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EVALUATION OF SUPPLIER SUSTAINABLE DEVELOPMENT PROGRAMS USING THE HFLTS-QFD METHOD

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ABSTRACT

Objective: This study proposes a decision model for evaluating sustainable supplier development programs (SSDPs) using the HFLTS-QFD technique, which is a combination of Hesitant Fuzzy Linguistic Term Sets (HFLTS) with the Quality Function Deployment (QFD) method.

Theoretical Framework: The implementation of supplier development programs is important to improve supplier performance in aspects related to economic, environmental and social aspects. The evaluation of these programs is necessary to decide on their continuation or discontinuation, as well as to direct the allocation of resources.

Method: The bibliographical research supported the definition of the requirements and criteria used for the evaluation of SDPs. The implementation of the model was done using MS Excel® software. The application in an illustrative case involving the evaluation of five SDPs allowed us to demonstrate the applicability of the model.

Results and Discussion: The most relevant criteria were organization strategy, social responsibility, employee training and environmental management. The programs with the best classification were SDP_4 and SDP_5.

Research Implications: The proposed model supports the selection of criteria considering their relative weights and the degree of difficulty in collecting data from suppliers when evaluating each PDFS. It also has the capacity to assist group decision-making, enabling the assignment of weights to decision-makers.

Originality/Value: Unlike previous models for evaluating PDFS, which use economic or environmental criteria, the proposed model considers criteria related to the three dimensions of the Triple Bottom Line, in addition to allowing the use of linguistic expressions to deal with decisions under hesitation and uncertainty.

Keywords: Evaluation of Sustainable Supplier Development Programs, Multicriteria Decision Making, Hesitant Fuzzy Linguistic Term Sets, Quality Function Development.

AVALIAÇÃO DE PROGRAMAS DE DESENVOLVIMENTO DE FORNECEDORES SUSTENTÁVEIS UTILIZANDO O MÉTODO HFLTS-QFD

RESUMO

Objetivo: o presente estudo propõe um modelo de decisão para avaliação de programas de desenvolvimento de fornecedores sustentáveis (PDFS) usando a técnica HFLTS-QFD, que é uma combinação de Hesitant Fuzzy Linguistic Term Sets (HFLTS) com o método Quality Function Deployment (QFD).

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Referencial Teórico: A implantação de programas de desenvolvimento de fornecedores é importante para melhorar o desempenho dos fornecedores em aspectos relacionados a aspectos econômicos, ambientais e sociais. A avaliação desses programas é necessária para decidir sobre a continuação ou interrupção destes, bem como para direcionar a alocação de recursos.

Método: A pesquisa bibliográfica embasou a definição dos requisitos e critérios utilizados para avaliação de SDPS. A implementação do modelo foi feita utilizando o *software* MS Excel®. A aplicação em um caso ilustrativo envolvendo a avaliação de cinco PDFS permitiu demonstrar a aplicabilidade do modelo.

Resultados e Discussão: Os critérios com maior peso foram estratégia da organização, responsabilidade social, treinamento e gestão ambiental. Os programas com melhor classificação foram $PDFS_4$ e $PDFS_5$.

Implicações da Pesquisa: O modelo proposto permite apoiar a escolha de critérios considerando seus pesos relativos e o grau de dificuldade de se coletar dados dos fornecedores ao avaliar cada PDFS. Também possui capacidade de auxiliar a tomada de decisão em grupo, possibilitando a atribuição de pesos aos decisores.

Originalidade/Valor: Ao contrário dos modelos prévios para avaliação de PDFS, que utilizam em critérios econômicos ou ambientais, o modelo proposto considera critérios relacionados às três dimensões do Triple Bottom Line, além de permitir a utilização de expressões linguísticas para lidar com decisões sob hesitação e incerteza.

Palavras-chave: Avaliação de Programas de Desenvolvimento de Fornecedores Sustentáveis, Tomada de Decisão Multicritério, Conjuntos de Termos Linguísticos Fuzzy Hesitantes, Desenvolvimento da Função de Qualidade.

EVALUACIÓN DE LOS PROGRAMAS DE DESARROLLO SOSTENIBLE DE LOS PROVEEDORES MEDIANTE EL MÉTODO HFLTS-QFD

RESUMEN

Objetivo: Este estudio propone un modelo de decisión para evaluar los programas de desarrollo sostenible de proveedores (PSD) utilizando la técnica HFLTS-QFD, que es una combinación de conjuntos de términos lingüísticos difusos vacilantes (HFLTS) con el método de despliegue de funciones de calidad (QFD).

Marco teórico: La aplicación de programas de desarrollo de proveedores es importante para mejorar el rendimiento de los proveedores en aspectos relacionados con los aspectos económicos, ambientales y sociales. La evaluación de estos programas es necesaria para decidir si continúan o se suspenden, así como para dirigir la asignación de recursos.

Método: La investigación bibliográfica respaldó la definición de los requisitos y criterios utilizados para la evaluación de los programas de desarrollo sostenible. La implementación del modelo se realizó con el software MS Excel®. La aplicación en un caso ilustrativo que implica la evaluación de cinco PSD nos permitió demostrar la aplicabilidad del modelo.

