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Multicriteria Evaluation of Technological Competitiveness in Diversification Processes. An application to the Automotive Components Industry

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Abstract

Considering Technological Competitiveness in diversification processes as the existence of key technologies that guarantee the current and future effective running of firms in terms of their technological and operational potential, this paper presents a multicriteria approach for its evaluation and provides an index for measuring the technological competitiveness of diversification processes. The application of this multicriteria approach, based on the Analytic Hierarchy Process, in three real technological diversification processes allows: (i) the validation of the hierarchical model (5 levels and 25 attributes) and the index (73 indicators) proposed for evaluating the technological competitiveness; (ii) the use of this hierarchical model and index to confirm the suitability of the diversification process and to extract knowledge related to the technological and operational potential of the firm; and, (iii) the exploitation of this knowledge in order to guaranty the long-term survival of automotive components industry's firms. The methodology finds the most relevant attributes in the automotive component sector (innovative capacity and activity, good functioning of the management and finance departments). Its practical application determines the firm's suitability for a diversification process, identifies the attributes that require some improvement, and the decision opportunities. After five years, the three companies that have been studied showed a behavior aligned with the values and recommendations of the index developed to assess technological competitiveness. The main limitation lies in the difficulty of studying companies if they change or disappear in the future.

Keywords: Multicriteria Evaluation; AHP; Strategic Management; Technological Diversification; Technological Competitiveness; Automotive Components Industry

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1. Introduction

In the context of a global economy and in the framework of the Knowledge Society, we should begin by highlighting the need for strategic management in business systems to make them truly competitive, i.e. to ensure their long-term survival. One of the instruments available to achieve the long-term survival of firms is industrial and technological diversification, understood as the development of new products in new markets (Ansoff, 1965) based on technology.

Starting from the identification of the key technologies, the diversification processes are used to construct the associated technological tree and select the most suitable diversification strategy (applications and products) for the future running of the firm (Larrodé et al., 2012). The complexity and cost of these diversification processes suggest the development of new tools and indexes that allow an assessment of the suitability of their implementation.

Extending and completing the methodological proposal made by Larrodé et al. (2012) and Muerza et al. (2014) for the development of industrial and technological diversification processes (ITDP), this work defines the concept of *Technological Competitiveness* in *Diversification Processes* (TCIDP), constructs an index (TCIDPI) for the evaluation of suitability, and provides the thresholds that make this index operational. A cognitive multicriteria approach (Moreno-Jiménez and Vargas, 2018; Arduin, 2023; Vargas et al., 2023) based on the Analytic Hierarchy Process (AHP) (Saaty, 1980) is proposed for the evaluation of Technological Competitiveness in the Automotive Components Industry (ACI).

Defining the TCIDP as the existence of key technologies that guarantee the current and future effective running of firms in terms of their *technological* and *operational* potential, this new concept is introduced because it is necessary to consider both engineering and management activities related with the organisation's capacity to exploit its technological potential (TP). In this context, operational potential (OP) refers to the skill, aptitude, capacity or suitability to undertake or intervene in a technological diversification process. In short, the TCIDP combines technological capacity and competence to effectively compete in the medium and long term.

According to the methodology proposed for the ITDP, the indicator TCIDPI allows the confirmation of the suitability of the diversification process. At the conclusion of the first phase of the ITDP methodology (Evaluation of Technological Diversification Suitability), there is an initial assessment of the suitability of the technological diversification based on the information exclusively provided by the firm when completing a first questionnaire on the general situation of the firm. This first questionnaire (see Appendix 1) was developed, as part of a national project, by the research team (*the Analyst Group* - AG) in collaboration with 23 firms of the ACI, and consists of 16 attributes evaluated with 16 indicators on the general situation of the company (5 for actors and 11 for factors).

This information is complemented by a visit to the firm and the completion, by the AG with the firm's managers (the *Firm Group* - FG), of a second questionnaire on *technological competitiveness* (TC) that includes 25 attributes (10 for TP and 15 for OP) and 73 indicators (25 for TP and 48 for OP). The information included in this second questionnaire is what allows us to obtain the TCIDPI and the extraction of the knowledge associated with products, processes and people that the cognitive orientation requires.

The multicriteria approach followed for the assessment of the TCIDP and the calculus of the TCIDPI has been applied to three ACI companies. This sector was chosen for two main reasons: (i) the high level of competition in a complex and dynamic business context which complicates the long-term survival of firms; and, (ii) the importance of technology and continuous technological development for the future of the ACI sector and the accompanying processes of diversification. Although the theoretical framework of the multicriteria approach is generally valid for firms in different industries; the hierarchical model, the evaluation system (valuation of relevant aspects and setting of operative thresholds) and knowledge extraction are specific to the industry in question. For the ACI, a hierarchy with 5 levels (goal, 2 criteria, 4 first level sub-criteria, 10 second level sub-criteria and 25 third level sub-criteria or attributes) is constructed. Thresholds have been established as a reference to accept or reject the industrial and technological diversification processes. These thresholds have been obtained as the sum of the priorities of the recommended categories for the attributes.

After this introduction, Section 2 focuses on the background of the work, it includes an overview of the Automotive Industry, the presentation of the methodology considered for industrial and technological diversification and the multicriteria approach (AHP) used in the evaluation; Section 3 describes the multicriteria approach (the theoretical framework and hierarchical model) proposed for the evaluation of the technological competitiveness of firms in ACI and the calculation of the TCIDPI; Section 4 applies the methodology to the analysis of diversification processes in three companies from the ACI; Section 5 highlights the most important findings of the paper, some limitations of the proposal, and future research lines.

2. Background

2.1. Industrial and Technological Diversification Processes (ITDP)

In the industrial sector, in which there is often a limited product life-cycle, diversification strategies are seen by many firms as a risk reduction strategy in a business environment of constant innovation and technological adaptation. However, diversification opportunities are not always easy to find because of declining related sectors, traditional character of the industries or territories in which the company is located, economic or financial crises (Zabala-Iturriagagoitia et al., 2020).

The concept of diversification from a technological perspective include different definitions. Technological diversification can be defined as the expansion of the firm's technological competences in other technological areas (Lin et al., 2006). A firm's absorptive capacity is particularly important to the success of technology and knowledge integration, and the external environment may also accelerate or hinder the efficacy of technological diversification (Lin and Chang , 2015).

Chen et al. (2010) argue that technological diversification is concerned with the increase in the diversity of the technological capabilities of a firm, its exploratory calibre, long-term investments in new technological sectors and the global expansion of its current technological scope.

More recently, Santoalha et al. (2021) link the concept to the appearance of new industrial paths. Meanwhile, Wang et al. (2020a) use the term *Technological Trajectory* to map the changes related to the technological progress in terms of the citation links between patents, showing the diversification directions, and Choi and Lee (2021) consider technological diversification determines R&D productivity of a firm.

