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EVALUATION MODEL OF INDUSTRIAL ENGINEERING INTERNSHIP PROGRAMS BY THE HYBRID FUZZY DEMATEL-VIKOR METHOD

MODELO DE AVALIAÇÃO DE PROGRAMAS DE ESTÁGIO DE ENGENHARIA DE PRODUÇÃO PELO MÉTODO HÍBRIDO FUZZY DEMATEL-VIKOR

Paulo Henrique Amorim Santos[1]
Nicolle Christine Sotsek[2]

ABSTRACT

Purpose – The internship is an activity that must be carried out in a real work environment by Industrial Engineering students as a requirement for obtaining the degree. The internship programs, in turn, are entities that mediate the processes related to intern student's admission, achievement and evaluation. The aim of this article is to propose a model to evaluate internship programs in Industrial Engineering courses.
Design/methodology/approach – Scientific mapping methods and multicriteria decision-making methods were used. Fuzzy DEMATEL was applied to a group of experts to determine criteria weights, by cause-and-effect evaluation. Subsequently, based on a survey with Industrial Engineering students from Brazilian universities, Fuzzy VIKOR was used to classify and evaluate internship programs.
Findings – Using bibliographic techniques and analysis of social networks, it was possible to identify the main criteria related to internship quality: the student's technical learning; student employability; development of student interpersonal skills; dealings with social issues; the themes developed during the internship; and the internship model and student experience. The model proved to be useful both for comparing different programs, from different universities, as for comparing the evolution of a single program over time.
Research, practical & social implications – The proposed model promises to enhance the quality of internship programs, enabling objective comparisons between institutions and inspiring innovations. The success of multicriteria methods advances knowledge in internship management, highlighting the social relevance of the research in addressing issues such as gender inequality, contributing to equity in a practical and replicable manner.
Originality/value – Besides the unprecedented proposal of using multicriteria decision making to evaluate internship programs, the bibliographic survey brings original issues on the theme as genre equality and discrimination.
Keywords - Internship; Engineering Education; Industrial Engineering; Higher Education; Multi-Criteria Decision-Making Methods.

RESUMO

Finalidade – O estágio obrigatório é uma atividade que deve ser realizada por alunos dos cursos de engenharia de produção em um ambiente de trabalho real, como requisito para que possam obter a graduação. Os programas de estágio, por sua vez, são entidades que mediam os processos relacionados ao ingresso, realização e avaliação do aluno estagiário. O objetivo deste artigo é propor um modelo de avaliar os programas de estágio dos cursos de engenharia de produção.
Desenho/metodologia/abordagem – Foram utilizados métodos de mapeamento científico da literatura e métodos de tomada de decisão multicritério. Fuzzy DEMATEL foi aplicado à um grupo de especialistas para determinar os pesos dos critérios, por avaliação de causa e efeito. Em sequência, a partir de uma pesquisa de levantamento com alunos de engenharia de produção de universidades brasileiras, Fuzzy VIKOR foi utilizado para fins de classificação e avaliação dos programas de estágio.
Constatações – Com o auxílio de técnicas bibliográficas e de análise de redes sociais foi possível identificar os principais critérios relacionados à qualidade do estágio: o aprendizado técnico do aluno; a empregabilidade do aluno; desenvolvimento de habilidades interpessoais do aluno; a tratativa sobre questões sociais; os temas desenvolvidos durante o estágio; e o modelo de estágio e a experiência do aluno. O modelo se provou útil tanto para comparar diferentes programas, de diferentes universidades, quanto para comparar a evolução de um único programa pelo tempo.
Contribuições, implicações práticas e sociais – O modelo proposto promete aprimorar a qualidade dos programas de estágio, possibilitando comparações objetivas entre instituições e inspirando inovações. O sucesso dos métodos multicritério avança o conhecimento na gestão de estágios, destacando a relevância social da pesquisa ao abordar questões como desigualdade de gênero, contribuindo para a equidade de forma prática e replicável.
Originalidade/valor – Além da proposta inédita de utilizar métodos de tomada decisão multicritério para avaliação dos programas de estágio, o levantamento bibliográfico traz questões originais ao tema, como desigualdade de gênero e discriminação.
Palavras-chave - Estágio; Ensino de Engenharia; Engenharia de Produção; Ensino Superior; Métodos de Tomada de Decisão Multicritério.

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[1] *Minas Gerais State University (UEMG), Passos - Minas Gerais – Brazil. Email: paulo.amorim@uemg.br Orcid: https://orcid.org/0000-0003-4735-7747*
[2] *Email: nicolleramos@ufpr.br Orcid: https://orcid.org/0000-0001-8567-5522*

1. INTRODUCTION

For Industrial Engineering, the 21st century presents itself as a challenging time, demanding a new particular set of skills (Paravizo et al., 2018). Today's students will work in an increasingly globalized, automated, virtualized, connected, and flexible world (Motyl et al., 2017). Thus, the industry has shown a greater affinity to hire people with adequate practical knowledge, capable of facing industrial challenges with an open and ethical mind (Maheso; Mpofu; Sibanda 2018). New generations of workers must be trained in emerging skills, demanded by the advancing industrial world, thus being empowered to proactively support innovation (Perini et al., 2017).

Higher education is expected to provide students not only with adequate knowledge in their field but also with the skills and competencies necessary to perform their job duties (Alves et al., 2017). The need to bridge students' academic skills and enhance their preparation for the job market is widely addressed in the literature (Burnik & Kosir, 2017). In today's competitive society, students face a selective job market that values experience (Collins, 2002). Practical engineering experience and the development of interpersonal skills are crucial for a successful engineering career (Burnik & Kosir, 2017).

In light of this, universities are confronted with new challenges, to identify future employment profiles and correlate competence requirements (Abele et al., 2015). To effectively address the emerging challenges in education and qualification of industrial engineers, the educational paradigm in manufacturing needs to be revised (Abele et al., 2017).

Engineering schools should seek to evolve pedagogical practices in higher education to achieve a balance between social competencies and technical training (Baena et al., 2017). The more developed the social skills, the greater the chances of the student satisfactorily dealing with the demands of different environments and interlocutors (Lopes et al., 2015). On the other side, a shift is noticeable in how students are engaging in this new learning process (Paravizo et al., 2018). There is a growing search by university students for practical experiences, to complement the classroom experience (Maheso; Mpofu; Sibanda, 2018).

The need to adjust existing curricula arises alongside new challenges, which are more easily overcome with better interaction between industry and academia (Abele et al., 2017; Gordon et al., 2019). For successful collaboration, both sides must overcome communication and cultural barriers that have separated this integration and harmed its potential (Alsheri et al., 2016). Educational institutions and companies would benefit more from collaborating to better understand each other's goals (Zehr & Korte, 2020). This not only improves the knowledge base but also brings trust between the two partners (Alsheri et al., 2016). Moreover, for the student, the transition from higher education to employment is a challenge that can be more easily resolved through this integration (Turcu & Turcu, 2018).

Internships play an important role in the career choices that engineering students make about their future (Matusovich et al., 2019). The authentic learning enabled by internships is at the center of graduates' daily lives (Thomson, 2020). During this period, students must learn new skills and think about employability, while the related organizations must also help them achieve their goals (Ashraf et al., 2018). A well-structured work experience has clear and positive effects on graduates' ability to secure employment within six months after graduation (Taylor & Hooley, 2014).