Resultados y Discusión: Los criterios más relevantes fueron la estrategia organizacional, la responsabilidad social, la formación de los empleados y la gestión ambiental. Los programas mejor clasificados fueron SDP4 y SDP5.

Implicaciones de la investigación: El modelo propuesto apoya la selección de criterios, teniendo en cuenta sus ponderaciones relativas y el grado de dificultad para reunir datos de los proveedores al evaluar cada PDFS. También tiene la capacidad de ayudar a la toma de decisiones en grupo, permitiendo la asignación de pesos a los responsables de la toma de decisiones.

Originalidad/Valor: A diferencia de los modelos anteriores de evaluación de los PDFS, que utilizan criterios económicos o ambientales, el modelo propuesto considera criterios relacionados con las tres dimensiones de la Triple línea de fondo, además de permitir el uso de expresiones lingüísticas para hacer frente a las decisiones bajo vacilación e incertidumbre.

Palabras clave: Evaluación de Programas de Desarrollo Sostenible de Proveedores, Toma de Decisiones Multicriterio, Conjuntos de Términos Lingüísticos Difusos Vacilantes, Desarrollo de Funciones de Calidad.

1 INTRODUCTION

One of the challenges for organizations to gain a competitive advantage over competitors at a global level is to incorporate sustainability into supply chain management. Due to regulations or external pressure from customers, supplier development is important for organizations involved in supply chains with increasingly stricter environmental and social requirements in order to achieve relevant results regarding the *triple bottom line. line* – TBL) (Finger & Lima, 2022). The entire supply chain can be impacted by suppliers not adopting sustainable practices. Many suppliers are unable to implement or take sustainability into account due to a lack of managerial and technological *expertise* , among other resources. Consequently, it is necessary to implement supplier development programs (PDF) to improve their performance in aspects related to economic, environmental, and social aspects (Schmidt, Foerstl & Schaltenbrand , 2017).

Supplier development is a set of support activities undertaken by the manufacturer to improve the supplier's capabilities and/or performance (Glock, Glosse, & Ries, 2017). In this sense, organizations must decide which suppliers will be developed, which programs will be implemented, how they will be evaluated, and what maintenance will be necessary. Identifying which PDFs are efficient can support decision-making in organizations , especially regarding investment allocation . However, it is necessary to analyze whether the implemented programs are having an effect (Resende, Lima & Carpinetti , 2023).

In the literature, there are some models proposed to support the evaluation of PDFs , which consider evaluation criteria such as: quality, logistics , financial health and technical resources (Araz & Ozkarahan , 2007; Sarkar & Mohapatra , 2006; Omurca , 2013; Rezaei & Ortt , 2013). Three systematic literature review articles were found that contemplate decision models for evaluating PDFs. Zimmer et al. (2016) analyzed 143 articles that presented quantitative and qualitative models to support decision-making in the management of sustainable suppliers, encompassing the stages of selection, monitoring and development of suppliers. Glock et al. (2017) reviewed 46 articles and presented a list of decision models for supplier development, comprising the phases of selection, development, and monitoring and evaluation. The article developed by Zimmer et al. (2016) demonstrates that most of the studies studied (81%) are focused on the problem of supplier selection, while few studies encompass supplier development and evaluation. In the study by Glock et al. (2017), this neglect is also observed, since there is a low frequency of models that evaluate supplier development programs (10.9%). Resende et al. (2023) reviewed 65 articles on models to support the formulation and evaluation of DFs. They also found a scarcity of models focused on the evaluation of sustainable DFs (SDFs), as well as the need for models focused on decisions under hesitation.

In addition to these literature review studies on decision models for supplier development, Lima, Oliveira & Resende (2023) presented a systematic review on applications of techniques based on *Hesitant Fuzzy Linguistic Term Sets* in problems related to supply chain management. These authors did not find studies that apply this type of HFLTS techniques in the evaluation of supplier development programs. Therefore, based on these systematic review articles and through bibliographic research carried out in the present study, it was found that:

i. None of the studies found presents a decision model for evaluating sustainable supplier development programs, that is, one that considers criteria associated with the economic, environmental and social dimensions ;
ii. None of the models support the choice of PDF evaluation criteria taking into account the intensity of the relationship between these criteria and the supplier's development requirements, that is, the factors in which the supplier needs to improve. They also do not consider the difficulty in collecting information on PDF performance as a decision factor in the choice of criteria;
iii. In the literature, there are no models that use HFLTS techniques in PDF evaluation. Thus, none of the models found allows decision makers to use two or more linguistic terms , as well as expressions linguistic (such as "between medium and high") to express their judgments about metrics or PDFs ;
iv. Although several techniques are used in PDF evaluation, only 6 models (Awasthi & Kanna , 2016; Bai & Sarkis , 2011; Fu et al., 2012; Kumar & Routroy , 2017a; Kumar & Routroy , 2017b; Routroy , Pradhan & Kumar, 2016) are suitable for group decision -making , that is, with two or more decision makers.