Firms that undergo a technological diversification process need to identify and assess their internal capacities (human resources and technology) and know-how. For the purposes of this research, this set of company skills and abilities is called *Technological Potential* (TP).

Larrodé et al. (2012) consider technological diversification as "*the search for new products and markets based on the exploitation of the technological potential of the firm by identifying its key technologies, competitive advantages and potential opportunities*"; this is the definition that is utilised in the present work.

Despite technological diversification is linked to the long-term survival of the firm, it also cause some costs (Choi and Lee, 2021), particularly for the coordination and integration of resources (Kook et al., 2017). The decision to start a diversification process is highly complex due to uncertainty, potential risks and opportunities so the employment of appropriate methodologies and tools for the analysis of technological diversification processes are required. A summary of these methodologies and tools with their characteristics and limitations can be found in Muerza et al. (2016). The main criticism of the aforementioned methods and tools is that they cannot, by themselves, be used in a complete process of diversification because they lack the information support for a decision-making procedure of these characteristics.

In an attempt to mitigate this problem, Muerza et al. (2014) proposed a methodological framework (ITDP Methodology) for diversification processes that consists of four phases: (1) Evaluation of Diversification Suitability – problem formulation (Stage 1.1) and the selection of those companies with the potential to carry out a diversification process through the use of multicriteria techniques (Stage 1.2); (2) Selection of the Technological Diversification Strategy – diversification suitability is confirmed (Stage 2.1), the technological tree (GEST, 1986) is built (Stage 2.2) as a basis for the selection (from a top-down or bottom-up perspective) of the best technological strategy (Stage 2.3), and the relevant knowledge is extracted (Stage 2.4); (3) Implementation of the Best Diversification Strategy – the design of the appropriate business strategy for the selected technological alternative (product or product portfolio) (Stage 3.1), the most effective, efficacious and efficient option for the implementation process (Stage 3.2); and (4) Evaluation of the Effectiveness of the Diversification Process.

This paper concerns the confirmation of the technological diversification suitability and the extraction of knowledge for the stages and phases of the methodology.

2.2. The Analytic Hierarchy Process (AHP)

AHP (Saaty, 1980) is a methodology widely used in multicriteria decision-making processes (e.g. Ishizaka and Labib, 2011; Ho and Ma, 2018; Oliveira et al., 2018). It allows determining the weights of the criteria, and the resolution of highly complex problems, such as the confirmation of technological diversification suitability, which is characterised by the existence of multiple criteria, scenarios, and actors. Saaty's AHP methodology consists of three stages (Saaty, 1980): modelling, valuation, and prioritisation and synthesis.

AHP has four specific characteristics that favour its practical application in solving complex problems: (i) it allows measurement of the inconsistency of the decision maker when eliciting the judgments (Aguarón and Moreno-Jiménez, 2003); (ii) it can count on the theoretical developments and the information technology tools needed to evaluate the model's robustness and the stability of the solutions (Aguarón et al., 2003); (iii) it has excellent results in multi-actor (group, negotiated and systemic) decision making (Salvador et al., 2015); and, (iv) it can address (ANP) the interdependencies that characterise the holistic view of reality that is typical of the Knowledge Society (Moreno-Jiménez et al., 2014).

Nevertheless, AHP has not been free of criticism (Smith and von Winterfeldt, 2004), from both a methodological and an operational point of view. Methodologically, the most questioned aspect is known as the rank reversal problem (Belton and Gear, 1983). Operationally, the main limitation is the large number of comparisons that must be performed when dealing with large-scale problems (Takeda et al., 1987). Neither of these potential and refuted drawbacks affect the conclusions of the present work due to its cognitive orientation (Moreno-Jiménez and Vargas, 2018; Vargas et al., 2023), the use of absolute measurements, and the small size of the model. A more detailed study of the rank reversal problem can be seen in Saaty and Sagir (2009).

The results obtained allow the firm to gain knowledge on the implementation of a diversification process; the methodology explains how one firm can be more technologically competitive than another. In addition to an internal analysis of the firm, the process extracts knowledge that is fundamental for the firm's future, irrespective of its suitability for a diversification process or the implementation of the selected diversification strategy.

3. Technological Competitiveness in Diversification Processes for the ACI

3.1. Technological competitiveness: a theoretical framework

Over the last 25 to 30 years, the concept of technological competitiveness has been interpreted in a variety of ways and has been used in different industrial or economic environments, but no specific references have been found to the automotive industry.

Jolly (2003, 2012) distinguishes between *Technological Competitiveness* (under the control of the firm) and *Technological Attractiveness* (beyond the control of the firm). Based on a review of the literature, the same author identified a list of 32 criteria (16+16) that illustrate the two concepts.

From an industrial perspective, Technological Competitiveness (TC) has been linked to: (i) the existence of a technological advantage (Hwang et al., 2006); (ii) the technological ability to ensure survival and sustainable growth (Mittal and Momaya, 2015); (iii) a strategy of innovation of products and markets (Pianta, 2001); and (iv) the existence of resources that are not easily imitable and the use of technology as a competitive advantage (Wang et al., 2020b).

Bogliacino et al. (2013) believe that a TC strategy concerns product innovation, knowledge creation, and development of new markets; these are the main points of the ITDP that are considered in this paper. For the purposes of the present work, Technological Competitiveness is defined as the existence of key technologies that guarantee the current and future effective running of a firm (survival and sustainable growth) in terms of its technological and operational potential. The detailed study of the firm's potential provides information that, in addition to assessing TC, is needed to construct the technological tree. Thus, along with the inventory, classification and selection of the key technologies, the company SWOT matrix is constructed to evaluate the technological strengths and weaknesses, opportunities and external threats. The analysis of the technological strengths is used with other indicators to select the appropriate technological strategy.

In order to confirm the suitability of diversification, the Analyst Group (AG) – in this case a research group of industrial and academic experts – visit the company to ensure that the Firm Group (FG) utilises a common vocabulary, i.e. there is mutual structural coupling in communication. In this communication, the two groups analyse the readiness and willingness of the owners to address those aspects that were considered as negative in the first stage.

After the technological competitiveness analysis, a series of recommendations are made for each of the scenarios identified by the company (Table 1).