Evaluating internship programs is a fundamental activity to ensure the quality of training of future professionals and the success of these programs. This process aims to assess both the interns' experience and the impact of these programs on the organizations that offer them (Jackel, 2011). This evaluation plays a crucial role in the continuous improvement of the training of future industrial engineers, in adapting the programs to market needs, and in enhancing partnerships between educational institutions and companies. It is a practice that contributes to the formation of more qualified professionals prepared for the challenges of the production sector.

However, despite the existing literature on internships suggesting that the internship experience is universally beneficial for students' career outcomes, the fact is neglected that the positive effects of internships can be limited (Zuo et al., 2020). Although the benefits of the internship experience for the training of future engineers are widely accepted, the efficacy of internship courses should not be overestimated (Almeida Sá, 1992; Luk & Chan, 2020). Students may experience issues such as lack of support, uncertainty, and low learning yield during internships. Also, social issues, such as gender inequality, are common. It is often the experiences at work that compromise women's confidence and willingness to pursue a career in engineering (Seron et al., 2015). Female engineers continue to face significant obstacles in both social and professional environments, and discrimination, including sexual harassment, remains an issue at work or during internships (Mozahem et al., 2019).

Despite existing brazilian studies addressing the curricular guidelines in engineering and the crucial role of internships in professional training, there is a notable absence of specific research on the evaluation of internships in the field of Industrial Engineering (Ferreira; Reis, 2016; Azambuja; Grimoni, 2021; Correia, 2022). The lack of dedicated work on this theme underscores the importance of filling this gap, as effective evaluation of internships, through a duly validated instrument, represents a fundamental tool for gaining valuable insights capable of enhancing the learning experience of students (Luk & Chan, 2020).

The implementation of an appropriate evaluation instrument would not only allow the identification of areas amenable to improvement but also enable a meticulous analysis of the design of internship programs. This would encompass aspects such as the desired learning outcomes, the methods of evaluation employed, the efficacy of the pre-internship training offered, and the effectiveness of the partnerships established with employers (Luk & Chan, 2020). In this regard, the aim of this paper is to propose a model to evaluate the internship programs of Industrial Engineering courses. To achieve this aim, methods of scientific literature mapping and multi-criteria decision-making (MCDM) were used. Initially, from the literature, the criteria related to the performance of engineering internship programs were raised. Subsequently, Fuzzy DEMATEL was applied to a group of experts to determine the weights of the criteria through cause and effect evaluation. Following this, a survey with Industrial Engineering students from Brazilian universities was conducted, and Fuzzy VIKOR was used for ranking and evaluation purposes.

The following sections of this article are organized as follows: section 2 presents the literature review on the topic; section 3 shows the research method used, detailing the steps of data collection, analysis, and interpretation; section 3 presents the compiled results; section 4 brings the discussion between the collected evidence and the existing literature; and finally, section 5 presents the concluding remarks.

2. LITERATURE REVIEW

The purpose of an internship is to acquire specific course skills and establish a connection between theory and practice (Ferreira & Reis, 2016). The internship not only complements academic training but also helps students develop specific skills in the field, understand market demands, and establish professional contacts. Over the years, various studies have highlighted the importance of internships as a bridge between academia and the job market (de Almeida Sá, 1992; Carneiro et al., 2017).

The rules for curricular internships, established by Law No. 6494 of 1977 and regulated by Decree No. 87497 of 1982, define the internship as an activity aimed at learning, with categories such as Curricular Internship and Non-Curricular Internship (Sereno et al., 2007). The legislation stipulates that only regularly enrolled students can participate in internships, highlighting the importance of the internship as a complement to education, without establishing an employment relationship (Sereno et al., 2007). The enactment of the New Internship Law in 2008 gave educational institutions the responsibility to supervise and monitor the learning process of students, while establishing new guidelines for hiring by companies (de Oliveira Melo & Tonini, 2013). The signing of a commitment agreement between the student, the educational institution, and the company is a crucial norm for the realization of the internship (Sereno et al., 2007).

Thus, the internship in engineering is a crucial step for the professional development of students, providing the opportunity to apply the theoretical knowledge acquired during the course in practical situations (de Almeida Sá, 1992; Carneiro et al., 2017). In general, the literature on internships in engineering and Industrial Engineering emphasizes the relevance of this experience for professional development. The supervised internship in the area of Engineering, as an educational experience, enables the integration of theoretical knowledge acquired in the classroom with practical application in the professional environment (de Oliveira Melo & Tonini, 2013).

When it comes to Industrial Engineering, the internship plays a crucial role in the training of professionals capable of optimizing processes and resources (Sereno et al., 2007). The emergence of the Industrial Engineering course in Brazil in the 1950s was driven by the market's need for professionals who could meet the demands of multinational companies, and the Industrial Engineering course is recognized for its multidisciplinary approach, integrating areas such as economics, management, and engineering (Sereno et al., 2007).

In a highly competitive job market scenario, the demand for versatile professionals in multidisciplinary teams has driven the progressive increase in employment and internship opportunities in the area of Industrial Engineering (Sereno et al., 2007). It is noteworthy that Industrial Engineering interns have the unique opportunity to apply methods and techniques learned in the classroom to improve efficiency and productivity in organizations. The professionals trained have the ability to design and manage complex systems and can work in various areas such as operations, planning, finance, logistics, and marketing, in both public and private organizations (Sereno et al., 2007).

Therefore, it is crucial to establish an internship project that promotes the connection between the university, the student, and the company, with a special focus on the student's development (Carneiro et al., 2017). The need to ensure the quality of the internship as an educational experience implies coordination between the educational institution, the supervising professor, the internship coordinator, the intern, and the internship supervisor, as indicated by Ferreira and Reis (2016). Evaluating internship programs is crucial to ensure that these experiences are enriching and prepare students for the challenges of the job market. It is essential that there be a close relationship between those involved, as any distancing can be detrimental to all parties (Carneiro et al., 2017).

The identification of problems related to internship programs is old (de Almeida Sá, 1992; Zuo et al., 2020). Critical factors in acquiring skills during the execution of the internship include gaps in orientation, in the use of documents generated during the internship, and in the public presentation of the internship at the investigated educational institution (de Francisco & dos Santos, 2005). Thus, the evaluation is not limited only to the benefits for the students but also considers the positive impact that interns can have on organizations. Evaluation methods must go beyond the simple counting of hours, seeking to measure the impact of the internship on the professional and academic training of students. Moreover, the supervision and integration of the intern in the companies are highlighted as crucial points (de Francisco & dos Santos, 2005).

