organizations [12], [13]. All things considered, OI is a given organization's ability to use its internal and external resources to improve its competitiveness and performance [14]. Company borders, therefore, no longer limit the creation and management of ideas, as the larger the number of novel solutions, the greater are the possibilities for innovating. The speed at which organizations can adapt depends, in large part, on their financial capacity, maturity, organizational culture, processes, and structure [15]–[19].

Given OI complexity, most of the models developed to date have had limitations in terms of quantitative data (e.g., only interviews), geographical limitation, and/or a lack of evaluation

systems (e.g., goals versus failures) [5], [7]. Furthermore, the current practices used to analyze OI determinants in SMEs still display limitations in how these practices and models identify the criteria to be incorporated in the analysis mechanisms [5], [12]. Another issue is the analysis of the cause-and-effects relationships among OI determinants, which should be carried out in a dynamic manner [5], [20]–[22]. In this context, the use of multicriteria techniques to support decision making can offer a more transparent, complete view than that available in the existing literature on this topic. Multiple-criteria decision analysis (MCDA), in particular, is a useful interactive approach that combines subjective and objective elements to solve complex decision problems.

MCDA methods have a constructivist epistemological basis and facilitate the combination of objective and subjective elements in complex and multidimensional decision problems. Specifically, this article applied cognitive mapping techniques to define and structure the decision problem under analysis (i.e., OI dynamics). The decision-making trial and evaluation laboratory (DEMATEL) approach was also used to facilitate the identification and analysis of decision-criteria interdependence. The methodologies were implemented based on two face-to-face groupwork sessions with a decision-maker panel comprising SME entrepreneurs from different sectors of activity. This application of multicriteria techniques to support decision making created a robust, complete, and coherent analysis model that can be put to practical use in evaluations of OI impacts on SMEs [20]–[22]. No prior research was found that has applied cognitive mapping and DEMATEL in this context, so the proposed framework adds to the extant literature on OI, entrepreneurship, SME performance evaluation, and operational research/management science (OR/MS).

The rest of this article is organized as follows. The next section provides a review of the relevant literature on OI. Section III presents the methodological background. Section IV presents the application of the techniques and respective results, including the advantages and limitations of the proposed framework. This section also describes the evaluation system's practical validation by a project manager at COTEC Portugal—*Associação Empresarial para a Inovação* (Business Association for Innovation). This organization is a leading think-and-action network for advancing technology diffusion and business innovation cooperation. Section V concludes this article.

II. Related Literature and Research Gap

The majority of authors have defined innovation as the development and implementation of new ideas, that is, *"a new product which did not exist in the market, a new production method, a new raw material, a new business area, a new financial method or organization scheme"* [23, p.82]. Accelerated change on a global level and consumers' increasingly demanding behavior have driven the innovation process toward diversification not only of products but also services and processes. According to Rabechini *et al.* [24], at least three aspects can influence innovation: information, time, and people. These factors guide organizations in how to integrate into the market by providing relevant responses to their consumers, with special attention paid to direct competitors' behavior.

Porter [25] reports that innovation is linked to company performance and value creation. Firms use their internal resources to devise strategies that are difficult to imitate and replace, exploring opportunities and dealing with threats in order to generate competitive advantages [26]. Chesbrough [27] argues that, in many sectors, a centralized approach to R&D, namely closed innovation, is becoming obsolete. This paradigm needs to be replaced by OI, which is *"a distributed innovation process based on purposefully managed knowledge flows across organizational boundaries"* [28, p.17]. Chesbrough [27, p.43] notes that "[OI] *means that valuable ideas can come from inside or outside the company and can go to market from inside or outside the company as well. This approach places external ideas and external paths to market*[s] *on the same level of importance as that reserved for internal ideas and paths."*

This conceptualization of OI fosters the integration of internal and external competencies with knowledge transfer while bearing in mind that most innovative ideas come from outside organizations [29]–[33]. Enkel *et al.* [14] further observe that companies adopt different OI strategies to expand their organizational ambidexterity. These strategies can include the following:

1) outside-in processes (i.e., use of internal technology and/or external knowledge);
2) inside-out processes (i.e., use of external technology and/or internal knowledge);
3) coupled processes (i.e., partnerships through alliances, cooperation, or joint ventures).

Lee *et al.* [12] claim that no evidence has been found to prove that large companies are better at innovation than SMEs are. Roijakkers *et al.* [34] suggest that SMEs should use OI to deal with their business realities since this approach allows these firms to develop more resilience and competitive advantages. However, Gassmann [35] argues that OI is not suitable for all situations or companies. Different aspects and characteristics must be assessed to decide under which conditions SMEs should invest in OI.

Based on a database of 605 innovative SMEs in the Netherlands, Van de Vrande *et al.* [36] identified varied reasons companies adopt OI, including seven drivers. The first is greater control over activities, which leads to a better organization of complex processes. The second is focus, which ensures essential skills are adjusted to match key activities. The third is innovation processes that develop new procedures and products and/or improve existing ones, and then market these innovations by integrating new technologies. The fourth is the acquisition of new knowledge that makes organizations more competitive, while the fifth is cost, profit, and efficiency management. The sixth is predicted capacity problems, which obliges SMEs to seek external solutions. The last driver is monitoring the market development, responding to customers, and increasing growth and/or market share. Van de Vrande *et al.* [36, p.432] concluded that *"using new innovation methods is regarded as a*