Table 1
Confirmation analysis of suitability for diversification

Validation of the Technological Potential	Validation of the Operational Potential	Recommendations
YES	YES	Carry out the diversification process
NO	YES	Confirm the existence of key technologies and re-evaluate the technological potential
YES	NO	Undertake a mentoring process to develop the necessary structure
NO	NO	A diversification process is discouraged

3.2. A hierarchical model for technological and operational potential

The *Technological Potential* (TP) of the company is the set of technologies of a firm that are used in the creation of one or more products. Research and development plays a fundamental role and forms the trunk from which the different products grow. At the same time, *Operational Potential* (OP) – the capacity of the firm to manage its organisational and operational structure – must be studied because of its importance in the recommendation of a diversification process. A firm must take the key technology as the starting point of the diversification process but it must also possess the operational capacity to adopt the necessary changes.

Increased knowledge of the TP and OP is gathered through a second questionnaire (see Appendix 2) which covers all technological and structural aspects of the firm; the questionnaire compliments the information provided by the firm in Phase 1 of the methodology (first questionnaire on the general situation of the firm); it deals with information associated to the hierarchical model utilised to evaluate competitiveness (see Fig. 1). The information extracted from this second questionnaire with 73 indicators is utilised to classify the technologies of the company and to assess the suitability of a diversification process.

3.2.1. Construction of the hierarchy model

The construction of the hierarchical structure and its evaluation is undertaken in collaboration with the same group of six experts with experience in the automotive industry as in Phase 1 (Larrodé et al., 2012) acting as a simple entity or group. The profiles of these six experts of the AG were: one Full Professor and one Assistant Professor specialised in diversification processes; one Full Professor and one Assistant Professor specialised in Multicriteria Decision Making and Strategic Planning; and 2 Consultants specialised in the ACI sector. The profiles of the experts of the FG were: Managing Director, Manager of the Engineering Department, Manager of the Production Department, Manager of the R&D&i Department, Manager of the Logistics Department, Manager of the Marketing Department.

The participation process between the AG and FG is described in more detail as follows. The AG

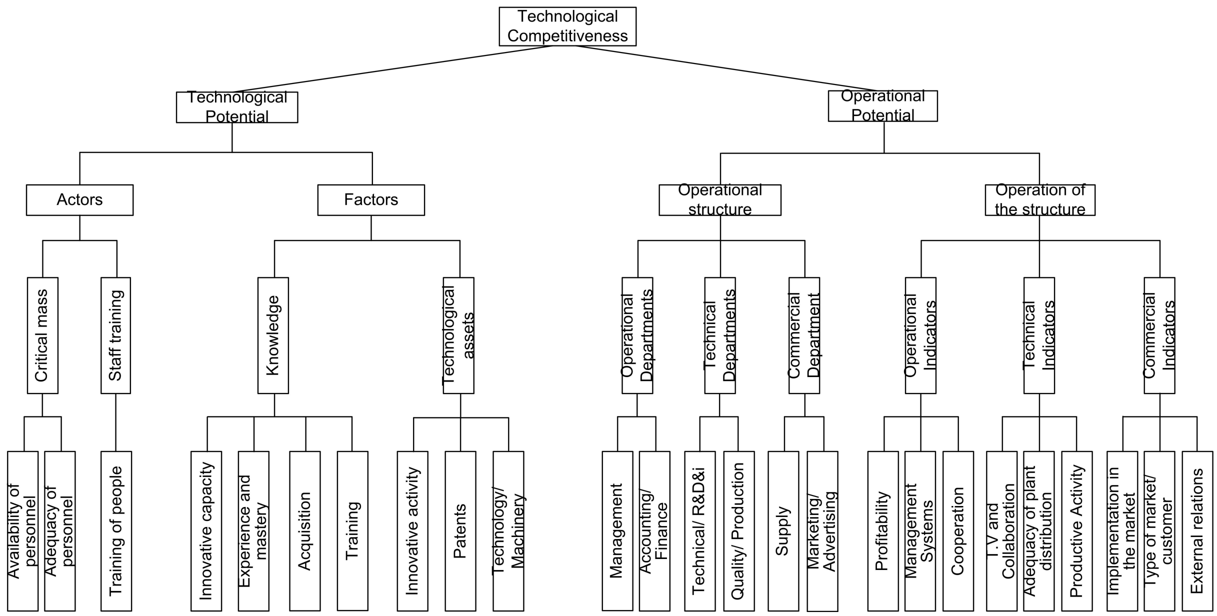

Fig. 1. Structure for the confirmation of the technological diversification suitability

drew up an initial list of elements of the hierarchy from literature and their experience. Meanwhile, the FG proposed a series of attributes based on its experience. A first discussion meeting between both groups (AG and FG) was organised with two objectives: (i) to explain the fundamentals of AHP, and (ii) to define the elements to be included in the model, and the structure of the hierarchy. The AG and FG structured the problem into a hierarchy in five levels (Fig. 1): goal; 2 criteria (C1: TP, C2: OP); 4 first level sub-criteria (SC1.1: Actors (A), SC1.2: Factors (F), SC2.1: Operational Structure (S), SC2.2: Operation of the Structure (OoS)); 10 second level sub-criteria; and 25 third level sub-criteria (attributes - ATR). The structure of the model built to assess the technological potential and the operational potential of a firm is based on the initial structure (16 attributes) constructed for the multicriteria evaluation (AHP) of suitability for technological diversification (Stage 1.2) and can be found in Larrodé et al. (2012). In this case, a 'zoom' of the actors and factors involved in the diversification process is performed in order to go into detail on the analysis undertaken in the first phase of the methodology. Because of the discussion process, additional elements to those identified in literature were incorporated into the model, in particular those related to the OP. In addition, unlike Jolly (2012), our model considers the TP is within the control of the company.

Next, four discussion meetings were organized to assess the hierarchy. The first meeting focused on the valuation of the hierarchy elements. Collective judgements were elicited by consensus. The details of the process are provided in Section 3.3. The second and third meeting were used to define the indicators and to measure the attributes in the framework of the knowledge of the experts. To do this, a questionnaire was designed (see Appendix 2). As an example, Table 2 shows the rules established to measure ATR2 (the elements of the hierarchy are defined in Section 3.2.2). The fourth meeting consisted of the valuation of the alternatives with regard to the attributes. A sensitivity analysis was performed after the process by the AG to confirm the validity. Another meeting was organized to discuss the results of the sensitivity analysis performed to adjust the levels of the model categories. We completed the flow of communication between the AG and FG by email.

Table 2
Assessment rule to measure the adequacy of personnel for technological tasks (ATR2)

Attribute	Rule
ATR2*	ATR2 = 0.3*I4 + 0.7*I5

* Note: I4 (degree of versatility), I5 (policompetence). Range of values for I4 and I5 [Very High (1), High (0.8), Medium (0.6), Low (0.4), Non available (0)]. A low valuation of ATR2 implies the firm has limited specific human resources in the technical and production area for performing the usual activity, and therefore the potential of these resources to be used in other activities is low.