3. METHODOLOGY

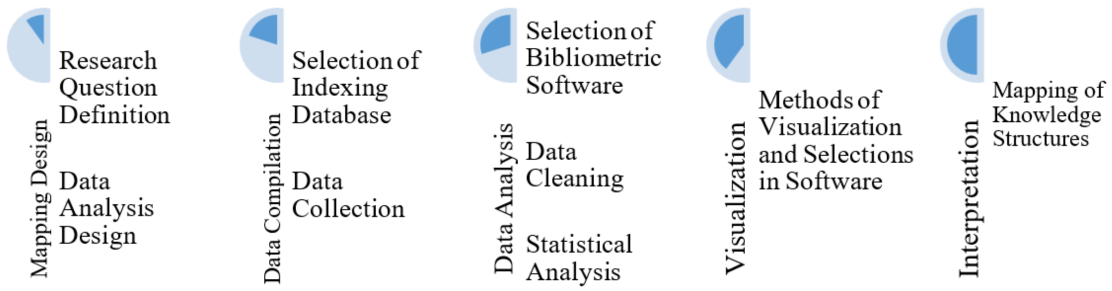
The research method used combines scientific mapping techniques (descriptive bibliometrics, social network analysis, and content analysis) and the multi-criteria decision methods Fuzzy DEMATEL and Fuzzy VIKOR (Lin et al., 2011; Morioka et al., 2018). Scientific mapping provides an overview of the state-of-the-art on the topic and allows for the identification of criteria related to the evaluation of internship programs. Subsequently, Fuzzy DEMATEL was applied to a group of experts to determine the weights of the criteria through cause-and-effect evaluation. The study requires a deeper analysis of the dependencies among the criteria, and DEMATEL is the most suitable choice. It enables the identification of criteria that are both dependent and independent, which is essential for the intended evaluation (Tzeng et al., 2007). Following this, a survey with Industrial Engineering students from Brazilian universities was conducted, and Fuzzy VIKOR was used for ranking purposes, particularly suitable when weights are assigned to the criteria (Lin et al., 2011). The methods are described in the following subsections.

Non-probabilistic sampling has been a useful approach in Multi-Criteria Decision Making methods like DEMATEL. This type of sampling offers specific advantages, especially when the research goal involves identifying qualitative relationships in a limited data set and does not intend to extrapolate results to a larger population. In summary, non-probabilistic sampling can be an effective approach in MCDM, especially when dealing with complex qualitative analyses and studies focused on interdependent relationships among criteria, as in the case of DEMATEL (Yoon; Hwang, 1995).

3.1 Scientific Mapping

Scientific mapping was used to identify patterns in the literature through descriptive charts. This method plays a crucial role in research, providing a solid theoretical foundation and identifying key criteria relevant to empirical research. The history of publications and their classification help to prevent the omission of important criteria, validate the selection of criteria, and ensure that the research is consistent with the field. Figure 1 presents the 5-step procedure adopted for bibliometric methods, proposed by Zupic and Cater (2015). Each step is described in sequence.

Figure 1
Steps for scientific mapping.



Source: Adapted from Zupic & Cater (2015).

To address the proposed research questions, we focused in analyzing the conceptual structure.

Data Collection: The Web of Science indexing database was chosen for data collection due to its referencing by DOI, being the only one that allows for the reliable counting of local citations (from within the sample). This feature is necessary for the creation of graphs such as bibliographic coupling. To ensure the consistency and eligibility of the documents, only articles published in peer-reviewed journals were considered. The following search string was used in the database: (TS=((internship) AND (engineer* OR "industrial" OR "operations manag*"))) AND DOCUMENT TYPES: (Article).

Data Analysis: The initial sample was processed using the Bibliometrix package, version 3.1.3, in the RStudio environment, version 1.4.1106 (Aria; Cuccurullo, 2017). Descriptive bibliometrics allowed us to identify the main themes related to research in the field. Social network analysis and content analysis made it possible to reduce the initial sample to a final sample of articles closely related to the theme. The NVivo software version 11.0 was used for text mining.

Visualization: Bibliometrix enabled the creation of graphs and tables using document metadata. The development of graphs was also aided by the use of Excel spreadsheets, version 3.2.0. A keyword co-occurrence map was created using the VOSviewer software version 1.6.16.

Interpretation: The selection of criteria was carried out by comparing the evidence collected in the resulting maps, which include keyword co-occurrence; bibliographic coupling of documents; and data mining.

3.2 Fuzzy sets theory

To overcome the imprecision of human judgment about preferences, MCDM methods will be associated with Fuzzy set theory (Geldermann; Spengler; Rentz, 2000; Wang; Chang, 2005; Wu; Lee, 2007). This paradigm addresses the problem of quantifying uncertainty from different perspectives, making the results more realistic (Khuman; Yang; John, 2014). Since Fuzzy sets are not suitable for matrix operations, it is common to use a defuzzification algorithm along with the application of MCDM methods. The defuzzification method used in this work will be the Center of Area method, given by the operation between the three values of the Fuzzy scale used (l; m; u).

$$CDA = \frac{(u-l)+(m-l)}{3} + l \qquad \text{Eq. (1)}$$

The linguistic variables used in the questionnaires (Appendices A and B) reflect the opinions of experts and students. The fuzzy scales are presented in Tables 1 and 2.

Table 1

Linguistic Variables for Degrees of Influence (used in the Fuzzy DEMATEL method)

Linguistic Variable	Fuzzy Scale
No Influence	(0, 0, 1)
Low Influence	(1, 2, 3)
Medium Influence	(4, 5, 6)
High Influence	(7, 8, 9)
Very High Influence	(9, 10, 10)

Table 2
Linguistic Variables for Degrees of Evaluation (used in the Fuzzy VIKOR method)

Linguistic Variable	Fuzzy Scale
Very Bad	(0, 1, 2)
Bad	(2, 3, 4)
Medium	(4, 5, 6)
Good	(6, 7, 8)
Very Good	(8, 9, 10)

3.3 Fuzzy DEMATEL

In this study, the values used in the DEMATEL method come from the evaluation of direct influences of a group of criteria. This evaluation is performed by a number of experts, who assign to each pair of criteria a linguistic variable (listed in Table 1) that is most appropriate for each influence in question. Although data collection is performed in the form of numbers in fuzzy sets, the method operates with crisp numbers, converted using the CDA defuzzification method. Next, the mathematics of the DEMATEL method, adapted from Tzeng, Chiang, and Li (2007), is detailed.

Step 1 - Generate the matrix of the direct influence averages of the group of criteria Let A be the matrix of the direct influence averages of the group of criteria expressed by:

$$\boldsymbol{A} = \frac{1}{m}\sum_{k=1}^{m} \boldsymbol{A}_{ij}^{k} \qquad \text{Eq. (2)}$$

Where m is the number of experts, $\boldsymbol{A}_{ij}^{k}$ is the matrix obtained by the individual evaluation of each expert and is expressed by:

$$\boldsymbol{A}_{ij}^{k} = [a_{ij}]_{n\times n}^{k} \qquad \text{Eq. (3)}$$

Where a_{ij} are the values assigned by each expert to the direct influence between each pair of n criteria (influence of criterion i on criterion j). The main diagonal elements (a_{ii}) are set to zero.

Step 2 - Establish the normalized direct influence matrix. Let X be the normalized direct influence matrix defined by:

$$\boldsymbol{X} = s.\boldsymbol{A} \qquad \text{Eq. (4)}$$

Where:

$$s = \min\left(\frac{1}{max_{1\le i\le n}\sum_{j=1}^{n}|a_{ij}|}, \frac{1}{max_{1\le j\le n}\sum_{i=1}^{n}|a_{ij}|}\right) \qquad \text{Eq. (5)}$$

Thus, each element x_{ij} of the matrix X represents the relationship between the elements in a contextualized way.

