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Defining indicators for performance evaluation in science and technology parks

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Abstract

Performance evaluation is highly relevant given the importance of science and technology parks for developing and disseminating knowledge and innovation. In this sense, this study sought to validate indicators for evaluating the performance of science and technology parks in the Brazilian context. To achieve the proposed objective, 213 indicators were selected, divided into 10 assessment areas, and validated by 15 experts in the field. Our findings revealed that, from the total number of indicators selected, 136 were validated, drawing attention to the parks' relational area, which had the most indicators, both in the literature analyzed and in the validation process. Hence, this study provides theoretical and practical contributions that, through empirical data, can help evaluate performance and develop the management of science and technology parks since applying validated indicators can generate pertinent information, help articulate strategies, and promote innovation and entrepreneurship.

Keywords: Performance Evaluation; Fuzzy Delphi; Indicators; Science and Technology Parks;

1 Introduction

Environments geared toward innovation and entrepreneurship have been vital for area development and knowledge propagation. In this context, Etzkowitz and Zhou (2006) reported that the interaction between governments, universities, and companies is a primary factor in aligning innovation conditions in knowledge-based environments. Based on this statement, one can say that science and technology parks have been investigated for their ability to provide growth potential to organizations and regions, as well as technology transfer and interaction among tenants and with academia (Hu, 2007; Lecluyse and Knockaert, 2020; Löfsten et al., 2020; Phan et al., 2005; Pique et al., 2021).

Science and technology parks are physical spaces where companies and universities meet, generating knowledge exchange, value generation, and (in)formal innovation (Link and Scott, 2015; Ng and Junker et al., 2020; Olvera et al., 2020a; Silva et al., 2020). They can also be understood as clusters of companies with innovative research and resources that lead to technological innovation (Chen et al., 2013; Meseguer-Martinez et al., 2020a, 2020b; Nikina and Pique, 2016). In the literature, some authors, such as Yan et al. (2020), have argued that science parks and policies aimed at innovation have the main objective of leveraging innovative resources and fostering emerging industries. Moreover, the parks provide valuable mechanisms such as mentoring and training that help raise funds for new ventures (Xia et al., 2020).

In emerging countries such as Brazil, the government's promotion of parks had its initial milestone in the 2000s. This period ushered in government programs focused on the theme that were included in the Brazilian Federal Government's Pluriannual Plan (PPA-2004/2007) (Audy and Piqué, 2016; Teixeira et al., 2017); in fact, most Brazilian parks have been founded with direct financial support from the Brazilian government (Abreu et al., 2016; Silva et al., 2020).

Given this context and the importance of science and technology parks for the environments in which they are installed, it is pivotal to develop forms of evaluating, measuring, and demonstrating the progress of these parks in terms of performance. This is a crucial measurement factor for continuity in resource allocation, as it is fundamental to present the parks' operations to stakeholders (Dabrowska, 2011). In view of this, a research trend proposing methods and indicators to evaluate parks' performance is listed in Table 1.

[Table 1 - Research on performance measurement in science and technology parks]

Although there are numerous studies in the literature, there is still no consensus model to evaluate park performance, thereby underlining the research gap for research addressing this issue, despite the relevance of the topic for knowledge dissemination and developing entrepreneurship and innovation (Dabrowska, 2011; Ferrara et al., 2016; Ribeiro et al., 2021; Rodeiro-Pazos and Calvo-Babio, 2012; Salvador et al., 2019; Saublens et al., 2008).

As a result of this topic's practical and managerial relevance, this article aimed to answer the following research question: Which indicators for performance measurement can be applied to evaluate science and technology parks in the Brazilian context? Hence, this article sought to validate indicators to evaluate the performance of science and technology parks in the Brazilian context.

The literature contributes to collecting relevant information for developing and propagating knowledge regarding science and technology parks.

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Studies have highlighted the difficulty in defining indicators to evaluate all types of parks, making further research of the utmost importance as evaluating their performance is germane to identifying the best practices and disseminating them (Ferrara et al., 2016; Ng et al., 2020; G. Wang et al., 2014).

Given the above, the rest of this manuscript is structured as follows: the second section presents the methodological procedures, the third one presents the analysis of the results, and lastly, the fourth section highlights the final considerations and recommendations.

2 Method

In order to define performance indicators for science and technology parks, our study was divided into a literature review, exploratory analysis, and empirical research; the methodological flow is illustrated in Figure 1.

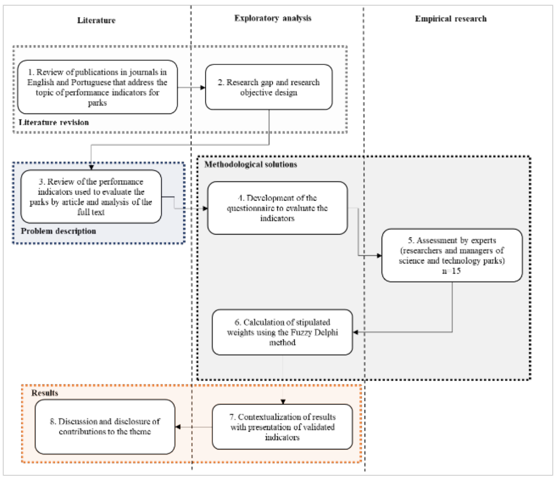

Figure 1 - Research methodological flow

In order to identify the theoretical gap and define this study's objectives, a literature review was conducted to address the topic of performance indicators for technology parks. In this study, the search terms "performance indicators" AND "science parks" OR "technological parks" were used in the databases Scopus, Web of Science, and Google Scholar. The search was limited to the terminologies written in Brazilian Portuguese and English.