3.2.2. Elements of the hierarchy

The sub-hierarchy that analyses the criterion associated with the technological potential of the company, it is composed of 4 second level sub-criteria (2 for each of the 2 first level sub-criteria) and 10 attributes (third level sub-criteria):

SC1.1.1. Critical mass (A1)

The critical mass of a company refers to the availability of a suitable set of human resources to carry out the activities of the company. Before instigating a technological diversification strategy, the firm must review its existing resources and capabilities, adapting them to the diversification (Chiu et al., 2008). The attributes that evaluate this sub-criterion are *Availability of personnel* (ATR1) and *Suitability of personnel for technological tasks* (ATR2). The work of the personnel in technological tasks is measured by means of the percentage of permanent employees and the number of shifts in the company; this indicates the availability of personnel for a diversification process. The suitability of personnel is measured by the turnover rate of production staff and the degree of policompetence - the skills for performing tasks, the preparation and maintenance of machinery and equipment, and knowledge of its theoretical foundations. Corporate resources are used as the driving forces to search for new business opportunities, benefiting from economies of scope in valuable, rare and inimitable resources (Bromiley and Rau, 2016).

SC1.1.2. Staff training (A2)

Staff training is measured by *Training of people* (ATR3). The learning capabilities of individual employees have an impact on organizational dynamic capabilities (Anand et al., 2009). For the different levels of training, the priority functions in R&D, Quality/Production and Technical/R&D&i are identified. A firm with a high R&D&i index will be better suited to a diversification process and have a higher technological potential.

SC1.2.1. Knowledge (F1)

Knowledge of the firm and its technology is the foundation of the business. Matusik and Heeley (2005) believe the knowledge of a firm is supported by each member of the organisation, work routines, documentation, procedures, shared experiences and know-how. These authors also argue that there is a relationship between the skills/technical knowledge of the staff, communication, the common understanding of business objectives and the capacity to absorb knowledge related to the firm.

Companies possess stocks of public and private knowledge (Matusik, 2002): private knowledge includes the terms unique, valuable, rare, and imperfectly imitable, it is knowledge that can be a source of competitive advantage (Kang et al., 2021); public knowledge is essentially a public good that, by itself, is not a source of competitive advantage, but a misapplication of the same in the company can be a source of competitive disadvantage. Knowledge is measured by evaluating the following attributes:

- ATR4. *Innovative Capacity*: this measures the suitability of the firm to implement innovative activities. Evaluation considers the existence of a defined and explicit technological strategy for innovation - the number of innovative projects or improvement actions per year and their success rate.
- ATR5. *Experience and mastery*: this is an indicator of the background of the firm through the identification of the activities in which it is expert and its years of experience. The attribute also identifies the way in which the information transfer of technology is carried out and the existence of trademarks.
- ATR6. *Acquisition*: the acquisition of knowledge in a company is achieved through participation in R&D&i programmes and the implementation of such projects in different areas (product, process, marketing, services and operations).
- ATR7. *Training*: training in technology is an indicator of the capabilities of the firm. The competitive advantages of a firm stem from its internal capabilities, that is to say the effective and efficient use of resources (Hitt et al., 2016). The aim is to assess the existence of adequate training for the organisation of the operation.

SC1.2.2. Technological assets (F2)

The technological asset of an organisation reflects its technological capabilities. The following attributes were defined:

- ATR8. *Innovative activity*: evaluated through the knowledge, development, collaboration and innovation of the firm in relation to its services. Innovation gives a firm a short term, quasi-monopoly position, until imitations or replacement products emerge in the market-place (Mackelprang et al., 2015). Innovative activity takes into account the percentage of the annual budget devoted to investment and technology acquisition. A technological acquisition strategy requires specific management skills (Granstrand, 2004) and external acquisition generally requires technology foresight, identification, assessment, access, transfer and integration of the new technologies and processes. Finally, the percentage of development or outsourcing in projects undertaken in the last five years involving technological innovation is noted and current work areas regarding improvement/technological projects.
- ATR9. *Patents*: patents are a primary source of information about the internal technological capabilities of a company; they may lead to diversification processes, i.e. new products and production methods (Santoalha et al., 2021). There is an underlying assumption that patents are linked to success in long-term development strategies (Wang et al., 2020b). The strategic use of patents, technologies and other intellectual property rights can improve the success of a firm in three different ways (Cesaroni, 2004): (i) through the accumulation and protection of an advantage in the market; (ii) by improving the financial results of firms (becoming aware of the 'hidden value' of patents); and, (iii) through the increase in competitiveness.
- ATR10. *Technology/Machinery*: technology is a significant factor of competitiveness (Wang et al.,

2020b). The assessment of the TP analyses the firm's differential and strategic product technologies in terms of: material-mechanical; electric-electronic; installation of equipment; treatment of products; and, sub-products and proficiency. In addition, production capacity and the use-capacity of the machinery are valued according to technological level and the market.

The *Operational Potential* (OP) of the firm illustrates a suitable operating structure, i.e. it has exploitation potential for the development of a technological diversification process. The AG identifies the elements in the OP sub-hierarchy: 6 second level sub-criteria (3 for each of the 2 first level sub-criteria) and 15 attributes (third level sub-criteria):

SC2.1.1. Operational Departments (S1)
The correct functioning of the operational departments is essential for the firm. The evaluation is based on *Management* (ATR11) and *Accounting/Finance* (ATR12). The management decides the type of diversification, determines the number of segments in which the firm operates and its distribution (Tan et al., 2007). The evaluation contemplates the participation in Development and Innovation and the existence of strategic, control and investment plans.

SC2.1.2. Technical Departments (S2)

- ATR13. *Technical/R&D&i*: provides the production department with the technology that lowers manufacturing costs. It analyses and improves the production tools and techniques and studies new investments to improve technology and the optimisation of space. The R&D&i department is responsible for the creation of new products. Firms are more productive in performing R&D in technological fields related to their core technology (Choi and Lee, 2021).
- ATR14. *Quality/Production*: the main function of the firm is to manufacture products; the department is also responsible for: analysing products/services; measuring execution times; safety and hygiene; designing work execution methods; inventory; and, quality control.

The evaluation of these attributes is based on the work of the R&D&i department, the existence of improvement activities and/or a process development plan (in some firms this is known as the R&D&i plan) and facilities, equipment and specific software for quality/ production control. In the opinion of the participating group of experts, the role of the Technical/R&D&i department is more important than the firm's production capacity for a technological diversification process – production capacity can be changed if finance is available.

SC2.1.3. Commercial Department (S3)

- ATR15. *Supply*: the department is responsible for supplying the materials for manufacturing, thereby supplying the sales department the products to sell. It is also responsible for stock control.
- ATR16. *Marketing and Advertising*: responsible for future action, market research, promotion, advertising and sales. In short, the department designs the firm's technological strategy.