Step 3 - Construct the total influence matrix. The direct influence matrix F represents the infinite series of direct and indirect effects of each element, obtained from the following matrix operations between the matrix X and its identity I:

$$\boldsymbol{F} = \boldsymbol{X}(\boldsymbol{I} - \boldsymbol{X})^{-1} \qquad \text{Eq. (6)}$$

Step 4 - Produce the map of influential relationships. Let the total influence matrix ***F*** be given by:

$$\boldsymbol{F} = [f_{ij}]_{n\times n} \qquad \text{Eq. (7)}$$

Define R_j and D_i as:

$$R_j = \sum_{i=1}^{n} |f_{ij}| \qquad \text{Eq. (8)}$$

$$D_i = \sum_{j=1}^{n} |f_{ij}| \qquad \text{Eq. (9)}$$

The map of influential relationships is constructed from the coordinates $D_i + R_j$ (prominence, x-axis) and $D_i - R_j$ (network effect, y-axis). Each criterion is plotted according to its coordinate pair, and the main direct influence relationships are indicated by arrows. To select the main influence relationships, the threshold value τ is calculated, such that only influences where $f_{ij} \geq \tau$. are considered. The threshold τ will be considered by the third quartile.

3.4. Fuzzy VIKOR

In this work, the values used in the VIKOR method come from the evaluation of q alternatives subjected to a group of n criteria. This evaluation is performed by a number of m experts, who assign to each alternative a linguistic variable (listed in Table 6) that is most appropriate for each criterion in question. Although data collection is performed in the form of numbers in fuzzy sets, the method operates with crisp numbers, converted using the CDA defuzzification method. Next, the mathematics of the VIKOR method, adapted from Opricovic and Tzeng (2004), is detailed.

Step 1 - Generate the matrix that corresponds to the average direct influence of the group of criteria and determine the best and worst value for all criteria. Let A be the matrix of average evaluations expressed by:

$$\boldsymbol{A} = \frac{1}{m}\sum_{k=1}^{m} \boldsymbol{A_{ij}^{k}}$$ Eq. (10)

Where m is the number of experts. $\boldsymbol{A_{ij}^{k}}$ is the matrix obtained by the individual evaluation of each expert and is expressed by:

$$\boldsymbol{A_{ij}^{k}} = [a_{ij}]_{q\times n}^{k}$$ Eq. (11)

Where a_{ij} are the values assigned by each expert to each criterion of each alternative. The best value for each criterion j is given by the highest value of a_{ij} if beneficial, or the lowest value, if not beneficial. The worst value for each criterion j is given by the lowest value of a_{ij}, if beneficial, or the highest value, if not beneficial.

Step 2 - Calculate the normalized Manhattan (S_i) and Chebyshev (R_i) distances.

Calculate the distances using the following equations:

$$S_i = \sum_{j=1}^{m}\left(\frac{X_i^{+} - X_{ij}}{X_i^{+} - X_i^{-}}\right)$$ Eq. (12)

$$R_i = max\left(\frac{X_i^{+} - X_{ij}}{X_i^{+} - X_i^{-}}\right)$$ Eq. (13)

Step 3 - Compute the classificatory parameters Q.

Calculate the distance to the ideal value Q_i given by the equation:

$$Q_i = 0{,}5.\frac{S_i - S^*}{S^- - S^*} + 0{,}5.\frac{R_i - R^*}{R^- - R^*}$$ Eq. (14)

$$S^* = min\ S_i$$ Eq. (15)

$$S^- = max\ S_i$$ Eq. (16)

$$R^* = min\ R_i$$ Eq. (17)

$$R^- = max\ R_i$$ Eq. (18)

Step 4 - Rank the alternatives by the values S, R and Q;

Sort in ascending order the values of Q_i and the respective distances S_i and R_i.

Step 5 - Propose a solution under the two conditions of acceptable advantage and acceptable stability. If one of the conditions is not met, propose a set as the solution.

Acceptable advantage:

$$Q(a^2) - Q(a^1) \geq DQ \quad \text{Eq. (19)}$$

Where

$$DQ = \frac{1}{q-1} \quad \text{Eq. (20)}$$

Acceptable stability: alternative a^1 must also be the best ranked by S or R.

If one of the conditions is not met, then a set of solutions is proposed, consisting of:

If acceptable stability is not met: alternatives a^1 and a^2

If acceptable advantage is not met: alternatives $a^1, a^2, \dots, a^h$, where a^h is determined by the relationship:

$$Q(a^h) - Q(a^1) < DQ \quad \text{Eq. (21)}$$

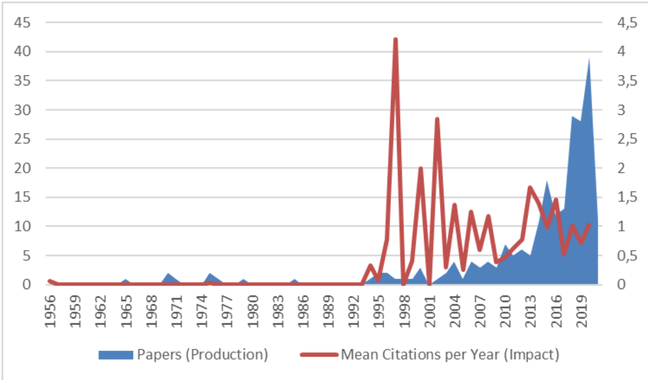
4. RESULTS AND DISCUSSION

The following presents the results of the scientific mapping of the literature and empirical methods of MCDM.

4.1. Scientific mapping

The data were compiled from the Web of Science, resulting in a total of 294 records. The publication period is from 1956 to 2022. Figure 2 shows the related scientific production (blue) and its impact in citations per year (orange). There is a significant increase in production at two points: from 2013 and from 2017, reaching 47 publications in 2022. The slope of the curve expresses a growing interest from the academic community in the subject over the last 10 years. Regarding impact, there are several peaks between 1995 and 2016, with the year 1997 standing out with an average of 4.2 citations per year. Despite being a period with fewer publications, some works stand out due to their impact. Naturally, the average citation curve is decreasing in recent years.

Figure 2
Annual scientific production and impact, in average citations per year.



Source: The Authors (2024).

As a first step towards mapping the conceptual structure of the field, a co-occurrence analysis of keywords was used, which can be described as a content analysis technique that uses words chosen by the authors to establish relationships (Zupic & Cater, 2015). Figure 3 presents the resulting map, created using VOSViewer software. It is possible to discern the formation of 5 distinct clusters of keywords:

Green Cluster: terms related to training methods for interns and their experience, including "creative problem solving"; "problem-based learning"; "virtual internship". Additionally, there is a connection with thematic terms such as "sustainable development" and "STEM" (science, technology, engineering, and mathematics);