TABLE I
RELATED STUDIES: CONTRIBUTIONS AND LIMITATIONS

AUTHORS	METHODS	CONTRIBUTIONS	LIMITATIONS ACKNOWLEDGED BY AUTHORS
Stephen *et al.* [37]	Product development survey	▪ Examined how internal knowledge and knowledge-sharing channels influence innovation's results.	▪ When changes occurred in the work teams, the authors were unable to predict what kind of impacts these changes would have on knowledge dynamics. ▪ The data had temporal limitations (*i.e.*, 1991 to 1993).
Lazzarott and Manzini [38]	Interviews	▪ Checked if SMEs can be defined using OI variables and if the latter are found in real companies.	▪ The conclusions were drawn from data on a limited set of companies (*i.e.*, 52 Italian SMEs). ▪ The model did not include quantitative data.
Lee *et al.* [12]	Intermediated network model	▪ Investigated SME ability to establish collaborations with external partners and examined external actors' roles in innovation processes.	▪ The model did not incorporate quantitative data. ▪ The concept of strategic collaborations and/or alliances needs further study. ▪ The use of additional methods such as interviews or questionnaires would strengthen the study's results.
Nordman and Tolstoy [39]	Quiz and ordinary least squares regression	▪ Sought mainly to understand networking impact on SME relationship with foreign markets, based on organization location.	▪ Two of the hypotheses were not confirmed by the statistical analysis. ▪ No distinction was made between radical and creative innovation, which influenced the authors' conclusions. ▪ Not all characteristics (*e.g.*, size, connection, or organizational culture) that have an impact on networking were examined.
Seo and Chae [40]	Agent-based innovation simulator	▪ Focused on market dynamics and investigated ways of conceptualizing innovation management in SMEs and maximizing their performance.	▪ The research was geographically limited to South Korea, which means the results are difficult to generalize. ▪ The study focused only on the market, and other drivers were not addressed.
Al-Belushi *et al.* [2]	Quantitative metric for measuring OI	▪ Developed a unique quantitative metric to measure OI impact on Oman's marine bioindustry sector.	▪ The authors were able to identify only a few issues given the small number of companies in the study (*i.e.*, 16). ▪ For future lines of research, the authors suggest creating a ranking system so that companies have more control of the goals achieved versus failures.
Oliveira *et al.* [41]	Design science research	▪ Created a framework that supports OI implementation in SMEs.	▪ Although the model is generic, the authors specify that its impact on SME management is directly linked to the industry in which the companies operate.

way to keep up with market developments and to meet customer demand, which eventually should result in increased growth, better financial results, or increased market share[s]."

SMEs motivated by at least one of the above reasons tend to engage in OI. According to Enkel *et al.* [14], OI dynamics have an impact on organizational performance. The cited authors report that *"measuring performance is crucial for managers who want to monitor the activities of a company* [… as this] *allows managers to plan and control their organizations more effectively"* [14, p.1162]. In recent years, different methods and techniques have been established to evaluate OI impact on SMEs (see Table I).

After a careful analysis of existing studies on this topic, some common obstacles and limitations were identified. First, most of the practices used to evaluate OI still display limitations in how these assessment models identify the criteria to be incorporated in evaluation mechanisms [5], [12], [21], [22], [36]. Another issue is the analysis of the cause-and-effects relationships among OI determinants, which should be carried out in a dynamic manner [21], [22].

In addition, Hossain *et al.* [42, p.16] observe that *"approaches for measuring* [… OI] *are still at a preliminary stage"* and further research is needed to explore the way new paths are discovered in OI contexts. Studying the dynamics of OI in SMEs

requires more in-depth attention to detail and a more precise definition of indicators, as well as more consistent results. In other words, a fuller understanding of OI determinants in SMEs requires deeper research, and more tools and mechanisms will have to be developed so that researchers and practitioners can feasibly work with more detailed data, thus obtaining more consistent results [5], [12]. Consequently, the present research explored a different methodological paradigm that combined cognitive mapping and the DEMATEL approach, and allowed both qualitative/subjective and quantitative/objective aspects to be integrated into decision-making processes.

III. Methodological Background

According to Wang *et al.* [43, p. 2265], MCDA *"is suitable for addressing complex problems with high uncertainty, conflicting objectives, different forms of data and information, multiple interests and perspectives,* [… as well as] *accounting for complex and evolving biophysical and socio-economic systems"*. This methodological approach ultimately handles issues involving different levels of responsibility ranging from main decision makers to entire organizations [44], [45]. The MCDA decision-support process is an open system whose components are the actors (i.e., decision makers and facilitators) and their actions [46]. In this approach, facilitators guide the decision-making support process without giving their opinions about the factors involved.

The present decision-support process comprised three stages. The first was defining and structuring the decision problem. Cognitive mapping techniques were applied to identify the evaluation criteria. The second was the evaluation phase, in which the DEMATEL technique was used to analyze the interdependence of different criteria. The last stage was the formulation of recommendations, which required a discussion of the advantages and limitations of the proposed framework [47]–[51].

A Cognitive Mapping

Ranhel [52] states that human cognition is based on observations of behavior from the most simple to most complex level of human reasoning. Each individual is subject to different stimuli and computes, evaluates, and reacts according to his or her own perception of the problem under analysis. Tolman [53] developed a methodological tool to capture this information called cognitive mapping.

According to Eden [54], this method involves the graphic representation of cognitive processes, typically using nodes and links between nodes. The nodes are individuals' key concepts or building blocks with regard to a particular topic. The objective of cognitive mapping is to interpret how individuals act in relation to a given decision problem in accordance with their preferences, experiences, beliefs, values, goals, or wisdom [44]. Cognitive maps thus help structure complex decision problems, allowing decision makers to understand, process, and advocate mental associations that support better decisions [55]–[57]. Eden [55] reports that cognitive mapping is a rich form of analysis, especially given its ease and flexibility of use despite the vast, interactive structures involved. Fig. 1 presents cognitive mapping functional logic.

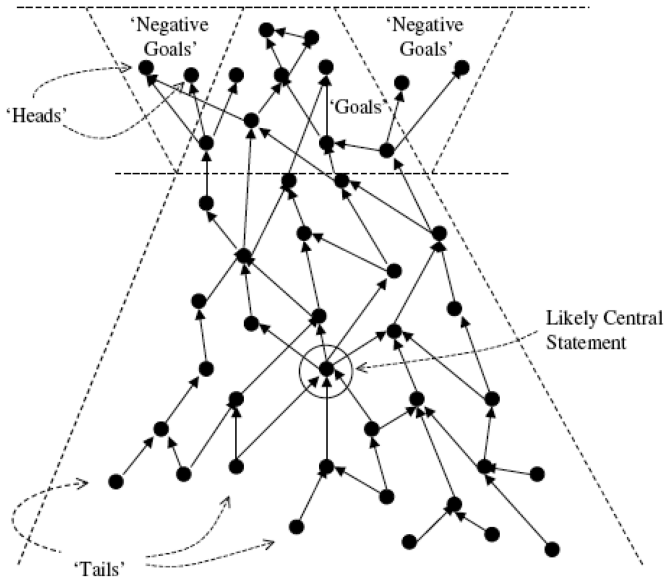

Fig. 1. Cognitive mapping functional logic. Source: Eden [55].