Based on the literature review, different indicators used by authors for park performance evaluation were verified. Based on these documents, the indicators included in the first questionnaire sent to the experts were sought. First, 213 indicators were listed (Appendix A) — the studies that composed the survey of indicators were those prepared by the authors (Bigliardi et al., 2006; Dabrowska, 2011; de Moraes, 2017; Ferrara et al., 2016; Hemati and Mardani, 2012; Kbar and Aly, 2015a; Lurdes and Bent, 2016; Ng, Appel-Meulenbroek, et al., 2020; Nosratabadi, 2015; Patthirasinsiri and Wiboonrat, 2017; Ribeiro et al., 2018, 2021a; G. Wang et al., 2014a). The indicators were divided into 10 areas to follow the same standard as the authors of the articles in the review. The area, number of indicators per area, and which indicators belong to each area are listed in Table 2.

[Table 2 - Areas of analysis of the indicators]

Based on the survey of the indicators (Appendix A), a questionnaire for experts in the field can be developed. The experts stipulated a weight for each of the indicators. At this stage, we obtained feedback from 15 experts; this is acceptable feedback since previous studies have reported 9 responses (Hsu et al., 2010), 10 responses (Bueno and Salmeron, 2008), 13 responses (Ma et al., 2011), and 15 responses (Singh and Sarkar, 2020a); Table 3 presents the general data of each expert.

[Table 3 - Participating experts]

The selected experts comprised managers working in different areas of knowledge and different parks, thus bringing diversity in opinions

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and generating evaluations with different points of view (Table 3).

In order to stratify and select the performance indicators applicable to the context of Brazilian science and technology parks, we sought an evaluation from experts using the premises of the fuzzy Delphi method to demonstrate the efficiency of the validated indicators (Table 2). The Delphi method was initially proposed by Dalkey and Helmer (1963) to assist in opinion polls of experts from the prerogatives of anonymity, iteration, and controlled response, as well as statistical response in groups (Bouzon et al., 2016; Hsu et al., 2010; Qiu et al., 2020).

In order to minimize the time, search costs, and uncertainties involved in the expert evaluation, Ishikawa et al. (1993) combined fuzzy logic with the traditional Delphi method, resulting in the fuzzy Delphi method (Bui et al., 2020; Tsai et al., 2020; Wang and Peng, 2020).

Since its proposition, the method has systematically helped validate several research tools (Sulaiman et al., 2020), conceptual design, new product development (Baskar et al., 2019, 2020), and the development of the ICT evaluation model (Sumrit, 2020). Therefore, based on the studies of Bouzon et al. (2016) and Singh and Sarkar (2020), the fuzzy Delphi method is divided into different stages. The first step involves identifying the indicators related to the performance evaluation of science and technology parks, which was done through a detailed review of the pertinent literature on the subject (Appendix A). After surveying the indicators, an n number of experts (park managers) were asked to determine the importance of each indicator (Appendix 1) using linguistic variables described in Table 4.

[Table 4 - Linguistic variables for evaluating the criteria using the fuzzy Delphi method]

Assuming that the fuzzy number is $\widetilde{a_{ij}}$, it will be j^{th}, where i^{th} is the importance of the indicator given by the specialist, being $\widetilde{a_{ij}} = (a_{ij}, b_{ij}, c_{ij})$ for I = 1,2,3..., n; j = 1,2,3, ..., m. Then, the fuzzy weights of the indicators ($\tilde{a}\_j$) are described as follows: $\widetilde{a_{ij}} = (a_j, b_j, c_j)$, where $\_j = min\{a_{ij}\}, b_j = \left(II_i^n\, b_{ij}\right)^{1/n}, c_j = max\{c_{ij}\}$.

The final step in applying the fuzzy Delphi method is to identify the relevant indicators for the context of performance evaluation for science and technology parks, which is done by comparing the weight of the criterion with the $\tilde{a}$ threshold where the weight of $\tilde{a}$ is calculated by averaging the weight of all indicators $\tilde{a_j}$ where the inclusion and exclusion principle is defined respectively by:

if $\tilde{a_j} \geq \tilde{a}$, then criterion j is selected, still if $\tilde{a_j} < \tilde{a}$, then the criterion j is rejected.

It is worth noting that $\tilde{a_j}$ and $\tilde{a}$ are a combined fuzzy set; thus, they must be transformed into crisp values to make the comparison. As in the study of Bouzon et al. (2016), this paper used the center of gravity method to defuzzify the fuzzy values.

Upon defining the indicators, the science and technology parks were selected for the performance evaluation. The aim was to demonstrate the validity of the selected indicators in a real situation to obtain empirical evidence based on the performance evaluation. Hence, at least one specialist needed to consider the criteria and alternatives for applying the fuzzy TOPSIS method to evaluate the selected parks' performance. At this stage, a specialist was defined to evaluate the parks in the light of the criteria since, in addition to being a park manager, this specialist is part of a national association of entities responsible for promoting innovation. Another critical point is that this specialist has been in contact with the selected parks over time. Notably, the choice of these parks was based on the proximity of the specialist to them. In this context, to carry out the evaluation based on the selection of indicators, a final sample consisting of 12 science and technology parks located in different Brazilian regions was selected due to the importance of each one for the context of the country's economy.

Chen (2000) and Awasthi et al. (2011) reported that the fuzzy TOPSIS method has different calculation steps, denoting, in the end, the best alternative according to the opinion of experts and decision-makers.

When using the fuzzy TOPSIS method, the alternatives are analyzed regarding the stipulated criteria. The multi-criteria model used has been widely applied in different contexts, helping in decision-making and defining more coherent alternatives in problem-solving (Çalık, 2020; C. T. Chen et al., 2006; Dube & Gawande, 2016; Lima Junior et al., 2014; Ng, Appel-Meulenbroek, et al., 2020; Yadav et al., 2018).