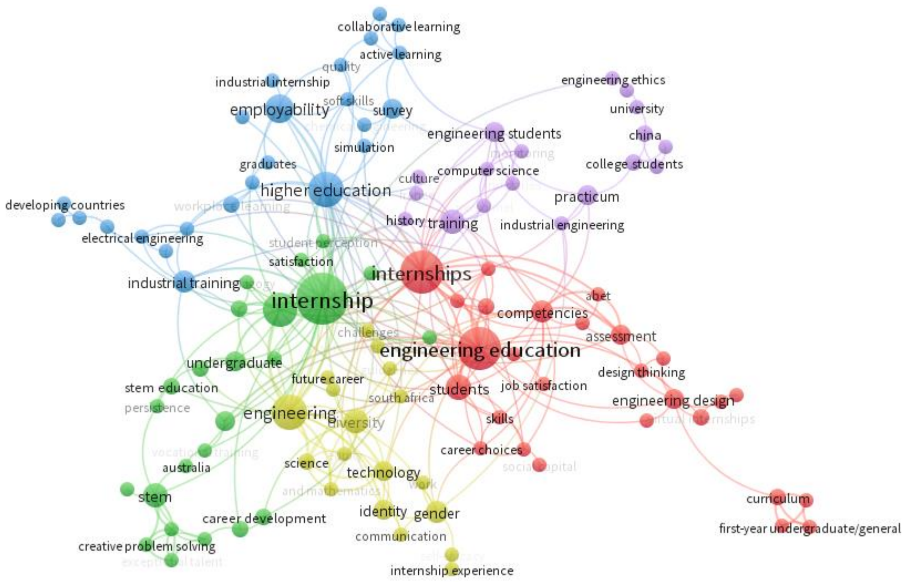
Red Cluster: terms related to recruitment, skills, and employability;

Yellow Cluster: terms related to career, diversity, and competencies;

Blue Cluster: terms related to quality and the evaluation of the internship;

Yellow Cluster: terms related to culture and social factors.

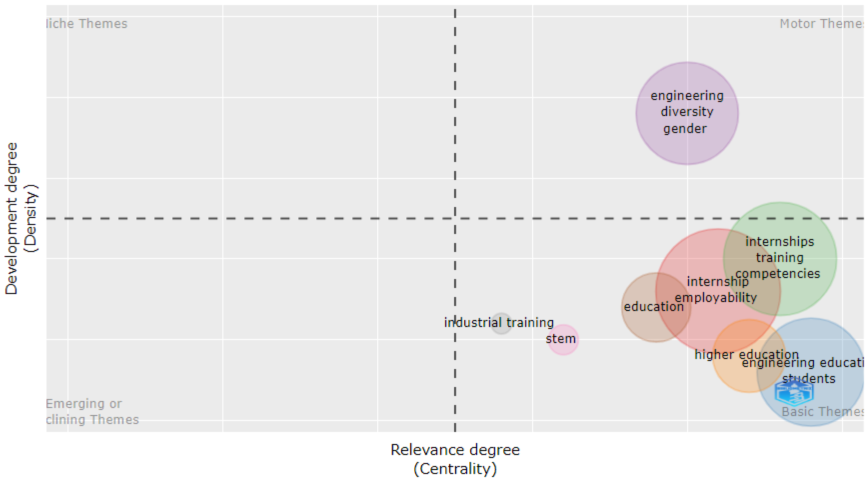
Figure 3
Authors keyword co-occurrence map (VOSviewer).



Source: The Authors (2024).

As a second analysis, thematic analysis is presented in Figure 4, which maps the themes according to their relevance and degree of development, generating clusters and classifying them as “Niche Themes”; “Motor Themes”; “Emerging or Declining Themes”; and “Basic Themes”. It is observed that there are no themes classified as “niche” or “emerging”. More dense and relevant themes (motor) are “engineering/diversity/gender” (Purple Cluster). The other themes are considered basic, divided into 7 Clusters, which can be understood as “industrial training”; “STEM”; “education”; “internship/employability”; “internships/training/competencies”; “higher education”; and “engineering education/students”.

Figure 4
Thematic map of the field (Bibliometrix).

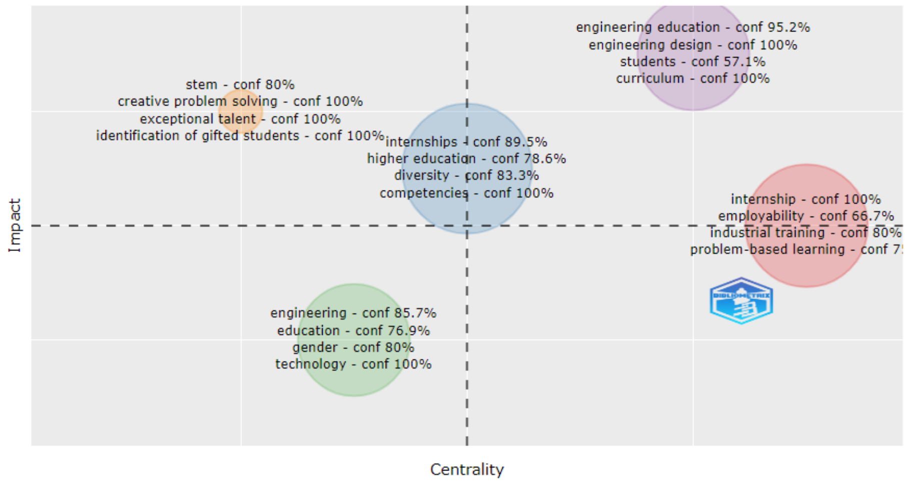


Source: The Authors (2024).

The next map presented is the bibliographic coupling of the documents (Figure 5). It is possible to group the documents from the initial sample of 294 articles into 5 distinct clusters:

Low impact, high centrality: Orange;
Low impact, low centrality: Green;
Medium Impact, high centrality: Blue;
High impact, high centrality: Purple;
High impact, medium centrality: Red.