The valuation of these attributes involves the participation of the R&D&i department, a protocol for selecting suppliers and a marketing plan.

SC2.2.1. Operational Indicators (OoS1)

- ATR17. *Profitability*: measured by financial profit, the level of debt and changes in numbers of employees in the last three years. The higher the debt, the greater the probability of inefficient management decisions.
- ATR18. *Management Systems*: refers to a proven structure for the management and continuous improvement of the policies procedures and processes of the firm. The implementation of the systems involves the development of specific processes and standards.
- ATR19. *Cooperation*: inter-company cooperation is a strategic response to increasing competition and the necessity to access a wider range of technologies and capabilities (Sánchez-Peinado and Menguzzato-Boulard, 2009).

SC2.2.2. Technical Indicators (OoS2)

- ATR20. *Technological vigilance and collaboration*: enables a decision making process with lower risk based on internal and external understanding of the organisation. This indicator is measured through: the existence of a formal process of vigilance of competitors, customers and suppliers; the effectiveness of the technological vigilance process through the improvement or modification of any business aspect; and, the frequency of collaborations to improve competitiveness in the last three years. Matusik and Heeley (2005) argued that the level of exclusive knowledge of a firm expands when new external knowledge is combined with firm's existing technology to create new knowledge or fill gaps regarding capacities.
- ATR21. *Adequacy of plant distribution*: concerns the usable surface space in the case of diversification; surface availability, plant accessibility, and flexibility in the production process that facilities availability.
- ATR22. *Productive activity*: the main design and manufacturing processes of the firm, the increase in number of products, improvements in the product and production process.

SC2.2.3. Commercial Indicators (OoS3)

- ATR23. *Implementation in the market*: analysis of national and international market share and the geographical destination of the products.
- ATR24. *Type of market/customer*: the percentage of customers that absorb 80 % of the production, the tendencies of those customers in the last five years and the sectors to which they belong.
- ATR25. *External relations*: the different methods for marketing services and collaborations in commercial departments.

3.3. Valuation of the hierarchical model

The hierarchy, which can be applied to any manufacturing firm with minor changes in the judgments, is evaluated by means of a top-down approach (from the top of the hierarchy to the bottom). The AG, acting as a single entity (group), provides judgments through a process of consensus. For the evaluation of technological competitiveness (TC) the group provided 1 judgment for the pair-wise comparison matrix (PCM) that compares the relative importance of the two criteria (TP and OP) with respect to the goal. For the sub-hierarchy of the TP, the group elicited 1 judgment when comparing the actors and the factors with respect to the TP criterion, 2 judgments (1+1) when comparing the two second level sub-criteria with respect to the two first level sub-criteria (two PCMs) and 10 (1+6+3) judgments when comparing the attributes with regard to the second level sub-criteria (three PCMs). Similarly, for the sub-hierarchy of the OP, the AG elicited 1 judgment for the comparison of the first level sub-criteria and the OP criterion, 6 judgments (3+3) when comparing the two second level sub-criteria with respect to the two first level sub-criteria (two PCMs) and 12 judgments (1+1+1+3+3+3) when comparing the 15 attributes and the six second level sub-criteria (six PCMs).

The experts elicited by consensus the 33 judgments in line with Saaty's Fundamental Scale (Saaty, 1980). Inconsistencies of all the PCMs were analysed and found acceptable (CR less than 0.10). The range of CR values for the non-consistent matrices is [0.02-0.07]. The local priorities of the children that hang from all the nodes of the hierarchy are obtained using the eigenvector method as the prioritization procedure. The global priorities of the 25 attributes (with respect to the goal) are obtained by the principle of hierarchical composition (Fig. 2).

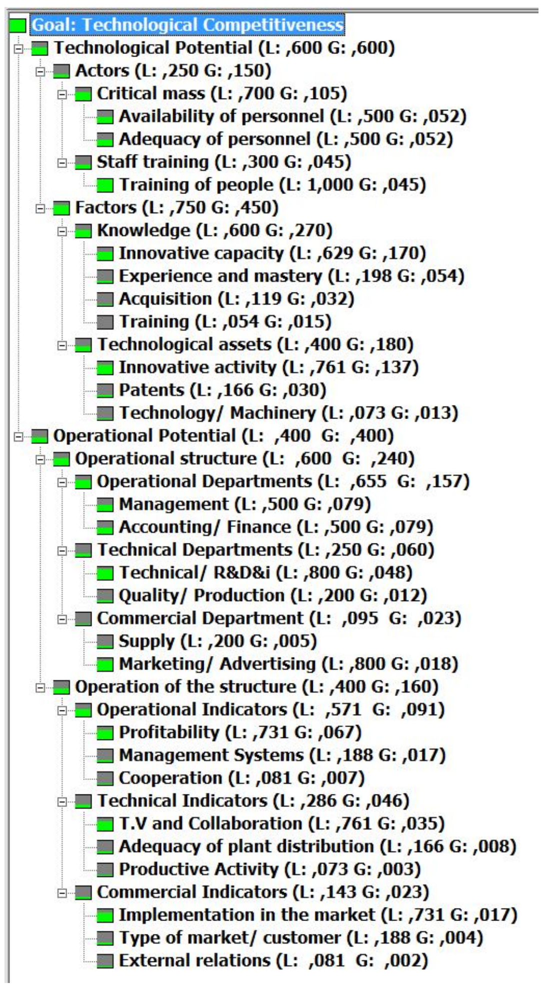

Fig. 2. Local (L) and global (G) priorities of the elements of the hierarchy

The alternatives are evaluated by means of absolute measurements using the rating module of Expert Choice™ software. Five categories (very high (A), high (B), medium (C), small (D) and very small (E)) are considered for each attribute. The priorities of these categories for each attribute are derived from their respective PCMs. The final score for the technological competitiveness of each firm is obtained by means of a multi-additive linear function (1).

$$TCIDPI(Firm_i) = \sum_{j=1}^{n} s_{ij} * k_j \tag{1}$$

Where s_{ij} is the local priority of the category (A, B, C, D or E) ascribed when evaluating the company *i* with respect to the ATR *j* (j=1,. . . ,25), normalised in an ideal mode, and k_j is the global priority of the attribute (ATR) *j*.

Table 3 presents the priorities (normalised in an ideal mode) of the five categories considered for the 25 attributes of the hierarchical model (Fig. 1). It also gives the minimum thresholds established by the AG (*italics*) to confirm the suitability of diversification (in terms of its TP and OP) indicating that the firm is competitive from a technological point of view and it has potential for the exploitation of its resources. Unlike the first phase of the ITDP (Larrodé et al., 2012), in which a series of critical thresholds and a final score were established to advise firms of the continuity of the analysis, the second phase does not have critical thresholds in the defined levels.