The fuzzy TOPSIS method presents different calculation steps, listing at the end the best alternative according to the decision makers' opinion. In **the first step**, scores are assigned to the criteria and alternatives, as represented by Equation 1. Assuming that there are J possible calls A = {A1, A2, …, Aj} and that they must be evaluated against m criteria C = {C1, C2, … Cm}, criteria weights are stipulated by W_i for I = 1,2, …, m. The performance classifications of each decision D_k for $k = 1,2,\dots,k$ for each alternative A_j for $j = 1,2,\dots,m$ and $A_j(j = 1,2,\dots,m)$ respecting the criteria C_i for I = 1,2, …, m are determined by Equations 1 and 2.

$$\tilde{X}_{ij} = \frac{1}{K}\left[\tilde{x}_{ij}^{1} + \tilde{x}_{ij}^{K} + \dots + \tilde{x}_{ij}^{K}\right] \tag{1}$$

$$\tilde{W}_{j} = \frac{1}{K}\left[\tilde{w}_{j}^{1} + \tilde{w}_{j}^{2} + \dots + \tilde{w}_{j}^{K}\right] \tag{2}$$

The second step consists of calculating the aggregate classifications of the fuzzy criteria, being them triangular numbers using $\underline{\tilde{R}_k}(a_k, b_k, c_k)$, $K = 1, 2, \dots, K$; hence, the aggregate fuzzy classification is given by $\tilde{R} = (a, b, c), k = 1, 2, \dots, K$ based on Equation 3:

$$a = min_k\{a_k\}, \quad b = \frac{1}{K}\sum_{k=1}^{k} b_k, \quad c = max_k\{c_k\} \tag{3}$$

If the fuzzy classification and decision importance weight $\tilde{x}_{ijk} = (a_{ijk}, b_{ijk}, c_{ijk})$ and $\tilde{w}_{ijk} = (w_{jk1}, w_{jk2}, w_{jk3}), i = 1, 2, \dots, m, j = 1, 2, \dots, n,$ the aggregated values of $(\tilde{x}_{ij})$ of the alternative in relation to each criterion is given by $\tilde{x}_{ij} = (a_{ij}, b_{ij}, c_{ij})$, as shown in Equation 4:

$$a_{ij} = min_k\{a_{ijk}\}, \quad b_{ij} = \frac{1}{K}\sum_{k=1}^{k} b_{ijk}, \quad c_{ij} = max_k\{c_{ijk}\} \tag{4}$$

In **the third step**, the fuzzy decision matrix is calculated for the alternatives $(\tilde{D})$, and the fuzzy vector for the criteria $(\tilde{W})$ is made according to Equations 5 and 6.

$$\tilde{D} = \begin{array}{c} A_1 \\ A_2 \\ A_3 \\ A_4 \end{array}\begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \dots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \dots & \tilde{x}_{2n} \\ \dots & \dots & \dots & \dots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \dots & \tilde{x}_{mn} \end{bmatrix} \tag{5}$$

$i = 1,2,\dots,m;$

and $j = 1,2,\dots,n$;

$$\tilde{W} = (\tilde{w}_1, \tilde{w}_2, \dots, \tilde{w}_n). \tag{6}$$

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The fourth step is to normalize the fuzzy decision matrix. The raw data is normalized using linear scale transformation to bring the various criteria scales into a comparable scale. The normalized decision matrix $\widetilde{R}$ is given by Equation 7:

$$\tilde{R} = [\tilde{r}_{ij}]_{mxn}, \quad i = 1, 2, \dots, m; \quad j = 1, 2, \dots, n \tag{7}$$

where:

$\tilde{r}_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right)$ and $c_j^* = max_i\, c_{ij}$ (benefit criteria)

$\tilde{r}_{ij} = \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}\right)$ and $a_j^- = min_i\, a_{ij}$ (cost criteria)

The fifth step covers the calculation of the weighted normalized matrix. The weighted normalized matrix $\widetilde{V}$ is estimated by multiplying the weights $\widetilde{W}_j$ of the evaluation criteria with the normalized fuzzy decision matrix $\tilde{r}_{ij}$, as per Equation 8:

$$\tilde{V} = [\tilde{v}_{ij}]_{mxm}, \quad i = 1, 2, \dots, m; \quad j = 1, 2, \dots, n \tag{8}$$

where

$$\tilde{v}_{ij} = \tilde{r}_{ij}(.)\widetilde{w}_j$$

The sixth step is calculated from the fuzzy ideal solution (FPIS) and negative ideal solution (FNIS). Thus, each alternative is calculated according to Equations 9 and 10.

$$A^* = (\tilde{v}_1^*, \tilde{v}_2^*, \dots, \tilde{v}_n^*) \; where \; \tilde{v}_j^* = \{v_{ij3}\}, \quad i = 1, 2, \dots, m; \quad j = 1,2, \dots, n \tag{9}$$

$$A^- = (\tilde{v}_1, \tilde{v}_2, \dots, \tilde{v}_n) \; where \; \tilde{v}_j^- = \{v_{ij1}\} \quad i = 1, 2, \dots, m; \quad j = 1,2, \dots, n \tag{10}$$

The seventh stage covers calculating each alternative's distance from the FPIS and FNIS. The distance (d_i^*, d_i^-) of each weighted alternative $i = 1, 2, \dots, m$ from FPIS and FNIS are calculated as follows:

$$d_i^* = \sum_{j=1}^{n} d(\widetilde{v_{ij}}, \tilde{v}_j^*), \quad i = 1, 2, \dots, m \tag{11}$$

$$d_i^- = \sum_{j=1}^{n} d(\widetilde{v_{ij}}, \tilde{v}_j^-), i = 1, 2, \dots, m \tag{12}$$