Cognitive maps present a collection of concepts related to specific decision problems in order to express the essence of the cause-and-effect relationships that exist between concepts [44]. These random relationships are represented by arrows, and each arrow is associated with a positive (+) or negative (–) sign that indicates the relationship direction [44]. Klein and Cooper [58] explain that, when the connection between two concepts is negative, an increase (decrease) in the concept at the arrow tip causes a decrease (increase) in the concept at the arrow tail. A positive relationship means that a change in the first concept leads to a similar variation in the second concept.

In general, cognitive maps contain, at the top, the objectives; in the center, the strategic issues; and, finally, at the bottom, the actions that are possible solutions to the key issues [34]. To simplify the process, facilitators need to use simple language that helps decision makers understand the procedures more easily. Participants should think not only about the most logical way of expressing their reasoning but also about the map content quality [44], [49], [50].

B. DEMATEL Approach

Weighting the criteria accurately plays a fundamental role in solving complex decision problems based on multiple criteria. The decision makers' preferences are directly related to their individual opinions. Thus, each criterion's weight represents the importance given to that option in the final decision [59]. The DEMATEL technique was developed in the 1970s with the main objective of solving complex decision problems through the identification of cause-and-effect relationships between different criteria [60], [61]. According to Kobryn [62, p.155], *"in*

the DEMATEL method, structural relationships occur between the analyzed elements [… and] *express* […] *the mutual influence of the analyzed objects in terms of cause-and-effect relationships"*. The main goal is to *"convert the interrelations between factors into an intelligible structural model of the system"* [63, p.2]. To apply the DEMATEL method, six steps should be followed.

Step 1: Constructing Group Direct-Influence Matrix Z*:* To assess the relationships between multiple factors (*n*) $F = \{F_1, F_2, \ldots F_n\}$ and a particular group of experts E who make collective decisions $E = \{E_1, E_2, \ldots. E_n\}$, the direct influence that a factor F_i has on factor F_j needs to be determined. A scale is used on which no influence is 0, weak influence is 1, medium influence is 2, strong influence is 3, and very strong influence is 4. Thus, the direct influence matrix of a given group is given as follows:

$$\mathrm{Z} = \begin{bmatrix} 0 & a_{12} & \ldots & a_{1n} \\ a_{12} & 0 & \vdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{1n} & a_{2n} & \ldots & 0 \end{bmatrix} \tag{1}$$

in which $Z = [\, a_{ij}]_{nxn}$ and value a_{ij} represents the influence of criterion a_i on criterion a_j.

Step 2: Building Normalized Direct-Influence Matrix X*:* This step is done based on the following equations:

$$S = \max\left(\max_{1\le i\le n}\sum_{j=1}^{n} z_{ij}, \max_{1\le i\le n}\sum_{i=1}^{n} z_{ij}\right) \tag{2}$$

$$X = \frac{Z}{s}. \tag{3}$$

Step 3: Creating Total-Influence Matrix T*:* Using normalized direct-influence matrix *X*, the total influence of matrix $T = [\, t_{ij}]_{nxn}$is calculated by adding all the direct and indirect effects as shown in the following equation:

$$\begin{aligned} \mathrm{T} &= \lim_{k\to\infty}\left(X + X^2 + X^3 + \cdots + X^h\right) \\ &= X\,(I - X)^{-1}. \end{aligned} \tag{4}$$

The threshold value is also defined in the third step. This value is the average of matrix *T* elements, thus eliminating any elements with minor effects within the matrix. The values equal and/or above the average are seen as values with a significant impact within the matrix. The threshold can be calculated using the following equation:

$$\alpha = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}[t_{ij}]}{N}. \tag{5}$$

Step 4: Producing an Influential Relation Map (IRM): In this final step, vectors *R* and *C* represent the total of lines and columns, respectively, of total influence matrix *T*. These vectors are defined by the following equations:

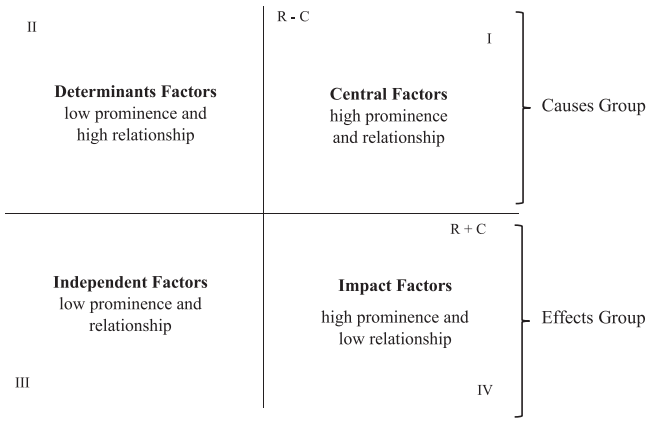

Fig. 2. IRM. Source: Si *et al.* [63].

TABLE II
GROUP DIRECT-INFLUENCE MATRIX *Z* (CLUSTERS)

	C1	C2	C3	C4	C5	C6	**Total**
C1	0.0	0.1	2.0	2.5	1.0	2.0	**7.6**
C2	3.0	0.0	1.0	2.0	0.1	3.0	**9.1**
C3	3.0	0.2	0.0	3.0	1.0	3.0	**10.2**
C4	3.0	1.0	4.0	0.0	3.5	2.5	**14.0**
C5	4.0	0.3	4.0	4.0	0.0	3.3	**15.6**
C6	1.2	0.1	3.0	4.0	3.8	0.0	**12.1**
Total	**14.2**	**1.7**	**14.0**	**15.5**	**9.4**	**13.8**	

$$\mathrm{R} = [r_i]_{\ nx1} = \left[\sum_{j=1}^{n} t_{ij}\right]_{\ nx1}, (i = 1, 2, 3 \ldots n) \tag{6}$$

$$\mathrm{C} = [c_i]'_{\ nx1} = \left[\sum_{i=1}^{n} t_{ij}\right]'_{\ nx1},\ (i = 1, 2, 3 \ldots\ n). \tag{7}$$

If $i = j$ and $i, j \in \{1, 2 \ldots. n\}$, then the horizontal axis of vector $(r_j + c_j)$ depicts the importance that a given factor has in the system. The vertical axis $(r_j – c_j)$, in turn, determines the classification of this same factor. If $(r_j – c_j)$ is positive, then factor F_j will have a direct influence on the other factors, and this factor should be part of the causes group. If $(r_j – c_j)$ is negative, then factor F_j is influenced by the other factors, in general, and the factor should be placed in the effects group (see Fig. 2).