The AG established a rule (R) and a recommendation (RE) when evaluating the technological competitiveness of a firm for a diversification process with the proposed hierarchy:

- R. Firms have to simultaneously surpass the thresholds fixed for the assessment of technological (0.332) and operational potential (0.115). These values are obtained by adding the local priorities associated with the recommended categories in each of the attributes. The minimum score for TCIDPI, when a firm is suitable for diversification, is therefore 0.447 (0.332 + 0.115).
- RE. Firms should surpass the minimum recommended thresholds (italic values in Table 2) for each attribute established for the assessment of the TP (ATR1-ATR10) and the OP (ATR11-ATR25).

Firms that surpass the thresholds fixed for technological and operational potential (R), possess the level of technological competitiveness required for an industrial and technological diversification process. As long as rule (R) is complied with, failure to reach the minimum recommended thresholds (RE) in some of the attributes does not mean that the firm does not have the level of technological competitiveness required for a diversification process. However, improvements should be made regarding those attributes that have not reached the minimum recommended threshold.

The most relevant attributes (higher global priority) in the hierarchy for analysing the TC are (Table 2): ATR4 (Innovative Capacity) and ATR8 (Innovative Activity) for the TP, and ATR11 (Management), ATR12 (Accounting/Finance) and ATR17 (Profitability) for the OP.

The TC score of the firm, obtained as the sum of the TP and OP scores, is used for comparing the evaluated firms. The analysis of the attribute scores should involve a cognitive orientation (Moreno-Jiménez and Vargas, 2018; Lins et al., 2023), that aims to identify areas for improvement. This cognitive and evolutionary approach is in line with the proposals of Mittal and Momaya (2005) and Bogliacino et al. (2013), oriented to ensure survival and sustainable growth of the firms in the medium and long term by means of knowledge creation, product innovation (product development) and market internationalization (market development).

Table 3
Priorities of the attribute categories and thresholds for the suitability confirmation of the diversification process

	Actors			Factors							Operational structure					
	A1		A2	F1				F2			S1		S2		S3	
IN [a]	ATR1	ATR2	ATR3	ATR4	ATR5	ATR6	ATR7	ATR8	ATR9	ATR10	ATR11	ATR12	ATR13	ATR14	ATR15	ATR16
A Very high	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
B High	0.500	*0.500*	0.701	*0.701*	*0.682*	*0.608*	0.550	*0.701*	0.701	0.701	0.682	0.701	0.701	0.550	0.500	0.608
C Medium	*0.234*	0.234	*0.210*	0.210	0.239	0.370	*0.274*	0.210	*0.210*	*0.210*	*0.239*	*0.210*	*0.210*	*0.274*	*0.234*	*0.370*
D Small	0.107	0.107	0.101	0.101	0.126	0.225	0.133	0.101	0.101	0.101	0.126	0.101	0.101	0.133	0.107	0.225
E Very Small	0.058	0.058	0.068	0.068	0.069	0.137	0.076	0.068	0.068	0.068	0.069	0.068	0.068	0.076	0.058	0.137
GP [b]	0.052	0.052	0.045	0.170	0.054	0.032	0.015	0.137	0.030	0.013	0.079	0.079	0.048	0.012	0.005	0.018
MT [c]	0.234	0.500	0.210	0.701	0.682	0.608	0.274	0.701	0.210	0.210	0.239	0.210	0.210	0.274	0.234	0.370

	Operation of the structure											
	OoS1			OoS2			OoS3					
IN[a]	ATR17	ATR18	ATR19	ATR20	ATR21	ATR22	ATR23	ATR24	ATR25			
A Very high	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000			
B High	0.701	*0.608*	0.550	*0.608*	0.701	0.682	0.550	*0.682*	0.500			
C Medium	*0.210*	0.370	*0.274*	0.370	*0.210*	*0.239*	*0.274*	0.239	*0.234*			
D Small	0.101	0.225	0.133	0.225	0.101	0.126	0.133	0.126	0.107			
E Very Small	0.068	0.137	0.076	0.137	0.068	0.069	0.076	0.069	0.058		Score	
GP [b]	0.067	0.017	0.007	0.035	0.008	0.003	0.017	0.004	0.002	TCIDPI	TP	OP
MT [c]	0.210	0.608	0.274	0.608	0.210	0.239	0.274	0.682	0.234	**0.447**	**0.332**	**0.115**

[a] IN: Ideal normalisation.
[b] GP: Global prioritisation.
[c] MT: Minimum threshold.

Having identified the firm's suitability for a diversification process (Stage 2.1), Phase 2 would continue with the Selection of the Technological Diversification Strategy and the first stage is the Confirmation of the technological diversification suitability.

For the purpose of confirmation, the concept of Technological Competitiveness is analysed; it can be defined as the existence of key technologies that guarantee the current and future effective running of a firm (survival and sustainable growth) in terms of its Technological Potential (TP) and Operational Potential. TP is understood as the set of technologies of a firm that are used in the creation of one or more products, OP is the capacity of the firm to manage its organisational and operational structure.

The model (25 attributes) proposed to evaluate the Technological Competitiveness of a firm in Stage 2.1 of the methodology is the result of the improvement made to the initial model (16 attributes) used in Stage 1.2 for assessing the suitability of industrial and technological diversification. This initial model was based on a previous study (Larrodé et al., 2012), involving 22 companies from the automotive components industry (ACI), carried out during 2010-2011 with the Council of the Chamber of Commerce, Industry and Shipping in Spain (CCCISS). During the following two years (2012-2013), the AG improved the initial ITDP methodology in particular Stages 2.2 and 2.3, integrating the feedback received from the companies (FG) during its practical application.

The methodology was applied to a product selection problem with a top-down orientation (Muerza et al., 2014) and the need to reorient and systematise the confirmation of suitability was revealed (Stage 2.1). Based on collaboration with the companies whose results are given in this paper, a number of versions and structures were adopted. The final model built on consensus is presented in detail. The new methodological proposal is a ”zoom” of the actors and factors involved in the diversification process that reinforce the key aspects of the organization. The proposal expands the analysis that was carried out in the first phase of the methodology. The necessary information is extracted to identify and select the key technologies as a previous step to the construction of the company's technological trees.

To test the validity of the proposed methodology, in particular its predictive capacity in a real situation, there was a five-year follow-up evaluation of the model and the indicator (TCIDPI) employed to assess the technological competitiveness of the companies and the possibility of implementing an industrial and technological diversification process. The five-year evaluation aimed to determine the 'predictive capacity' of technological competiveness (TCIDP) and the indicator defined for its assessment (TCIDPI). The behaviour and the situation of the three companies were studied, along with its relationship to the feedback provided by the AG.