Where $d_v(\tilde{a}, \tilde{b})$ is the distance between two fuzzy numbers, $\tilde{a}$ and $\tilde{b}$ and $d_v(\tilde{a}, \tilde{b}) = \sqrt{\frac{1}{3}[(a_1 - b_1)^2 + (a_2 - b_2)^2 + (a_3 - b_3)^2]}$

Each alternative's proximity coefficient (CC_i) is calculated in **the eighth step**. The proximity coefficient simultaneously represents the distances between the FPIS (A*) and FNIS (A-). The proximity coefficient of each alternative is calculated based on Equation 13:

$$CC_i = \frac{d_i^-}{d_i^* + d_i^-}, \quad i = 1, 2, \dots, m \tag{13}$$

The ninth step covers the classification of alternatives. The alternatives are classified according to the proximity coefficient (CC_i), expressed in descending order.

3 Analysis and discussion of the results

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3.1 Validation of the indicators by the fuzzy Delphi method

By applying the fuzzy Delphi method, it is possible to analyze the indicators as shown in Table 5 (Appendix B). Out of the 213 indicators raised, 78 were rejected because the Se $\widetilde{\alpha_j} \geq \tilde{\alpha}$, therefore criterion j is selected, yet if $\widetilde{\alpha_j} < \tilde{\alpha}$, then the criterion j is rejected and the $\widetilde{\alpha_j}$ calculated for this study using the center of gravity method (Bouzon et al., 2016) was $\widetilde{\alpha_j} = 0.622$. Hence, 135 valid indicators remained, which the experts deemed pertinent to the context of the park, as presented in Table 5.

[Table 5 - Validated indicators]

Based on the validated indicators, one can note that the dimension of analysis with the highest number of indicators was the relational aspect, with 30 validated indicators. According to Etzkowitz and Zhou (2006), this is relevant because interaction is necessary for innovation propagation and generation. In the study by Phongthiya et al. (2021), the authors clarified the role of parks as generators and facilitators of relationships and collaboration between universities and the industry. Furthermore, the relational aspect is relevant to a region's economic and social development (Audy and Pique, 2016; Pique et al., 2018; Piqué et al., 2020).

The second aspect with the highest number of indicators concerns the so-called human aspect, covering indicators that deal with staff, training, capacity building, and acquired knowledge. Sayer and Morgam (2018) discussed the shortage of competent and qualified labor to work in the technology sector. Moreover, Cadorin, Klofsten, and Löfsten (2021) emphasized that parks are a source of relationships, knowledge generation, and talent attraction and development.

Knowing that the park is a structure that promotes a knowledge exchange relationship (Olvera et al., 2020; Silva et al., 2020), its structural aspect must be evaluated to obtain the maximum benefits. Regarding this area, 17 indicators were validated (Table 5), involving an evaluation from the physical space for coworking to the ICT structure.

As shown in Table 5, 13 evaluation indicators were validated by the experts for the innovation aspect. Nikina and Pique (2016) demonstrated how parks generate innovation, contributing significantly. Thus, evaluating parks' performance regarding the innovation aspect is highly relevant as it is possible to assess the progress and health of the park.

As for the internationalization aspect, 9 indicators were identified as relevant to the evaluators. Si et al. (2021) revealed that internationalization is positively related to companies' innovation performance; therefore, measuring parks' performance concerning internationalization is highly relevant. The internationalization indicators include evaluations of integration with regional and global markets and networking at the international level.

Regarding the financial and credit aspect, 8 indicators were defined as relevant; indeed, a good portion of the resources for structuring parks comes from government subsidies (Abreu et al., 2016; Silva et al., 2020). Furthermore, parks are essential for technology-based companies providing resources (Lindelöf and Löfsten, 2002). Given this context, one can note the relevance in evaluating the financial and credit performance, which also leads to the importance of the marketing aspect or return on investment and the new services offered by the parks, where 8 indicators were validated.

Effective management makes parks achieve better performance and growth, as it can further enhance the innovative performance of these parks

(Campanella et al., 2014). Hence, 20 indicators contemplated this aspect of management and development of the parks, covering indicators regarding the number of tenant companies and their satisfaction with the management of the parks.

In the social and environmental aspects, 3 indicators were validated by the experts. Sustainability — of the parks and installed businesses — must be aligned with the sustainability bias, seeking technological development and, at the same time, preserving the environment (Yamamoto and dos Reis Coutinho, 2019).

Lastly, the academic evaluation aspect had 6 indicators validated by the experts. The relevance of these indicators lies in the interaction between the park and the academia, bringing a relevant exchange, generating knowledge and research taken to the industry, resulting in growth and development for both of them (Olvera et al., 2020b).

3.2 Performance evaluation of parks using the fuzzy TOPSIS method

With the validated indicators in hand, the parks to be evaluated were defined in order for the decision maker to evaluate the criteria and alternatives concerning the criteria and linguistic scale and define the triangular fuzzy numbers. Hence, Table 6 presents the linguistic scale and the triangular fuzzy numbers for evaluating the alternatives and criteria.

[Table 6 - Linguistic terms to classify the alternatives and criteria]

Different studies in the literature present various explanations and have used the method proposed herein, mainly to assist in ranking and evaluating alternatives in environments that use subjective judgment and multi-criteria decision-making, among which we can highlight: Bostancı and Erdem (2020), Doğan et al. (2020), Senapati and Yager (2020), Yatsalo et al. (2020), and Yucesan and Gul (2020).