The relationship map is divided into four quadrants (Qs): I, II, III, and IV. Each Q corresponds to a specific type of factor (see Fig. 2). QI contains central factors that are quite prominent and that have strong relationships. QII comprises determinants factors that have little prominence but strong relationships. QIII includes independent factors that have little prominence and weak relationships. Finally, QIV consists of impact factors that are quite prominent but have weak relationships.

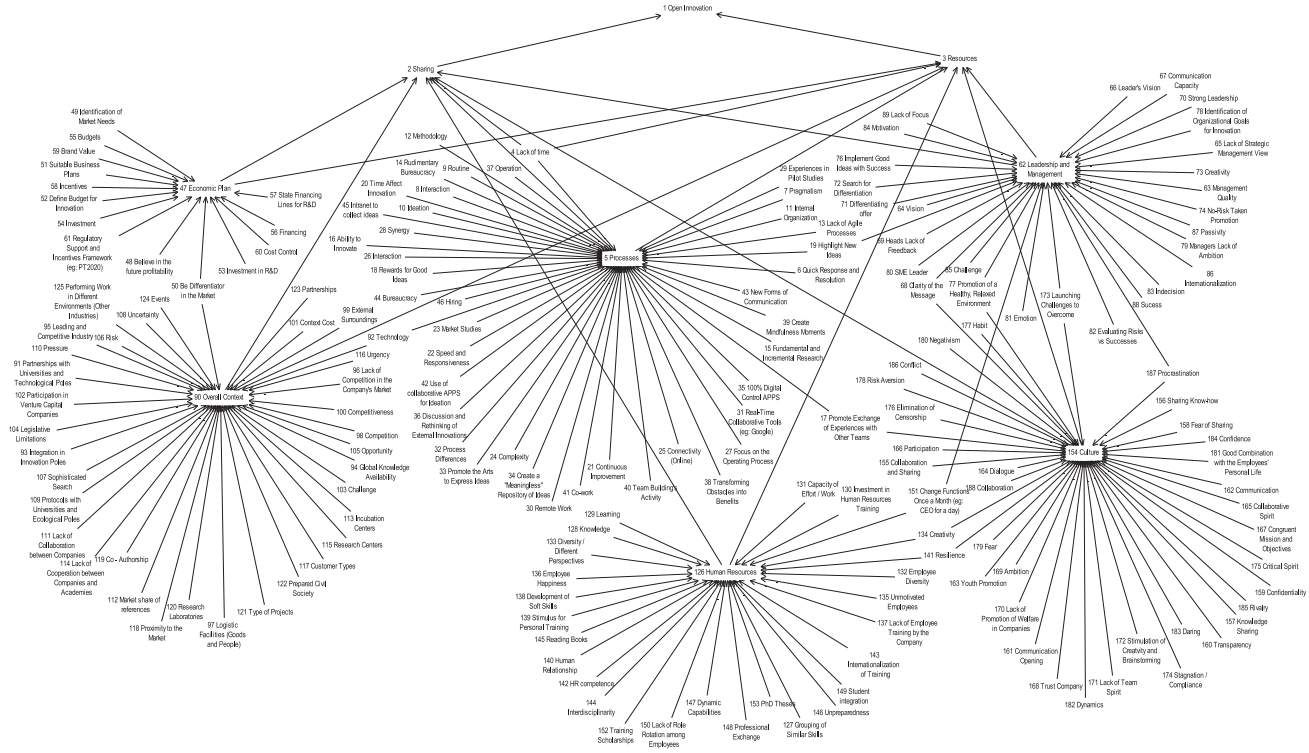

Fig. 3. Group cognitive map.

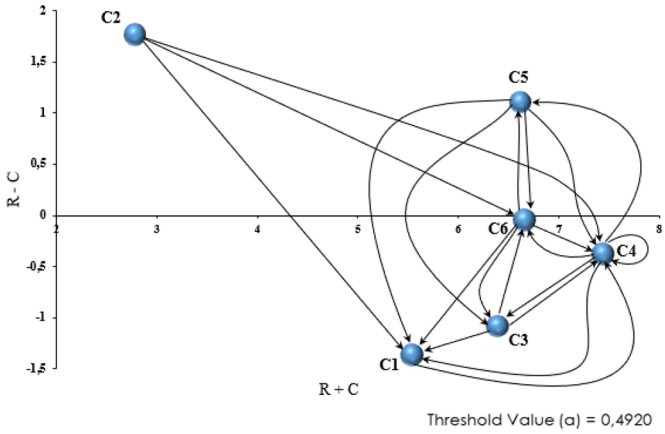

Fig. 4. IRM for cluster analysis.

TABLE III
NORMALIZED DIRECT-INFLUENCE MATRIX X

Max	15.5	15.55
1/max	0.0645	0.0643
1/s	**0.06431**	

	C1	C2	C3	C4	C5	C6
C1	0.0000	0.0064	0.1286	0.1608	0.0643	0.1286
C2	0.1929	0.0000	0.0643	0.1286	0.0064	0.1929
C3	0.1929	0.0129	0.0000	0.1929	0.0643	0.1929
C4	0.1929	0.0643	0.2572	0.0000	0.2251	0.1608
C5	0.2572	0.0193	0.2572	0.2572	0.0000	0.2090
C6	0.0772	0.0064	0.1929	0.2572	0.2412	0.0000

IV. APPLICATION AND RESULTS

This article involved applying cognitive mapping techniques based on the strategic options development and analysis (SODA) [64] method and DEMATEL. To this end, a panel of decision makers was created of specialists in OI topics who were available to participate in 2 face-to-face groupwork sessions that lasted an average of 4 h each. Regarding the number of participants, Bana e Costa *et al.* [47] assert that *"a decision-making group of 5–7 experts and other key-players"* is the norm. In the present study, the panel comprised eight decision makers who were chief executive officers, managers, or administrative members of SMEs from different sectors of activity, with extensive experience in and knowledge about OI.

Due to the constructivist and process orientation of the proposed metacognitive framework, the objective of the group meetings was not to achieve representativeness or make generalizations but rather to maintain a strong focus on process [47]–[50]. This approach facilitated an enriched discussion of OI dynamics in SMEs. In addition, the group sessions were led by two facilitators (i.e., researchers) who were responsible for guiding the negotiation process and recording the results obtained.