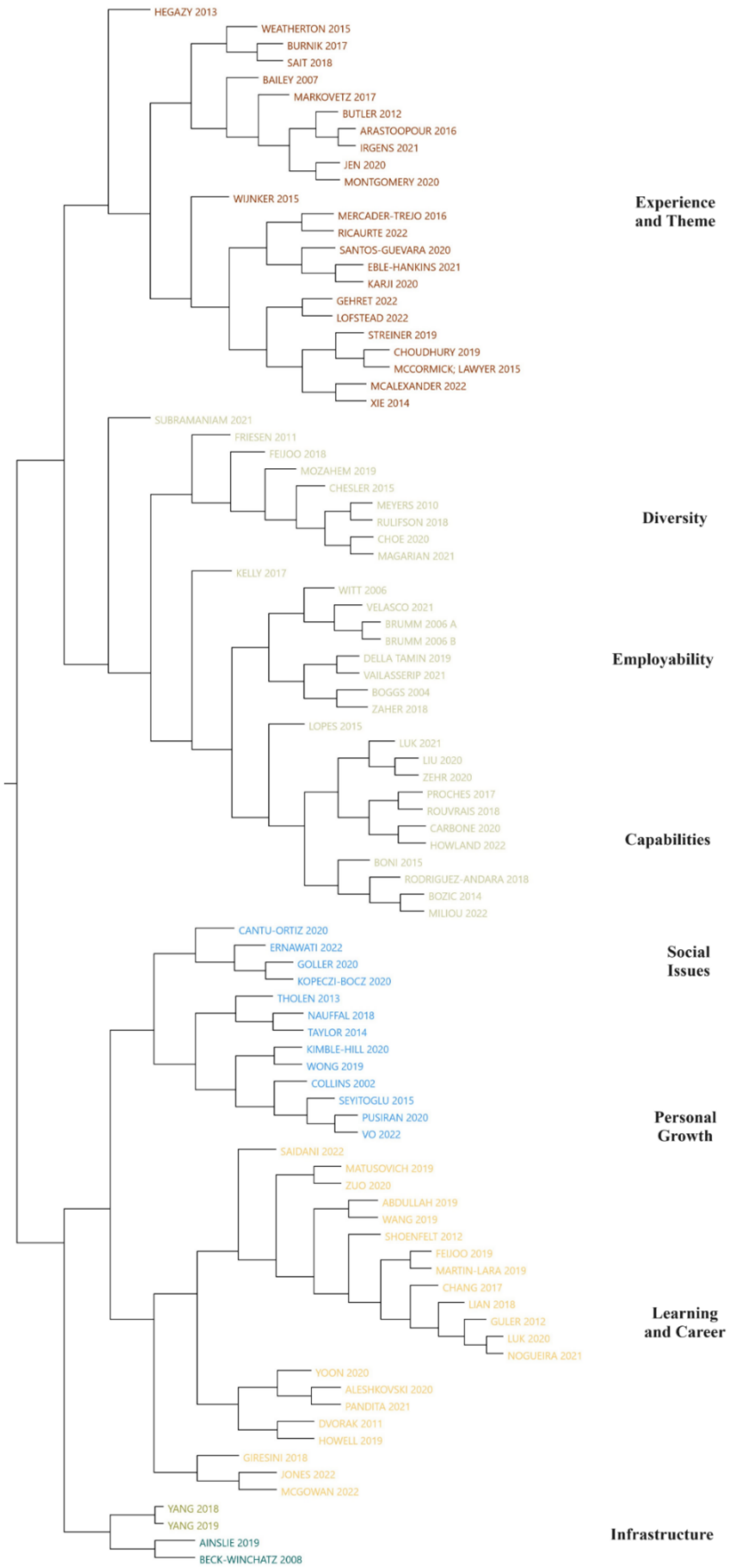
Figure 5
Bibliographic coupling of documents (Bibliometrix).



Source: The Authors (2024).

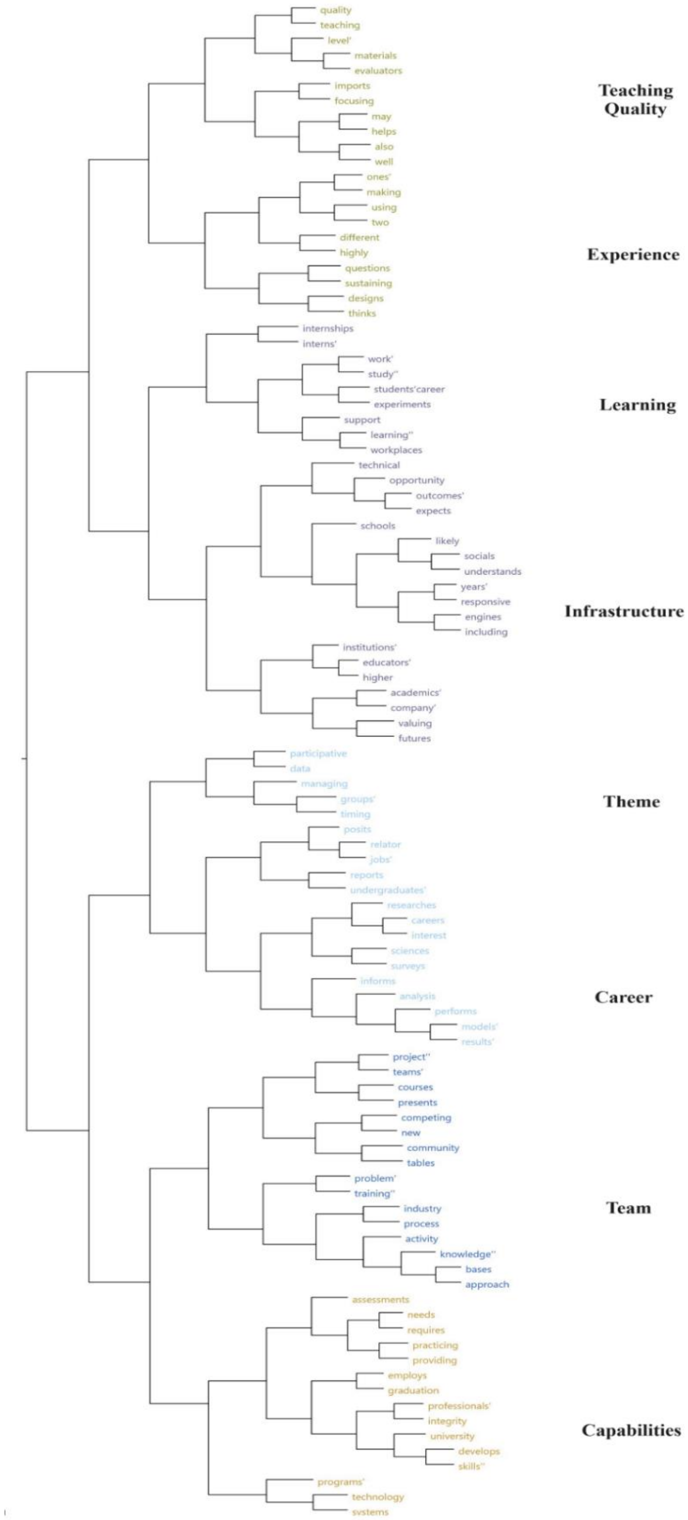
The three largest clusters (blue, red, and purple) are closely related to the theme and were chosen for a sub-sample text mining investigation. Figure 6 presents the grouping of these 107 documents by word similarity. From the analysis of titles and abstracts, the formation of 8 main clusters is noted, whose themes reinforce the findings from Figures 3, 4, and 5. Figure 7 complements Figure 6, displaying the most frequent terms in the textual bodies by similarity of use. This analysis allows a better understanding of the relationship between the constructs. It is evident that disregarding terms common to scientific research, 8 clusters are formed. Figures 6 and 7 are presented below in the form of descriptive dendrograms. Lastly, Table 1 presents a summary of the interpretation of the maps resulting from the conceptual structure of the field. From the relational analysis between the clusters of Figures 3, 4, 5, 6, and 7, the criteria defined for use in the hybrid Fuzzy DEMATEL-VIKOR method are presented: the student’s technical learning (TL); the student’s employability (SE); development of the student's interpersonal skills (IS); the handling of social issues (HSI); the developed themes during the internship (DT); and the internship model and the student's experience (IM&SE).

Figure 6
Document clusters by word similarity (NVivo).



Source: The Authors (2024).

Figure 7
Word clusters by similarity of occurrences (NVivo).



Source: The Authors (2024).