Table 7 lists the weights stipulated by the decision-making expert for each criterion. The criteria order in Table 7 was organized according to the accepted and validated indicators.

[Table 7 - Criteria fuzzy weights]

Table 7 presents the weights stipulated by the decision maker for the validated criteria. Subsequently, the alternatives were evaluated where the decision maker stipulated notes based on Table 6.

After defining the fuzzy weights for each of the alternatives in relation to the criteria, the values are normalized using Equation 7. It is worth noting that all criteria were normalized as a benefit criteria. After normalization, the matrix was weighted using Equation 8 by multiplying each value found for the alternatives in the normalized matrix by the weight of the calculated criterion. From this, the FPIS was defined as the maximum value reached by the alternative and the FNIS as the minimum value reached by the alternative (Equations 9 and 10) (Chen, 2000; Awasthi et al., 2011); therefore, the negative and positive distances were defined using Equations 11 and 12.

Lastly, by using Equation 13, the performance values of each of the alternatives were generated. The best alternative is the one closest to the value of 1 and farthest from 0 (Chen, 2000). Figure 2 presents the performances obtained for each of the analyzed parks.

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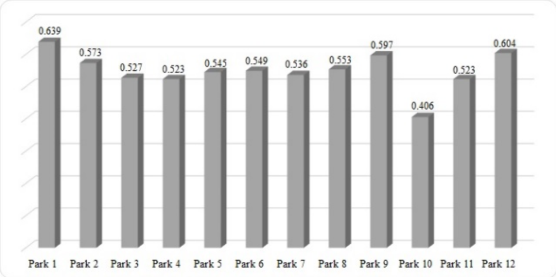

Figure 2 - Park performance ranking

As shown in Figure 2, the park that obtained the best performance was A1, obtaining a score of 0.639. This park has been in operation for roughly 20 years and is located in southern Brazil. The second park with the best performance is "A12." This park has been operating for approximately 12 years and is located in northern Brazil. Finally, the third best performing park was "A9," which has been operating for about 9 years and is located in southern Brazil.

4 Implications

This paper presented theoretical and managerial contributions.

4.1 Theoretical implications

The first theoretical contribution is organizing and systematizing different performance indicators for science and technology parks. Thus, it contributes to research on the theme, developing and disseminating knowledge about parks and providing further insight that may guide future research. Second, it lists indicators that, in addition to being validated for the Brazilian park context, can be replicated by researchers, validating them in their contexts and based on the theoretical basis of the study developed here.

4.2 Managerial implications

As for the managerial contributions, we highlight the validation of indicators that will allow parks to constantly evaluate their performance, considering different areas and helping formulate strategic guidelines so parks can develop more and more. Furthermore, park managers can verify which points need improvement so the park can effectively play its role in its ecosystem. Secondly, as a managerial contribution, we can highlight the validation performed by managers and researchers who work directly with parks, moving from the theoretical to the managerial context. This shows practical results that can be put into practice, considering that it is necessary for the entire network of agents involved in the park to be aligned, generating development and innovation.

These analyses shed more light on the relevant information for the parks' performance to be evaluated through validation with the experts, verifying the best indicators to generate effective and efficient information. The validation of the indicators for the Brazilian context is an exciting achievement, which may help other countries manage parks, as Brazil has been consolidating itself in innovation and entrepreneurship development. In Latin America, Brazil is the leader in the number of science and technology parks (Ribeiro et al., 2021).

4.3 Conclusions

This study aimed to validate indicators to assess the performance of science and technology parks in the Brazilian context. Evaluating performance is relevant for increasingly assertive decision-making, as it assists in implementing new strategies, making it possible to verify to what extent these changes influence the performance of an organization (Abernethy et al., 2021). When planning to use indicators to generate information, the data to be collected must be authentic to ensure the descriptions' reliability. Furthermore, our findings underline the importance of ensuring the reliability of the information generated through the stipulated metrics (Almanasreh et al., 2019; Radici Fraga et al., 2020; Rodrigo et al., 2019).

This paper demonstrated the validation of indicators for the scope of science and technology parks. A systematic literature search was conducted on park performance evaluation for the indicator survey, resulting in 12 studies and indicators for park performance evaluation. Through an online questionnaire, 15 experts provided their opinions on which indicators were adequate, and by applying the fuzzy Delphi method and these experts' evaluations, 135 indicators were validated (Table 5).

With the data in hand, the validated indicators were shown to apply to the Brazilian context and revealed relevant information for the continuous development of the parks. Furthermore, the validated indicators were strategically organized into 10 areas in order for it to be possible to establish a consistent and focused analysis that helps managers in the decision-making process. Therefore, the 136 validated indicators are part of a relevant process for decision-making, bringing information that makes up a short-, medium-, and long-term strategic environment regarding formulating actions to improve the park's performance.

Regarding the limitations of this study, one can highlight the number of respondents to evaluate the parks in light of the indicators, considering the large number of indicators surveyed, as many managers did not perform the assessment. For further research, we suggest evaluating the existing relationships between the areas and the indicators and investigating the influence that each one plays on the other. Nevertheless, another suggestion is to expand this study to the international sphere, contributing significantly to developing the theme of the performance evaluation of science and technology parks. Moreover, this study's focus was not to perform a detailed evaluation of the parks but to demonstrate the validation of the indicators, not being attentive, in a detailed and discussed way, to the evaluation, leaving this limitation as a suggestion for future research.

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Table 1 - Research on performance measurement in science and technology parks.