A. Collective Cognitive Map

The first session comprised the structuring phase in which the decision problem was defined. At the beginning, the panel members were given a brief overview of the research aims and the concepts underlying the methodologies to be applied. The experts were then asked the following trigger question:

TABLE IV
TOTAL-INFLUENCE MATRIX T

I

	C1	C2	C3	C4	C5	C6
C1	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000
C2	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000
C3	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000
C4	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000
C5	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000
C6	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000

I-X

	C1	C2	C3	C4	C5	C6
C1	1.0000	-0.0064	-0.1286	-0.1608	-0.0643	-0.1286
C2	-0.1929	1.0000	-0.0643	-0.1286	-0.0064	-0.1929
C3	-0.1929	-0.0129	1.0000	-0.1929	-0.0643	-0.1929
C4	-0.1929	-0.0643	-0.2572	1.0000	-0.2251	-0.1608
C5	-0.2572	-0.0193	-0.2572	-0.2572	1.0000	-0.2090
C6	-0.0772	-0.0064	-0.1929	-0.2572	-0.2412	1.0000

(I-X)^-1

	C1	C2	C3	C4	C5	C6
C1	1.3144	0.0557	0.4669	0.5009	0.3287	0.4191
C2	0.4978	1.0500	0.4327	0.5022	0.2986	0.4932
C3	0.5594	0.0736	1.4465	0.6233	0.4023	0.5495
C4	0.7023	0.1348	0.8010	1.6140	0.6200	0.6599
C5	0.7945	0.1061	0.8594	0.8790	1.4833	0.7398
C6	0.5848	0.0855	0.7312	0.7893	0.6221	1.4897

Matrix *T*

	C1	C2	C3	C4	C5	C6	*R*
C1	0.3144	0.0557	0.4669	0.5009	0.3287	0.4191	**2.0858**
C2	0.4978	0.0500	0.4327	0.5022	0.2986	0.4932	**2.2746**
C3	0.5594	0.0736	0.4465	0.6233	0.4023	0.5495	**2.6546**
C4	0.7023	0.1348	0.8010	0.6140	0.6200	0.6599	**3.5321**
C5	0.7945	0.1061	0.8594	0.8790	0.4833	0.7398	**3.8621**
C6	0.5848	0.0855	0.7312	0.7893	0.6221	0.4897	**3.3026**
C	**3.4533**	**0.5057**	**3.7377**	**3.9089**	**2.7550**	**3.3513**	

"Based on your values and professional knowledge, what factors influence or can influence OI in SMEs?". This question provided the basis for defining the decision problem.

The panel was asked to share their personal values, opinions, and experiences related to OI. This exchange of information was facilitated by applying the "post-its technique" [49], [64]. Each post-it note contained only one evaluation criterion. If a negative or positive cause-and-effect relationship existed between the criteria and decision problem, a minus or plus sign, respectively, was written in the upper righthand corner of each post-it note.

After obtaining a significant number of criteria, the decision makers were asked to group the post-its by areas of interest

TABLE V
TOTALS OF GIVEN AND RECEIVED INFLUENCE BETWEEN CLUSTERS

	C1	C2	C3	C4	C5	C6	*R*	*C*	*R+C*	*R–C*
C1	0.3144	0.0557	0.4669	0.5009	0.3287	0.4191	2.0858	3.453258	5.5391	-1.3675
C2	0.4978	0.0500	0.4327	0.5022	0.2986	0.4932	2.2746	0.505681	2.7803	1.7689
C3	0.5594	0.0736	0.4465	0.6233	0.4023	0.5495	2.6546	3.737708	6.3923	-1.0831
C4	0.7023	0.1348	0.8010	0.6140	0.6200	0.6599	3.5321	3.908853	7.4409	-0.3768
C5	0.7945	0.1061	0.8594	0.8790	0.4833	0.7398	3.8621	2.754973	6.6171	1.1071
C6	0.5848	0.0855	0.7312	0.7893	0.6221	0.4897	3.3026	3.351285	6.6539	-0.0487

(i.e., clusters), thereby dividing up the criteria by subjects and clarifying any cause-and-effect relationships that could exist between the criteria [49]. This discussion produced the following six clusters:

1) economic plan;
2) overall context;
3) processes;
4) human resources;
5) leadership and management;
6) culture.

The next step was to organize the criteria within each cluster based on a means-ends analysis. After the first group session, the data collected were input into the *Decision Explorer* software (http://www.banxia.com) to generate a cognitive map of the group's ideas.

In the second session, the map was presented to the panel members for analysis, debate, and validation. Thus, the decision makers were given a chance to insert, delete, and/or change decision criteria in terms of meaning and connections, as well as to adjust the cognitive structure format and/or reformulate the clusters. Fig. 3 shows the final version of the group cognitive map, which contains approximately 190 criteria related to OI dynamics in SMEs. An editable version of the map is available upon request.

The cognitive map gave the participants a more holistic perspective on the decision problem under analysis. The map-construction process materialized an extremely rich exchange of values, opinions, and experiences, enabling the decision makers to formalize their thoughts in a more structured way. The insights brought by the panel members, therefore, add to the extant literature regarding OI impact on SMEs. The next step was to apply the DEMATEL method.

B. DEMATEL Application

The evaluation stage was completed during the second group-work session. After a brief explanation of the technique to be used (i.e., DEMATEL), the decision makers were asked to analyze the degrees of influence between clusters using the traditional DEMATEL scale (i.e., 0 = no influence; 4 = very strong influence). Steps 1 through 4 (see Section III-B) used the data collected and six clusters [i.e., economic plan (C1), overall context (C2), processes (C3), human resources (C4), leadership and management (C5), and culture (C6)].

Step 1 involved constructing group direct-influence matrix Z by applying (1). Table II presents the results of this step.

Step 2 created normalized direct-influence matrix X based on (2) and (3). Table III shows the results.

Step 3 comprised constructing total-influence matrix T by using (4). Table IV presents the results.

The threshold value α was calculated using (5), namely, $\alpha = \frac{17.7118}{36} = 0.4920$. The totals for matrix T rows and columns were then estimated using (6) and (7) (see Table V).

Step 4 involved constructing an IRM to facilitate further cluster analysis. Fig. 4 depicts the results of this fourth step.

The horizontal axis $R+C$ distinguishes between the six clusters according to their importance. Fig. 4 reveals that C4 constitutes the most important area of concern as it presents the highest $R+C$ value (i.e., 7.4409). C2 is the dimension with the least impact, according to the expert panel, because this cluster has the lowest $R+C$ value (i.e., 2.7803). The overall prioritization by importance of the six clusters was C4 $>$ C6 $>$ C5 $>$ C3 $>$ C1 $>$ C2.