Table 3

Interpretation of the maps resulting from the conceptual structure and defined criteria

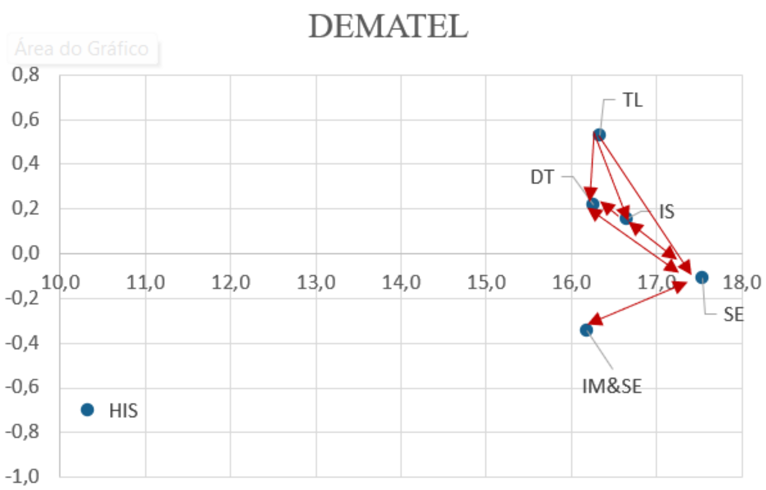
Figure 3 Authors keyword co-occurrence map	Figure 4 Thematic map of the field	Figure 5 Bibliographic coupling of documents	Figure 6 Document clusters by word similarity	Figure 7 Word clusters by similarity of occurrences	Defined Criteria
Quality; Evaluation	higher education	engineering education/engineering design/students/curriculum	Learning and Career	Teaching Quality	Technical learning of the student (TL)
	education			Learning	
Recruitment; Skills; Employability	internship/employability	Internship/employability/industrial training/problem based learning	Employability	Career	Student employability (SE)
	internship/training/competencies		Personal Growth	Capabilities	Development of interpersonal skills of the student (IS)
Competencies; Career; Diversity			Capabilities		
Culture; Social Factors	engineering/diversity/gender	internships/higher education/diversity/competencies	Diversity	Team	Handling of social issues (HIS)
		engineering/education/gender/technology	Social Issues		
Theme; Methods; Experience	engineering education/students	stem/creative problem solving/exceptional talent/identification of gifted students	Theme	Theme	Developed themes during the internship (DE)
	stem		Experience	Experience	Internship model and student experience (IM&SE)
	industrial training		Infraestructure	Infraestructure	

4.2. DEMATEL

The next step in development is to quantify the causal relationships between the criteria. For this purpose, data were collected by sending out a research instrument developed for this purpose (Appendix A). Opinions from 10 professors in the field from two different universities were collected. The data were analyzed using the DEMATEL method (Figure 8).

Figure 8

Map of influential relationships (DEMATEL).



Source: The Authors (2024).

The map provides the dispersion of the criteria by their prominence (x-axis) and network effect (y-axis). It is evident that technical learning, themes, and interpersonal skills have the greatest influence, with employability, and the model and experience being consequences.

The weighting method proposed by Lin et al. (2011) provides the weights w_j for each process (Table 4) by the equation:

$$w_j = \sqrt{(D_i + R_j)^2 + (D_i - R_j)^2} \qquad \text{Eq. (22)}$$

Table 4

Eight of Criteria calculated by the equation proposed by Lin et al. (2011)

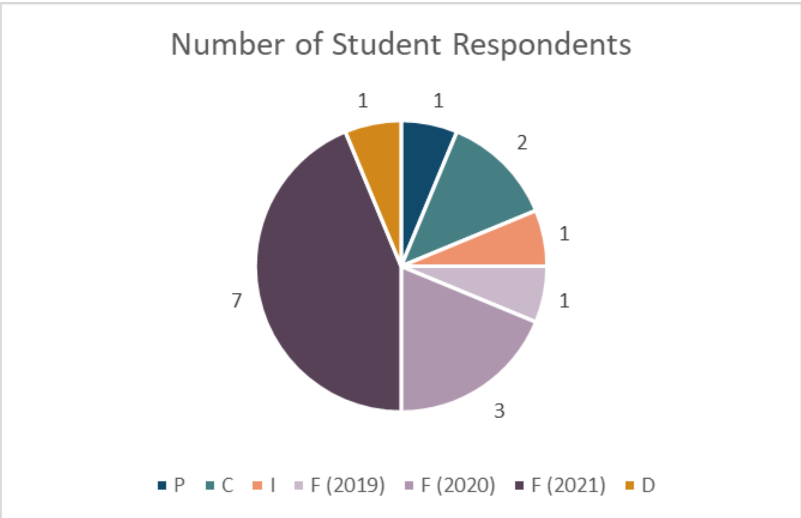
Criteria	Weight w
Technical Learning	0,18
Student Employability	0,19
Interpersonal Skills	0,18
Handling of Social Issues	0,11
Developed Themes	0,17
Internship Model & Student's Experience	0,17

4.3. VIKOR

The next step was to rank the internship programs of different universities, as an example of the proposed method. For this, another set of empirical data was collected through another research instrument (Appendix B). Figure 9 illustrates the number of respondents per university.

Figure 9

Number of student respondents by university.



Source: The Authors (2024).

The results obtained by the Fuzzy-DEMATEL method were then used in the Fuzzy-VIKOR method. The results are presented in Table 5.

Table 5
Ranking of internship programs (VIKOR)

University	S	R	Q	Ranking	Evaluation
“D”	0,912474	0,187952	1	7°	F
“F” (2019)	0,239174	0,086751	0,214903	2°	B
“F” (2020)	0,397779	0,174229	0,639934	5°	D
“F” (2021)	0,400552	0,149339	0,547693	4°	D
“C”	0,313327	0,087526	0,262246	3°	B
“I”	0,718813	0,175053	0,835336	6°	F
“P”	0,077724	0,055421	0	1°	A

The sample of 294 records shows that academic interest in engineering internships is long-standing. This interest continues to increase (Figure 2), and the various impact peaks show the spread of research in the field. The themes addressed by the initial sample can be observed in Figures 3 and 4. The keywords (Figure 3) point to methods of training the intern and their experience and covered themes; recruitment, skills, and employability; career, diversity, and competencies; quality and evaluation of the internship; and culture and social factors. The thematic analysis (Figure 4) highlights themes such as "engineering, diversity, and gender" as driving themes.

Through the bibliographic coupling of documents (Figure 5), it is noticed that the clusters with the highest impact and centrality address themes such as curriculum; engineering education; diversity; competencies; employability, and industrial training. The sub-sample of 107 articles closely related to the theme (Figure 5) shows trends when analyzing the similarity of their words (Figure 6) and the similarity of occurrences of these words (Figure 7). From the resulting maps of the conceptual structure of the field (Table 1), it was possible to summarize the interpretation of the evidence according to each criterion defined by the method:

Technical learning of the student: As the most influential criterion, technical learning is fundamental in defining the quality of the internship. Learning new skills is necessary for the daily life of the graduate in the process of immersing in the market, influencing themes, interpersonal skills, and their future employability. This result reaffirms the proposals of Ashraf et al. (2018) and Thomson (2020). These skills should focus on trends demanded by the market and technological innovation (Perini et al., 2017). Maheso, Mpofu, and Sibanda (2018) identify a growing search by university students for practical experiences to complement classroom experience, confirmed by Paravizo et al. (2018) on the change in how students are engaging in this new learning process.

Themes developed during the internship: As the second most influential criterion, the choice of themes is closely related to the university-industry relationship. On the one hand, there is a need to adjust existing curricula (Abele et al., 2015; Abele et al., 2017; Gordon et al., 2019). On the other, the student's interest must be taken into account through this integration (Turcu & Turcu, 2018). In addition to mutual benefits, this criterion is fundamental to spark the student's interest in continuing in the field (Zehr & Korte, 2020; Alsheri et al., 2016).