Authors	Article title	Article contributions
Ken Guy (1996)	Designing a science park evaluation.	It presented a method to evaluate the performance of science parks based on life cycle, commitment, and the role of stakeholders;
Bill Hogam (1996)	Evaluation of science and technology parks: the measurement of success.	It suggested the grouping of park success dimensions based on intrinsic and extrinsic categories;
Matt Staton (1996)	Science Park evaluation and goal-oriented project planning.	It established a logical model for evaluation based on project planning;
Barbara Bigliard et al. (2006)	Assessing science parks' performances: directions from selected Italian case studies.	It provided a methodological framework grounded in performance measurement theory;
Monck and Peters (2009)	Science parks as an instrument of regional competitiveness: measuring success and impact.	It established a reflection on the benefits and problems regarding park evaluation, presented a theoretical framework for impact evaluation, and reported the experience in of
Nosratabadi, Pourdarab, and Abbasian (2011)	Evaluation of science and technology parks by using fuzzy expert system.	It presented a system based on fuzzy theory to evaluate parks;
Hemati and Mardani (2012)	Designing a performance appraisal system based on balanced scorecard for improving productivity: Case study in Semnan technology and science park.	Based on the balanced scorecard framework, the authors used a structured method to calculate the efficiency of parks;
Maltseva Anna Adreevna (2013)	The Balanced Scorecard for estimation of science and technology parks.	The author proposed using the balanced scorecard to estimate park performance;
Wang, Wan and Zhao (2014)	Strategy map for Chinese science parks with KPIs of BSC.	It proposed an evaluation model of emphasis on processes rather than results;
Kbar and Aly (2015)	Goal-based Key Performance Indicators of Science Parks' Effectiveness: A Case Study at Riyadh Techno-Valley.	A procedure for measuring the effectiveness of the Riyadh Techno Valley (RTV) using a set of comprehensive and well-known multi-criteria performance indicators evaluating the performance indicators against the RTV's objectives was proposed.
From Lurdes Santana and Hansen (2016)	Performance evaluation of technology parks: Proposal from a study at TECNOPUC.	It proposed a system of indicators based on the perception of TECNOPUC's stakeholders.
Justyna Dabrowska (2016)	Measuring the success of science parks: performance monitoring and evaluation.	It proposed a matrix of key performance indicators for science parks.
Ferrara, Lamperti, and Mavilia (2016)	Looking for best performers: a pilot study towards the evaluation of science parks.	It applied the Multi-Attribute Value Theory based on Choquet's integral to elicit stakeholder preferences on different dimensions of Science Parks' performance to build a ranking index;
Patthirasinsiri and Wiboonrat (2017)	Measuring intellectual capital of science park performance for newly established science parks in Thailand.	It developed a form of measurement based on aspects of intellectual capital to evaluate the performance of newly established parks.
Lyra and Almeida (2018)	Measuring the performance of Science and Technology Parks: a proposal of a multidimensional model.	It proposed a multidimensional model to evaluate and monitor similar parks, considering different aspects such as business models and stakeholder engagement;
Wei Keat Benny NG et al. (2020)	Perceptual measures of science parks: Tenant firms' associations between science park attributes and benefits.	It investigated the indicators with the tenant companies, demonstrating their relevance, and

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		showed that interaction with park tenants is relevant to performance;
Juliane de Almeida Ribeiro et al. (2021)	A reference model for science and technology parks strategic performance management: An emerging economy perspective	It established a reference model based on the dominant logic of service and the balanced scorecard, validating a set of indicators and a management model for park management.

Table 2 - Areas of analysis of the indicators

Area	Quantity	Indicators
Structural	32	1–32
Human	29	33–61
Relational	42	62–103
Innovation	28	104–131
Internationalization	11	132–142
Financial and credit	12	143–154
Commercialization	18	155–172
Management and development	26	173–198
Social and environmental	6	199–204
Academic	9	205–213

Table 3 - Participating experts

Specialist	**Sex**	**Position**	**Area of Training**
Specialist 1	Male	Park Director	Applied Social Sciences
Specialist 2	Male	Park Administrative Manager	Applied Social Sciences
Specialist 3	Female	Park Director	Engineering
Specialist 4	Male	Chief Innovation Officer	Exact and Earth Sciences
Specialist 5	Male	President Director	Exact and Earth Sciences
Specialist 6	Male	Administrator	Applied Social Sciences
Specialist 7	Female	Park Coordinator	Applied Social Sciences
Specialist 8	Female	Executive Director	Humanities
Specialist 9	Female	Director of Innovation and Entrepreneurship	Health Sciences
Specialist 10	Female	Park Coordinator	Applied Social Sciences
Specialist 11	Female	CEO	Applied Social Sciences
Specialist 12	Female	Park Director	Applied Social Sciences
Specialist 13	Male	Coordinator	Engineering
Specialist 14	Male	Executive Coordinator	Applied Social Sciences
Specialist 15	Male	Park Manager	Exact and Earth Sciences

Table 4 - Linguistic variables for evaluating the criteria using the fuzzy Delphi method

Linguistic variable	Corresponding fuzzy numbers
Extremely unimportant	(0.1, 0.1, 0.3)
Unimportant	(0.1, 0.3, 0.5)
Normal	(0.3, 0.5, 0.7)
Important	(0.5, 0.7, 0.9)
Extremely important	(0.7, 0.9, 0.9)

Source: Adapted of the Singh and Sakar, 2020.