The axis $R–C$ divides the clusters into two groups: causes and effects. Thus, C1, C3, C4, and C6 form the effects group with negative values for $R–C$. These clusters are also influenced by the other clusters in general. C2 and C5 have positive values for $R–C$, meaning that they form the causes group and exercise direct influence on the other clusters. Finally, the analysis identified C5 as the central factor (QI), C2 as the determining factor (QII), and, finally, C1, C3, C4, and C6 as impact factors (QIV).

Similar analyses were carried out for each area of concern (i.e., cluster), from which the decision makers selected the most important criteria. This process was completed by using nominal group and multivoting techniques, generating a matrix of direct influence for each cluster considered in the proposed model. Table VI presents the results obtained in step 1. The numbers in bold represent the criteria selected by the expert panel in each cluster. Table VII summarizes the direct and indirect effects of each criterion in each cluster. Fig. 5 contains the respective IRMs.

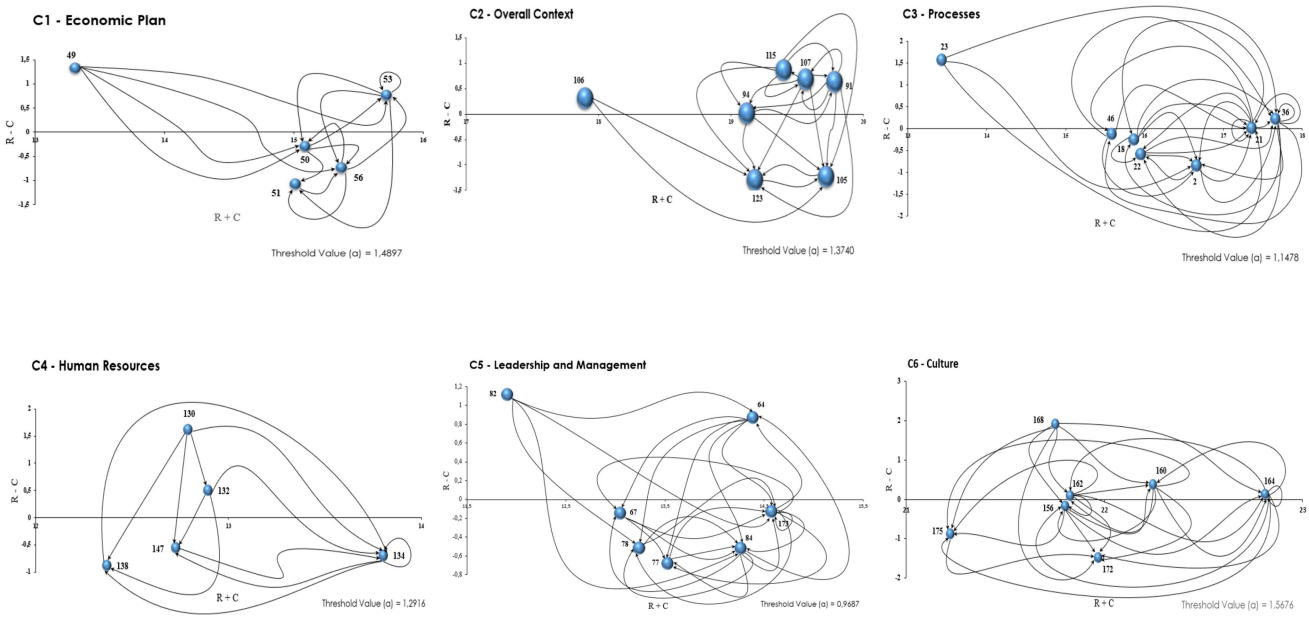

Fig. 5. Cluster IRMs.

Based on the *R–C* values, the six clusters were divided into two groups. The causes group comprises the criteria that present positive *R–C* values and directly affect the other criteria, while the effects group contains the criteria that have negative *R–C* values and that are mostly influenced by the other criteria.

Regarding the causes group (see Table VII and Fig. 5), five criteria present the highest positive *R–C* values. These criteria are company trust (168), investment in human resources training (130), market research (23), identification of market needs (49), and evaluating risks versus successes (82), with *R–C* values of 1.9139, 1.6194, 1.5683, 1.3275, and 1.1179, respectively. The results also show that organizational vision (64), research centers (115), partnerships with universities and technological centers (91), sophisticated demand (107), global market availability (94), and continuous improvement (21) have a similar degree of influence on the other criteria. These six criteria have extremely close *R–C* values: 0.8715, 0.8673, 0.6829, 0.6402, 0.0189, and 0.0141, respectively. The remaining criteria—investment in R&D (53), risk (106), discussion and rethinking of external innovations (36), employee diversity (132), communication (162), transparency (160), and dialogue (164)—have a medium degree of influence on the other criteria.

As for the effects group (see Table VII and Fig. 5), the criteria of hiring (46), launching challenges to overcome (173), communication skills (67), and sharing know-how (156) present the lowest negative *R–C* values. These are: –0.1224, –0.1289, –0.1477, and –0.1663, respectively. The four criteria are subject to the least influence by the other criteria. In contrast, the criteria of suitable business plans (51), opportunities (105), partnerships (123), and stimulation of creativity and brainstorming (172) are the most strongly influenced by the other criteria. These four criteria have the highest negative *R–C* values: –1.0697, –1.2282, –1.2909, and –1.4816, respectively. Last, the effects group also includes: financing (56), differentiation in the market (50), sharing (2), rewards for good ideas (18), quick response (22), creativity (134), dynamic capabilities (147), development of soft skills (138), promotion of a healthy and relaxed environment (77), motivation (84), identification of organizational goals for innovation (78), and critical spirit (175).

Based on the four Qs visualized in the IRMs in Fig. 5, the following categories were identified. QI contains the central factors that are quite prominent and have strong relationships: 21, 36, 53, 64, 91, 94, 107, 115, 160, and 164. QII comprises determinants factors that have little prominence but strong relationships: 23, 49, 82, 106, 130, 132, 162, and 168. QIII includes independent factors with little prominence and weak relationships: 67, 77, 78, 138, 147, 156, 172, and 175. Finally, QIV consists of impact factors that are quite prominent but that have weak relationships: 2, 18, 22, 46, 50, 51, 56, 84, 105, 123, 134, and 176. All these dynamics can affect OI in SMEs over time, so experts must constantly analyze and control possible variations of these factors and encourage flexible attitudes regarding how to manage OI processes.