4. Case study: application of the methodology to three automotive components firms

The methodology has been applied to three automotive Spanish firms. Firm 1 was founded in 1980, it has about 250 employees and its activities have always been related to the ACI, designing, developing and manufacturing electrical wiring, plastic parts and electromechanical systems. In 2002, the firm set up an R&D department. In 2003, conscious of the importance of innovation for the future, it developed and implemented an R&D&i Management System, certified under the UNE-166002 standard.

Firm 2 produces pumps and distributes automotive components, i.e. fuel pumps and filters for the spare parts sector. The firm is part of an international group which supplies millions of water and fuel pumps to the major vehicle manufacturers and the main distributors of automotive components worldwide. All products are manufactured according to the original equipment manufacturers specifications. The firm receives the finished product components from its factory in China, and assembles them in Spain.

Firm 3 designs, develops and manufactures tapered roller bearings, ball bearings and cylindrical roller bearings. It has been homologated by the main Tier 1 automotive companies worldwide. It has quality (ISO 9001, ISO TS 16949), environment (ISO 14001), and health and safety (OHSAS 18001) certifications.

After overcoming the diversification suitability threshold (Phase 1), the three firms continue with the diversification process (Phase 2) according to the methodology. The second phase includes the analysis of technological competitiveness (through the technological potential and operational potential), to confirm the suitability for diversification and to continue to the next stage of the methodology (see previous works of the authors mentioned in this paper). The analysis follows a cognitive orientation.

Stage 2.1 was conducted by the AG. Interviews with the FG lasted between 100 and 120 minutes. The questionnaire was sent to the FG before the interviews.

Table 4 shows the results for the three firms. The TCIDPI scores are higher than the threshold set by the group of experts (0.447). However, only Firm 3 was confirmed as suitable for diversification as it was the only one that complied with the R and RE.

Firm 1 scored over the thresholds set (R) for the assessment of TP (0.332) and OP (0.115), but it did not surpass the minimum recommended thresholds (RE) for attributes ATR19, ATR23 and ATR24. Firm 2 failed to surpass the thresholds set for the assessment of TP, and attributes ATR2, ATR4, ATR6, ATR9 and ATR19 did not surpass the minimum recommended thresholds.

The following recommendations were drawn from the results:

- Firm 3 is suitable for diversification and should proceed with the remaining stages of the ITDP.
- Firm 1 is also suitable for diversification but should improve attributes ATR19, ATR23 and ATR24, which did not meet the recommended minimum thresholds.
- Firm 2 must improve its technological potential (0.225), which scored below the set threshold (0.332), confirm the existence of key technologies and re-evaluate the technological potential.

The result obtained when evaluating the suitability of the diversification processes of the three firms considered is highly robust. Both, analytically and using the sensitivity analysis tools associated with Expert Choice, it has been verified that individual modifications (below 29%) in the priorities of the attributes do not affect the qualification of suitable (Firms 1 and 3) and non-suitable (Firm 2) assigned to the three firms evaluated. If modifications below 30% are made randomly and simultaneously to all attribute priorities, the scores obtained for the suitability of the three firms are maintained.

The knowledge acquired from the analysis of the three firms allowed the following observations to be made with regard to the most demanding (higher recommended thresholds - B) attributes of the hierarchical model (ATR2, ATR4, ATR5, ATR6, ATR8, ATR18, ATR20 and ATR24):

- Suitability of personnel to technological tasks (ATR2) is a requisite in any diversification process. It indicates the existence of qualified and polyvalent staff with sufficient versatility to undertake new activities. Firm 2 did not surpass the threshold due to the change in the type of activity.
- Innovative capacity (ATR4) indicates that the firm has the skills required for innovation. Firm 2 did not surpass the threshold and it should take steps to obtain a higher rate of success in the development of innovation projects.
- The three firms scored above the threshold for experience and mastery (ATR5), which indicates good management of expertise.

Table 4
Results of the confirmatory analysis of diversification suitability

	A1		A2	F1				F2		
	ATR1	ATR2	ATR3	ATR4	ATR5	ATR6	ATR7	ATR8	ATR9	ATR10
Firm 1	1.000	0.500	0.210	1.000	0.682	0.608	1.000	0.701	1.000	1.000
Firm 2	0.500	*0.234*	0.210	*0.101*	0.682	*0.225*	1.000	0.701	*0.068*	0.210
Firm 3	1.000	0.500	0.701	1.000	0.682	0.608	1.000	0.701	1.000	0.701

	S1		S2		S3	
	ATR11	ATR12	ATR13	ATR14	ATR15	ATR16
Firm 1	1.000	1.000	0.701	0.550	0.500	1.000
Firm 2	1.000	1.000	0.701	0.274	0.234	1.000
Firm 3	1.000	1.000	1.000	0.550	0.500	1.000

	OoS1			OoS2			OoS3		
	ATR17	ATR18	ATR19	ATR20	ATR21	ATR22	ATR23	ATR24	ATR25
Firm 1	0.210	0.608	*0.133*	1.000	0.701	0.239	*0.133*	*0.069*	0.234
Firm 2	0.701	0.608	*0.133*	0.608	0.210	0.682	0.550	1.000	0.500
Firm 3	0.701	0.608	0.550	1.000	0.210	0.682	0.274	1.000	1.000

	TP	**OP**	**TCIDPI**
Firm 1	0.468	0.288	0.756
Firm 2	**0.225**	0.312	0.536
Firm 3	0.486	0.344	0.830

- Acquisition of knowledge (ATR6) is critical because it allows the incorporation of improvements. Firm 2 scored two levels below the threshold in this attribute. In this case, the use of European or National public R&D&i funding programmes is recommended.
- Innovative activity (ATR8) establishes the commitment of the firm to innovation and/or improvement. All three firms surpassed the threshold. This attribute differs in Firm 2 with respect to ATR4 as, despite the intention of the firm to improve, it is unable to make decisions for innovation due to it being a subsidiary of a large business group.
- It was also the case that all three firms had a suitable level with regard to the implementation of management systems (ATR18), which affects the proper functioning of the business structure.
- A significant level of technological vigilance and collaboration (ATR20) enables better external and internal knowledge of the organisation. The three firms in this study surpassed the minimum threshold for this attribute: they execute a formal process of vigilance of competitors, customers and suppliers that, in some cases, has served to modify their functioning. However, Firm 2 should improve collaboration among its technical departments.
- One level below the threshold for attribute ATR24 implies a limited customer portfolio and potential problems caused by dependence - Firm 1 was at most risk, three of its customers account for 80% of its production.