Table 5 - Validated indicators

Structure	1: Number of spaces available in the park for coworking, collaborative activities, and business incubation; 2: Flexibility degree/expansion possibilities to use additional spaces in the park by moving to an existing building or by a new development; 3: Effective security service; 4: Visual communication and signage of external and internal areas; 5: Quantity and quality of updated information; 6: Quality of ICT infrastructure; 7: Proximity to an institute of higher education; 8: Geographical proximity to a university; 9: Geographical proximity to research institutes; Investments in infrastructure (telecommunication network); 10: Rate of budget spent on the improvement and expansion of the park; 11: Facilities for conducting business/services; 12: Quantity of research centers located in the park; 13: Quantity of research lab(s) existing in the park; 14: Access to R&D facilities and equipment; 15: Number of support facilities, services, and businesses; 16: Presence of a business incubator; 17: Management facilities (enabling an environment for park management activities);
Human	18: Number of permanent staff; 19: Number of experienced executive staff; 20: Number of experienced research staff; 21: Number of professional staff specialized in science, technology, and innovation; 22: Staff to create business-class technology activities at national level; 23: Staff to create business-class technology activities at universities; 24: Teams working in research and development (quantity trained by the park); 25: Training of employees (frequency and quantity); 26: Courses for training employees in innovation (quantity); 27: Availability of high value-added services (consulting, training, and capacity building); 28: Workshops on strategic issues for park residents; 29: Number of skilled and trained labor; 30: Training in intellectual property (e.g., patents); 31: Number of new competencies defined and identified; 32: Number of new knowledge acquired, developed, and shared; 33: New technical and scientific competencies acquired in the period; 34: Professional skills developed with the training and advisory services of the park (quantity); 35: Participants in knowledge:based learning (quantity of people involved in a period); 36: Facility of access to new ideas, skills, or knowledge from other resident organizations; 37: Level of employee satisfaction in environmental work (the activities developed by the park in the bias towards environmental preservation); 38: Level of satisfaction of park employees;
Relational	39: Number of park partners; 40: Level of stakeholder satisfaction involved in the park's technology transfer; 41: Customer complaints are handled by the park (quantity); 42: Number of customers using the park's services; 43: Partnership with a local laboratory; 44: Convenience of sharing resources; 45: Level of combining resources (organizing training and staff development, activities, marketing events, exhibitions, press conference); 46: Involvement in innovative activities with external innovation groups to expand market participation, reduce costs, and share resources; 47: Collaborative R&D; 48: Quantity of private R&D; 49: Number of results obtained through interaction of park stakeholders with scientific community technology centers; 50: Growth rate of new joint R&D and business projects; 51: Housing of research activities for incubators; 52: New products and/or processes adopted by local companies and developed in collaboration with the park; 53: Industry aggregation in park activities; 54: Use of park research results by companies for commercialization; 55: Degree of joint organization of the park to benefit the technology industry; 56: Number of research results commercialized and disseminated; 57: The image/reputation of the science park as a means of promoting the resident organizations; 58: Interaction with research groups and researchers (advisory and consulting, technology transfer, creation of spin-offs); 59: Promotion of partnership networks and networking (internal and external); 60: Access to laboratories and research facilities of the university; 61: Support in the contribution of resources to the university; 62: Number of possible business networks nurtured by the park 63: Networking opportunities created by the park with organizations outside the park for collaboration, business development, or funding purposes; 64: A park management acts in day-to-day operations and promotes interactions and networking among organizations inside and outside the park; 65: The number of services offered to clients outside the university; 66: The number of new start-ups in its accelerated growth program; 67: The number of old companies joining its accelerated growth program; 68: The number of high-tech companies in the park;
Innovation	69: Quantity of patent licenses under the park's domain that allows access to start-up companies; 70: Intellectual property revenues from commercialization; 71: Quantity of new products and new services generated by the park; 72: Increasing technology development; 73: Encouragement for the generation of innovative products and services of commercial success as a criterion for business performance; 74: Technological or R&D capabilities; 75: Revenues from design innovation service center installed in the park; 76: Satisfaction rate of the park's

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	technology units; 77: Innovation profile of the companies; 78: Support in the construction of state-of-the-art technology centers; 79: Strong scientific and technological base; 80: Creation of awareness about intellectual property; 81: Quantity of technology transfer activities;
Internationalization	82: Grade of integration with national or global markets; 83: Collaborative relationships and joint ventures between local, extra-regional, and international companies favored by the park; 84: Scientific collaboration agreements with other trans-regional or international parks; 85: Investment flows installed by the park from other regions or abroad; 86: Possible laboratories of extra-regional or foreign companies installed in the park during the period considered; 87: Number of multinational companies cultivated in the park; 88: International profile; 89: Flow of personnel driven by the park from other regions or foreign countries; 90: International networking opportunities created by the park for collaboration, business development, or financing purposes;
Financial and credit	91: External funding raised; 92: Growth rate of funding; 93: Number of joint projects funded; 94: Attraction of public and private investment; 95: Financial assistance received; 96: Percentage of return on capital invested; 97: Volume of funds raised to foster university and business research; 98: Assistance in raising public and private funds, including venture capital;
Commercialization	99: Debt management; 100: ROE (trend); 101: Risk capital; 102: Growth of turnover for royalties; 103: Sales; 104: Marketing; 105: Number and type of new services offered; 106: Media coverage;
Management and development	107: Turnover growth for area location; 108: Number of incubated companies newly entering the market; 109: Number of technology: based companies created and incubated; 110: Number of new start-ups; 111: Tenant retention rate; 112: Number and type of new academic off spins generated in the period; 113: Attraction of innovative companies to the region; 114: Tenant satisfaction; 115: Management performance; 116: Competence of the organization; 117: Use of selection criteria to choose new residents that contribute to the overall success and/or efficiency of the park; 118: Managerial capabilities; 119: Levels of fault logging service; 120: Coordination and events; 121: Level of promoting trust, collaboration among companies, and ultimately a community identity; 122: Clear communication of the park’s purpose; 123: Policy and procedure; 124: Company growth; 125: Size of the park’s community; 126: Percentage of the existence of promotion and encouragement in the park;
Social and environmental	127: Number of formal and informal jobs generated; 128: Number of workers employed in companies originating from collaboration with the park; 129: Number and type of environmental improvements made in collaboration with the park’s laboratory;
Academic	130: Number of contracts established with the academic institution; 131: Number of results of scientific research commercialized and disseminated; 132: Number of scholarships for training researchers; 133: Number of scholarships offered to undergraduate students; 134: Encouragement of scientific and technical production as a criterion of business performance; 135: Number of scientific competencies and capabilities developed.