C. Final Validation and Recommendations

The decision-maker panel expressed satisfaction with the results, but a consolidation session was also held to elicit the opinion of a neutral expert regarding the importance and applicability of the proposed system. This final expert was a project director at COTEC Portugal—a leading think-and-action network for advancing technology diffusion and business innovation cooperation—who did not participate in any of the previous group meetings.

TABLE VI
GROUP DIRECT-INFLUENCE MATRIX Z FOR EACH CLUSTER

C1: Economic Plan	51	53	56	49	50
51	0.0	3.0	3.5	2.5	2.8
53	4.0	0.0	4.0	2.8	3.7
56	2.7	4.0	0.0	2.0	3.8
49	3.8	3.1	2.6	0.0	3.0
50	3.6	2.7	3.8	2.6	0.0

C2: Overall Context	105	94	106	91	107	123	115
105	0.0	2.8	4.0	3.8	3.0	3.7	3.0
94	3.7	0.0	3.0	3.6	2.9	3.8	4.0
106	3.8	2.8	0.0	3.0	4.0	3.7	2.5
91	4.0	4.0	2.7	0.0	3.8	4.0	4.0
107	4.0	3.8	4.0	3.0	0.0	3.7	3.9
123	3.8	3.8	2.5	3.5	3.0	0.0	2.8
115	4.0	3.8	2.8	4.0	4.0	3.7	0.0

C3: Processes	2	18	36	22	21	46	23
2	0.0	2.0	3.6	3.0	4.0	2.4	2.3
18	3.8	0.0	3.0	3.6	3.0	2.0	1.8
36	3.8	3.5	0.0	3.6	4.0	3.3	1.8
22	3.2	3.6	2.7	0.0	1.8	3.7	2.0
21	4.0	4.0	3.3	3.1	0.0	3.0	2.0
46	1.8	3.3	3.5	2.3	3.3	0.0	2.8
23	2.8	1.0	3.5	2.7	3.3	3.0	0.0

C4: Human Resources	130	132	134	147	138
130	0.0	3.7	3.8	3.5	3.6
132	3.1	0.0	4.0	3.0	3.3
134	2.9	3.0	0.0	3.7	3.5
147	2.8	3.0	3.4	0.0	2.8
138	2.0	2.6	3.7	3.0	0.0

C5: Leadership and Management	67	173	77	84	64	78	82
67	0.0	4.0	3.4	3.5	2.9	2.4	2.0
173	3.3	0.0	3.9	3.8	3.1	3.7	3.0
77	4.0	2.9	0.0	3.9	2.9	2.6	1.9
84	3.6	3.8	3.8	0.0	3.1	3.2	2.1
64	3.7	3.3	3.9	4.0	0.0	4.0	3.3
78	1.7	4.0	2.9	3.1	3.3	0.0	2.8
82	2.2	3.3	2.3	2.8	4.0	3.8	0.0

C6: Culture	156	172	168	162	175	160	164
156	0.0	4.0	3.1	2.8	3.3	3.8	3.9
172	3.3	0.0	3.1	3.1	4.0	2.8	3.3
168	4.0	3.6	0.0	3.9	3.8	3.7	4.0
162	3.6	3.9	3.0	0.0	3.0	3.7	4.0
175	2.9	4.0	3.0	3.5	0.0	3.3	2.9
160	3.5	3.8	2.9	3.8	4.0	0.0	4.0
164	4.0	3.6	3.8	3.9	3.3	3.8	0.0

The session was carried out remotely via the Zoom platform due to the COVID-19 pandemic. The meeting lasted approximately one hour, and the session covered the following points. The first was a brief explanation of the study and methodologies used, while the second was a presentation of the results achieved. The third point was to obtain feedback with regard to using cognitive mapping and DEMATEL to build the model. The fourth was a discussion of the results and suggestions for improvement. The last point was an analysis of the decision-support system applicability.

The topic under study was thus summarized briefly, followed by an explanation of the epistemological approach and cognitive mapping and DEMATEL techniques. After the cognitive map was presented, the expert interviewee said that *"the criteria seem appropriate for the various clusters,* [...] *and I also agree with the causal relationships shown"* (in his words). One clear advantage of the proposed approach highlighted during the interview was that, throughout the structuring activity, the decision makers' cognitive representations could be preserved, modified, or reduced. The interviewee also considered the large number of evaluation criteria identified in the cognitive map to be an added value of the methodological framework.

Regarding the DEMATEL approach, the results achieved were in line with the interviewee's opinions. This expert also suggested that *"it would be interesting to decode the technical language to put the results of the diagrams into more everyday words so that all the management layers of companies and/or executives could have easier access to this information"* (again in his words).

In terms of the system practical applicability, the interviewee noted that *"SMEs are very diverse and they have different levels of maturity, and it is important to keep in mind that treating all SMEs the same would be a mistake"* (interviewee's words). When implementing this process in practice, the following precautions should be taken. First, the relevant processes need to be audited. The COTEC Innovation Scoring system is one useful tool created for this purpose. Second, managers need to verify their organization's maturity. The third precaution is to take into account SME financial capacity. Last, managers need to analyze their organization's capacity for innovation. However, the interviewee asserted, *"there are already many companies prepared to receive this type of approaches/processes, namely, the front runners of innovation"* (again in his words).

This expert thus acknowledged that the proposed combination of methods facilitates in-deep analyses of the dynamics created by OI in SMEs, as well as the overall impact of OI determinants. Nonetheless, practitioners need to bear in mind that the proposed metacognitive framework is constructivist and process-oriented, meaning that the aim was not to obtain an optimal solution. The main concern was, instead, to make the analysis of OI in SMEs as informed as possible, which is why a cognitive map was used in the information-gathering phase. In addition, since the proposed model was constructed based on the preferences of a specific group of decision makers, the results should not be generalized to other contexts without appropriate adaptations and adjustments. Overall, this model needs to be treated as a learning mechanism rather than a tool to obtain optimum solutions.