Development of interpersonal skills of the student: As a central criterion, the development of interpersonal skills holds the same importance as technical training, crucial for a successful engineering career (Burnik & Kosir, 2017); and increasing chances of satisfactorily dealing with the demands of different environments and interlocutors (Lopes et al., 2015). This balance is necessary to develop all the competencies to perform the job duties required (Alves et al., 2017; Baena et al., 2017).

Student employability: The future employability of the student is a consequence of the criteria described above. The internship represents a period of reflection and choices (Ashraf et al., 2018; Matusovich et al., 2019). The relationships found in the experts' responses align with authors in the literature on the value of experience (Collins, 2002); bridging academic skills (Burnik & Kosir, 2017); adequate practical knowledge, open mind, and ethics (Maheso; Mpofu; Sibanda 2018).

Internship model and student experience: The student's experience is closely related to future employability. The need to develop practical experience stands out (Burnik & Kosir, 2017). Moreover, related organizations must also help them achieve their goals (Ashraf et al., 2018; Alsheri et al., 2016). According to Taylor and Hooley (2014), this initial experience has clear effects on the graduates' ability to secure employment within six months after graduation.

Handling of social issues: Contrary to the literature, the results indicate a weak relationship of social issues with the other criteria. However, negative experiences during the internship can compromise the student's confidence and willingness to pursue a career in engineering, whether due to discrimination or harassment (Seron et al., 2015; Mozahem et al., 2019).

In both empirical methods, the Center of Area defuzzification proved useful in minimizing errors of human interpretation in the evaluation process. Regarding the calculation of weights for each criterion by the method of Lin et al. (2011), DEMATEL proved efficient. The greater influence of technical learning, themes, and interpersonal skills is noted, with employability, and the model and experience as consequences. Contrary to the analysis of the conceptual structure, social issues are not highlighted as influential or influenced by the other criteria. This may occur due to a lack of academic perception of the importance of these themes during the internship period.

In the last stage, of classification by the VIKOR method, it was noted that it is possible to perform the evaluation for different universities; periods; and number of students. It is suggested that in the replication of the model, standardizations and larger samples are used, determined by suitable statistical methods. It is possible to analyze from the results, for example, variations in the quality perceived by students, as in the case of university "F". Furthermore, the evaluation by classes allows a better understanding of quality instead of simple ranking.

The proposed model approaches the "instrument would help to obtain insights about areas for improvement, to leverage the learning experience of students" proposed by Luk and Chan (2020). According to the authors, such an instrument allows identifying the need to review the design of internship programs in terms of their intended learning outcomes, evaluation, pre-internship training, and partnership with employers.

5. CONCLUSION

In the current literature, it is neglected that the positive effects of internships can be limited. The efficacy of internship courses should not be overestimated, and this study emerges as an option to gain valuable insights into areas for improvement in the students' learning experience. The aim of this article was to propose a model for evaluating internship programs in Industrial Engineering courses.

For this purpose, methods of scientific mapping of literature and multi-criteria decision-making methods were used. Fuzzy DEMATEL was applied to a group of experts to determine the weights of the criteria, through cause-and-effect evaluation. Subsequently, a survey with Industrial Engineering students from Brazilian universities was conducted, and Fuzzy VIKOR was used for ranking and evaluating the programs.

Regarding bibliographic results, there is a growing academic interest in the subject over the last 10 years, with several peaks of impact between 1995 and 2016. With the help of bibliographic techniques, social network analysis, and data mining, it was possible to identify the main criteria related to the quality of the internship: the technical learning of the student; the student's employability; development of the student's interpersonal skills; the handling of social issues; the themes developed during the internship; and the model of the internship and the student's experience.

Expert opinions allowed the construction of a map of influential relationships and a classification of the criteria by their defined weights. The combination of multi-criteria decision-making methods proved useful both for comparing different programs, from different universities, and for comparing the evolution of a single program over time.

The introduction of the proposed model for evaluating internship programs in Industrial Engineering carries substantial managerial implications. By offering a structured approach, managers and coordinators have the opportunity to improve the quality of programs, identifying specific areas for improvement. Moreover, standardization allows for objective comparisons between institutions, promoting benchmarking and driving more informed decision-making. Innovation in internship models also becomes a real possibility, aligning programs with student expectations and the dynamic demands of the job market.

The replication of the model proposed in this article can be done in order to improve the experience of new students in a standardized way and identify improvement points in current internship programs. Such a tool would then enable the identification of the need to review the design of internship programs in terms of their intended learning outcomes, evaluation, pre-internship training, and partnership with employers.

From an academic standpoint, the successful application of multi-criteria methods in this research brings significant contributions. Besides advancing knowledge in internship management, the interdisciplinary approach adopted serves as a model for future research. The inclusion of social issues, such as gender inequality, reinforces the social relevance of internship management, highlighting the research as a driving force for equity. The emphasis on the replicability of the model highlights the practical nature of academic research, encouraging the direct application of findings to enhance the quality and inclusiveness of internship programs.

The research plays a crucial role in an expanding field and provides a valuable tool for assessing the quality of internships in Industrial Engineering courses, contributing to the enhancement of education and preparation of future professionals, as well as to the continuous progress of this essential field. Therefore, the importance of this study is not limited to its immediate impact but also to its potential to direct the future of Industrial Engineering and enhance the training of professionals in this constantly transforming area.

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APPENDIX A

Survey Form on the Relationships Between Factors Related to Internships in Industrial Engineering Courses (Example)

Research - Relationships between factors related to internships in Industrial Engineering courses

Thank you for your collaboration!!

This questionnaire aims to collect data to analyze the influence relationships between factors related to internships in Industrial Engineering courses.

The factors in question are:

The student's technical learning;
The student's employability;
Development of the student's interpersonal skills;
Handling of social issues (such as gender equality and diversity);
The themes developed during the internship;
The internship model and the student's experience.
Respondents are asked to choose one alternative per line for each of the following 6 questions (estimated total time: 15 minutes):

1. What is the influence of the student's technical learning on: *

	None	Low	Medium	High	Very High
The student's employability	○	○	○	○	○
Development of the student's interpersonal skills	○	○	○	○	○
Handling of social issues	○	○	○	○	○
The themes developed during the internship	○	○	○	○	○
The internship model and the student's experience	○	○	○	○	○

APPENDIX B –

Survey Form for Evaluating Factors Related to Internships in Inustrial Engineering Courses (Example)

Research - Evaluation of Factors Related to Internships in Industrial Engineering Courses

Thank you for your collaboration!!

This questionnaire aims to collect data to evaluate factors related to internships in Industrial Engineering courses.

The factors in question are:

The student's technical learning;
The student's employability;
Development of the student's interpersonal skills;
Handling of social issues (such as gender equality and diversity);
The themes developed during the internship;
The internship model and the student's experience.
Respondents are asked to answer the descriptive questions and finally evaluate the factors related to their internship.

Estimated total time: 5 minutes.

Factors Analysis

1. How do you evaluate your technical learning during the internship? *

	Very Bad	Bad	Medium	Good	Very Good
My technical learning was	○	○	○	○	○