Table 6 - Linguistic terms for alternative classifications and criteria

Alternatives		Criteria	
Linguistic value	Fuzzy function	Linguístic value	Fuzzy function
Very bad (VB)	(1; 1; 3)	Very low (VL)	(1; 1; 3)
Bad (B)	(1; 3; 5)	Low (L)	(1; 3; 5)
Acceptable (A)	(3; 5; 7)	Medium (M)	(3; 5; 7)
Good (G)	(5; 7; 9)	High (H)	(5; 7; 9)
Very good (VG)	(7; 9; 9)	Very high (VH)	(7; 9; 9)

Table 7 - Criteria fuzzy weights

Cr1	Cr2	Cr3	Cr4	Cr5	Cr6	Cr7	Cr8	Cr9	Cr10
(7;9;9)	(5;7;9)	(5;7;9)	(5;7;9)	(7;9;9)	(5;7;9)	(7;9;9)	(5;7;9)	(7;9;9)	(7;9;9)
Cr11	Cr12	Cr13	Cr14	Cr15	Cr16	Cr17	Cr18	Cr19	Cr20
(5;7;9)	(5;7;9)	(5;7;9)	(3;5;7)	(5;7;9)	(5;7;9)	(7;9;9)	(5;7;9)	(5;7;9)	(5;7;9)
Cr21	Cr22	Cr23	Cr24	Cr25	Cr26	Cr27	Cr28	Cr29	Cr30
(5;7;9)	(5;7;9)	(5;7;9)	(7;9;9)	(5;7;9)	(5;7;9)	(5;7;9)	(5;7;9)	(5;7;9)	(5;7;9)
Cr31	Cr32	Cr33	Cr34	Cr35	Cr36	Cr37	Cr38	Cr39	Cr40
(5;7;9)	(5;7;9)	(5;7;9)	(5;7;9)	(7;9;9)	(5;7;9)	(5;7;9)	(5;7;9)	(7;9;9)	(7;9;9)
Cr41	Cr42	Cr43	Cr44	Cr45	Cr46	Cr47	Cr48	Cr49	Cr50
(5;7;9)	(5;7;9)	(5;7;9)	(5;7;9)	(7;9;9)	(5;7;9)	(5;7;9)	(7;9;9)	(5;7;9)	(5;7;9)
Cr51	Cr52	Cr53	Cr54	Cr55	Cr56	Cr57	Cr58	Cr59	Cr60
(3;5;7)	(5;7;9)	(5;7;9)	(5;7;9)	(7;9;9)	(5;7;9)	(5;7;9)	(5;7;9)	(5;7;9)	(5;7;9)
Cr61	Cr62	Cr63	Cr64	Cr65	Cr66	Cr67	Cr68	Cr69	Cr70
(5;7;9)	(5;7;9)	(5;7;9)	(7;9;9)	(5;7;9)	(5;7;9)	(5;7;9)	(3;5;7)	(5;7;9)	(3;5;7)
Cr71	Cr72	Cr73	Cr74	Cr75	Cr76	Cr77	Cr78	Cr79	Cr80
(3;5;7)	(5;7;9)	(5;7;9)	(5;7;9)	(5;7;9)	(5;7;9)	(5;7;9)	(5;7;9)	(3;5;7)	(7;9;9)
Cr81	Cr82	Cr83	Cr84	Cr85	Cr86	Cr87	Cr88	Cr89	Cr90
(5;7;9)	(5;7;9)	(5;7;9)	(3;5;7)	(5;7;9)	(5;7;9)	(5;7;9)	(3;5;7)	(5;7;9)	(5;7;9)
Cr91	Cr92	Cr93	Cr94	Cr95	Cr96	Cr97	Cr98	Cr99	Cr100
(5;7;9)	(5;7;9)	(5;7;9)	(5;7;9)	(7;9;9)	(7;9;9)	(5;7;9)	(7;9;9)	(5;7;9)	(3;5;7)
Cr101	Cr102	Cr103	Cr104	Cr105	Cr106	Cr107	Cr108	Cr109	Cr110
(5;7;9)	(3;5;7)	(5;7;9)	(5;7;9)	(5;7;9)	(5;7;9)	(7;9;9)	(5;7;9)	(5;7;9)	(5;7;9)
Cr111	Cr112	Cr113	Cr114	Cr115	Cr116	Cr117	Cr118	Cr119	Cr120
(5;7;9)	(5;7;9)	(5;7;9)	(5;7;9)	(5;7;9)	(5;7;9)	(5;7;9)	(5;7;9)	(5;7;9)	(3;5;7)
Cr121	Cr122	Cr123	Cr124	Cr125	Cr126	Cr127	Cr128	Cr129	Cr130
(5;7;9)	(5;7;9)	(7;9;9)	(5;7;9)	(7;9;9)	(5;7;9)	(5;7;9)	(7;9;9)	(5;7;9)	(5;7;9)
Cr131	Cr132	Cr133	Cr134	Cr135	Cr136				
(5;7;9)	(5;7;9)	(7;9;9)	(7;9;9)	(7;9;9)	(5;7;9)				

Source: research data.