TABLE VII
DIRECT AND INDIRECT EFFECTS OF SELECTED CRITERIA

Criteria		(*R*+*C*)	(*R*–*C*)
C1: Economic Plan			
49	Identification of market needs	13.3090	1.3275
50	Differentiation in the market	15.0863	-0.2936
51	Suitable business plans	15.0101	-1.0697
53	Investment in R&D	15.7155	0.7677
56	Financing	15.3661	-0.7320
C2: Overall Context			
91	Partnerships with universities and technological centers	19.7817	0.6402
94	Global market availability	19.1196	0.0189
105	Opportunities	19.7180	-1.2282
106	Risk	17.8973	0.3098
107	Sophisticated demand	19.5640	0.6829
115	Research centers	19.3966	0.8673
123	Partnerships	19.1796	-1.2909
C3: Processes			
2	Sharing	16.6570	-0.8474
18	Rewards for good ideas	15.8615	-0.2489
21	Continuous improvement	17.3531	0.0141
22	Quick response	15.9490	-0.5835
23	Market research	13.4247	1.5683
36	Discussion and rethinking of external innovations	17.6565	0.2199
46	Hiring	15.5803	-0.1224
C4: Human Resources			
130	Investment in human resources training	12.7887	1.6194
132	Employee diversity	12.8934	0.5021
134	Creativity	13.8019	-0.6918
138	Development of soft skills	12.3678	-0.8764
147	Dynamic capabilities	12.7257	-0.5533
C5: Leadership and Management			
64	Organizational vision	14.3857	0.8715
67	Communication skills	13.0486	-0.1477
77	Promotion of a healthy, relaxed environment	13.5251	-0.6792
78	Identification of organizational goals for innovation	13.2376	-0.5170
82	Evaluating risks versus successes	11.9052	1.1179
84	Motivation	14.2636	-0.5166
173	Launching challenges to overcome	14.5709	-0.1289
C6 : Culture			
156	Sharing know-how	21.8008	-0.1663
160	Transparency	22.2449	0.3752
162	Communication	21.8275	0.0925
164	Dialogue	22.8090	0.1356
168	Company trust	21.7520	1.9239
172	Stimulation of creativity and brainstorming	21.9672	-1.4816
175	Critical spirit	21.2216	-0.8793

V. Conclusion

The main objective of this article was to develop a multicriteria analysis instrument by combining cognitive mapping and the DEMATEL technique to study OI dynamics within SMEs. The combined application of these techniques enabled the creation of a different model from those already available since it facilitates the clear structuring of information, provides a holistic view of the problem under study, and thus favors more informed decision making. The proposed approach also allows experts to identify key criteria that can influence OI in SMEs, including their level of influence and importance within these organizations. Indeed, the combined use of cognitive mapping and DEMATEL in our study allowed the opinions of different experts to be aggregated, creating a holistic framework that was shared by all, and within which cause-and-effect relationships among OI determinants in SMEs could be detected and understood. As such, our proposal is not a substitute for statistical approaches, but its application by managers and decision makers can provide insights on key feedback loops in the system, which might otherwise go undetected by statistical approaches alone. Although subjective in nature, cognitive maps promote the exchange of ideas and experiences, boost a deeper understanding of decision situations, and uncover the cause-and-effect relationships among criteria, allowing questions such as "why does this happen?" to be answered.

This article revealed that OI dynamics in SMEs involve six main dimensions: economic plan; overall context; processes; human resources; leadership and management; and culture. The application of the DEMATEL technique produced the following general conclusions. Human resources (i.e., C4) was considered the most important dimension based on its higher $R+C$ value (i.e., 7.4409). The criteria of investment in human resources training and employee diversity, in particular, directly influence the other dimensions. Culture (i.e., C6) comes next in terms of importance, with the second highest $R+C$ value (i.e., 6.6539). The criteria of transparency, communication, dialogue, and company trust are the most influential. The leadership and management dimension (i.e., C5) is the third most important, with an $R+C$ value of 6.6171. The findings include that organizational vision and evaluation of risks versus successes have the greatest impact on the remaining criteria. The fourth place goes to processes (i.e., C3) as it has an $R+C$ value of 6.3923. The criteria of discussion and rethinking external ideas, continuous improvement, and market research are more dominant than the other criteria. The second to last dimension is economic plan (i.e., C1) based on its $R+C$ value (i.e., 5.5391). The findings reveal that the criteria of investment in R&D and identification of market needs are the most influential. The last position in terms of importance goes to the overall context dimension (i.e., C2) given its low $R+C$ value (i.e., 2.7803). The criteria of global market availability, risk, partnerships with universities and technological centers, sophisticated demand, and research centers were considered more dominant than the other criteria by the expert panel.

The analysis system developed was validated by the decision makers, who considered it to be an advance in research on OI in SMEs. However, this article limitations should be highlighted, including the context-dependent nature of the proposed framework and results. The findings could have been different with other participants or longer sessions. As mentioned previously, the proposed decision-support system is constructivist and process-oriented, meaning that its aim is not to find an optimal solution. Instead, the main concern was to conduct a more informed analysis of OI in SMEs.

The present investigation confirmed the increasing importance of OI in SMEs, as well as the internal, external, organizational, and contextual factors that affect their performance and external relationships. This article sought to develop a new approach to this topic by combining two methodologies in an innovative way for this article context. In addition, the dual-methodology application contributed to a more complete, transparent, and holistic perspective on OI dynamics in SMEs as the proposed metacognitive approach facilitated the inclusion of objective and subjective elements in the same decision-making process and resulting framework.

Therefore, the study's main contributions are, first, a decision-support model that provides a holistic view of the problem in question. Second, the cognitive map was generated based on the decision makers' mental schemas, interactions, and knowledge (i.e., values, opinions, and experiences), thereby identifying about 190 evaluation criteria. Third, the results create a model that is easy to interpret. Last, the findings highlight the areas with greater or lesser impact and, in this way, provide a clearer view of which areas need more intervention.

Notably, the complementary stance of our study should be highlighted again: the aim is not one of substitution of previous methods or models, but rather their augmentation. In this regard, because our approach allows for the addition of new information over time, the proposed model is not only robust, but also versatile. Theoretically, its use is encouraged not only as a complement to previous work on OI determinants, but also as a springboard for additional, future studies. Also, the use of the methodological combination proposed in this article resulted in the design of a transparent and well-informed analysis system, comprising both objective and subjective components.

No methodology is free of limitations, so future research needs to take into consideration the advantages of similar studies using other multicriteria methods (e.g., system dynamics). A comparison of these results would present an interesting challenge. Regarding the decision criteria considered in the present research, future studies could analyze the performance and behavior of each dimension and/or criterion to compare the results. Any contribution that can bring greater empirical robustness and progress to the study of OI impacts on SMEs will always be considered a welcome addition.

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