- Patents reflect the technological capabilities. The analysis of Firm 2 only considered those patents held by the Spanish plant, which are not currently being used.
- Firms 1 and 2 lacked an appropriate level of cooperation between operational departments, as reflected in attribute ATR19. They need to improve in this area and access new knowledge.
- Firm 1 obtained a score one level below the threshold in the assessment of implementation in the market (ATR23). This is because its market is highly concentrated at the national level.

With reference to the five most relevant attributes of the hierarchy: ATR4 and ATR8 for TP, and ATR11, ATR12, and ATR17 for OP, it should be noted that the three firms were evaluated in categories 'A (very high)' or 'B (high)', except Firm 2 that was evaluated as 'D (small)' for attribute ATR4 (Innovative Capacity), and Firm 1 evaluated as 'C (medium)' for attribute ATR17 (Profitability).

The multicriteria approach used in this paper follows a cognitive orientation that gives the firms knowledge of its products, processes and people with which they can measure their technological competitiveness in a diversification process. This knowledge could be extended to other firms in the ACI.

When a firm wishes to analyse its technological competitiveness, if it follows the cognitive approach proposed in this research, it generates knowledge on how to take advantage of its capabilities and it acquires decision-making skills related to a possible diversification process. This is the way considered for the survival and sustainable growth of firms in terms of its technological and operational potential (TP and OP).

A five-year evaluation of the three firms in the study evaluated the predictive capability of our proposal for analysing the suitability of technological and industrial diversification processes, the predictive capability of the technological competiveness (TCIDP) concept and the indicator defined for its assessment (TCIDPI). The evaluation also analyses the relationship between the survival of the firms at five years and the recommendations (feedback) of the working group (AG).

The five-year analysis after the elicitation recommendations revealed that Firm 3, which comfortably exceeded all the thresholds and obtained a high TCIDPI score, is still in the market and has implemented a successful diversification process. Firm 2, which was handicapped by belonging to a multinational business group that prevented it from making its own decisions on innovative activity (ATR4), and did not surpass the technological potential threshold. This firm was highly vulnerable to market variations and did not implement a process of technological diversification so its sustainability was at risk. Recently, a multinational group from the same industrial sector has acquired this company, taking advantage of the technological capabilities and commercial possibilities that were identified by the study. Finally, we have Firm 1, which was heavily dependent on a small number of customers and did not surpass the thresholds related to the market (ATR23 and ATR24), but far exceeded the threshold for technological potential: this firm followed the recommendations related to the search for new markets/clients and implemented a successful diversification process. Due to the improved technological capacity, the firm was bought by a larger concern, a transaction that was specifically motivated by one of the technological potential capabilities that was highlighted by the analysis.

5. Conclusions

This paper has examined one of the most relevant questions for businesses and companies: how to guarantee survival in the medium and long terms. The work has reviewed the proposals put forward in the published literature on industrial and technological diversification strategies, understood as the development of new products in new markets. We have further examined a technology-based diversification strategy which combines both engineering and management activities.

By extending previous works on technology-based industrial diversification, the Operational Potential (OP) and the Technological Potential (TP) were included when defining and quantifying the technological competitiveness of the firms in a diversification process. The attributes utilised to quantify the level of technological competitiveness were determined through the AG and the FG. The information necessary for the construction of the firm's technological tree was extracted and used as the core for the identification of the diversification strategy. It was assumed that the firm owns key technologies that guarantee its current and future success in terms of technological and organisational potential for a diversification process.

To confirm the suitability for diversification, the evaluation of technological competitiveness used one of the most popular multicriteria techniques – the Analytic Hierarchy Process (AHP). The hierarchical model for ACI included 5 levels and 25 attributes (10 for TP and 15 for OP) which were evaluated in line with 73 indicators. Data was collected through a second questionnaire oriented to technological and operational aspects. The level of technological competitiveness of the firms was measured by a minimum score or threshold that had to be surpassed. Thresholds for the ACI have been established as a reference to accept or reject the industrial and technological diversification processes.

In addition to evaluating the technological competitiveness, the multicriteria model allowed the extraction of knowledge associated with products, processes and people that is necessary for improving industrial practice and providing theoretical support for decision making in diversification processes.

A case study of three automotive industry firms which had successfully completed the first phase of the analysis was described. Although all of them obtained a score that surpassed the minimum score set for the TCIDPI (0.447), only Firm 3 was found to be completely suitable for diversification. Firm 1 should increase attributes ATR19, ATR23 and ATR24 in the short-term in order to improve; Firm 2, which surpassed the minimum threshold for TCIDPI but failed to achieve the threshold set for TP (0.332), needs to confirm the existence of key technologies and technological potential.

The application of the methodology to the three firms has allowed the validation of the analysis model and the measurement index of their Technological Competitiveness over time. The predictive capacity of the methodology regarding the technological competitiveness of companies has been verified after five year. From the three companies analysed, only one obtained a positive index of technological competitiveness (TCIDPI), and it is the only one that enjoyed sustained growth after five years. The other two firms, which did not obtain an acceptable index, have disappeared; they were taken over by other business groups.

In the three cases, it can be seen that both the applied model and the measurement index of the Technological Competitiveness (TCIDPI) are valid for the analysis of the management of business operations, such as technological diversification. In short, the TCIDPI has made it possible for us to capture (with remarkable accuracy and realism) the situation of the companies and their potential to successfully undertake a technology-based process of diversification.

After five years, the three companies that have been studied showed a behavior aligned with the values and recommendations of the index developed to assess technological competitiveness. Due to several reasons (e.g. disappearance of companies, possible changes in ownership and/or management of the firms, the time needed to be able to test the behaviour of the firm over time), the main limitation of the study lies in the difficulty of analysing companies in the future. Although in our case it is not relevant due to the context (voluntary participation) in which the study was carried out, the communication to reach an agreement between the AG and the FG may be an additional limitation in other applications.

Technological competitiveness is becoming increasingly important in firms with a high technological component. In competitive markets and sectors, the proposed methodology allows the selection of the most suitable diversification strategy for a company based on its technological and operational potential.

Once the suitability of a firm's diversification process has been determined (a level of technological competitiveness above the set threshold) and the diversification alternatives are identified from its technological tree, future research will concentrate on the systematisation of Stages 2.3 and 2.4 of the methodology as a step prior to Phases 3 and 4 of the ITDP methodology, a multivariate analysis of the 25 attributes considered in the model, and the use of AHP Benefit*Opportunity/Cost*Risk (BO/CR) for the SWOT analysis.

This paper focuses on the ACI, in which technological potential is decisive for competitiveness. With slight modifications to the multicriteria model and its evaluation, the proposed TCIDP methodology is transferable, to any industrial sector.

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