The development of a new decision support model based on a combination of *Hesitant Fuzzy Linguistic Term Set (HFLTS) (Rodriguez, Martinez & Herrera, 2012) with the Quality Function Deployment* (QFD) methodology , called HFLTS-QFD, can contribute to filling the gaps found (Osiro, Lima & Carpinetti, 2018), allowing decision makers to use one or more linguistic terms or linguistic expressions to aid their judgment in environments of uncertainty and hesitation . In addition, it does not limit the number of requirements, criteria and PDFS that can be considered. In view of the above, the present study aims to propose a decision model to support the evaluation of sustainable PDFS in supply chains based on the HFLTS-QFD method. In this sense, it investigates how HFLTS-QFD can be used to build a model to support the evaluation of PDFS.

2 THEORETICAL FRAMEWORK

There is growing interest in supplier development due to its potential future benefits in strengthening the supply chain . However, its implementation requires significant organizational resources (Pourjavad & Shahin , 2020; Resende et al., 2023) . Given this, due to the heterogeneous performance of PDFS and the limited amount of resources to implement, companies prefer that the most appropriate and efficient programs are implemented and monitored (Dou et al., 2014).

To perform the evaluation of PDFS, several criteria can be considered. The process of evaluating the criteria itself presents an intrinsic imprecision due to the subjectivity of the weights attributed to the criteria by various decision makers, giving them uncertainty in the evaluation of PDFS (Pourjavad & Shahin , 2020). Therefore, the importance of using tools that evaluate both the criteria and the programs is highlighted in order to obtain adequate results regarding the evaluation of the programs (Kumar & Routroy , 2017b).

One way to evaluate supplier performance is to use multi-criteria decision-making methods (from the English *Multi-criteria Decision -Making,* MCDM) , which help to formalize and structure the decision-making process. Mathematical programming methods and approaches based on computational techniques and artificial intelligence (AI), such as those based on *fuzzy logic, are also used* (Glock et al., 2017; Resende et al., 2023) .

Table 1 presents the models for PDF evaluation identified in the literature, classifying them according to their support for group decision-making and the possibility of using linguistic terms for evaluation. Despite the various contributions of the studies shown in Table 1, among the 11 models identified, only seven provide support for group decision-making and two allow the weighting of decision-makers' opinions. Furthermore, although there are six models that enable the use of linguistic terms by decision-makers, none of them allow the use of linguistic expressions or the use of two or more terms simultaneously, which is desirable in cases where there is a lack of complete information for decision-making and hesitation in issuing judgments (Finger & Lima, 2022). The use of the HFLS-QFD method has the potential to overcome these limitations.

Table 1

Characteristics of decision models for evaluating PDF

Authors	Decision techniques	Supports group decision making	Consider the opinions of decision makers	Use of linguistic judgments
Bai and Sarkis (2010)	*Rough Set Theory*	No	No	No
Routroy et al. (2016)	*GTA (Graph Theoretical Approach)*	Yes	No	No
Kumar and Routroy (2017a)	*PVA (Performance Value Analysis)*	Yes	No	No
Pradhan e Routroy (2018)	*ISM (Interpretive Structural Modeling)*	No	No	No
Bai e Sarkis (2011)	*Grey System Theory e Rough Set Theory*	Yes	Yes	Yes
Fu et al. (2012)	*Grey System Theory* e *DEMATEL*	Yes	Yes	Yes
Routroy and Pradhan (2014)	*AHP and PVA*	No	No	No
Dou et al. (2015)	*Fuzzy Scoring and Fuzzy DEMATEL*	No	No	Yes
Kumar and Routroy (2017b)	*Fuzzy AHP and Fuzzy Weighted Average*	Yes	No	Yes
Forooresh e Tavakkoli-Moghaddam (2018)	*Interval-Valued Fuzzy Sets, Possibility Theory and TOPSIS*	Yes	No	Yes
Pourjavad and Shahin (2020)	*Fuzzy DEMATEL, AHP and TOPSIS*	Yes	No	Yes

Source: Own authorship (2024)

3 METHOD

The research in question is characterized as a normative axiomatic quantitative research , which aims to build a quantitative model that meets the existing needs of companies in PDFS assessments. The research procedures used in the work can be grouped into four stages:

i. The objective of this stage was to conduct a literature review on supplier development, multicriteria methods and the HFLTS-QFD method. By consulting the *Science Direct* , *Emerald* , *Scopus* , *Web of Science* and *Google Scholar databases* , a survey of the bibliography was carried out in order to map the PDF evaluation models , in order to identify the metrics used to evaluate the PDFs and the quantitative methods already used, which based the entire development of the subsequent stages of the research;

ii. At this stage, the proposed decision model was developed and the computational model based on HFLTS-QFD was implemented with the aid of MS Excel *software* , according to the equations presented in Osiro et al. (2018). The model aims to rank the PDFs, taking into account the individual performance of the PDFs in each criterion evaluated, as well as the respective weights of the criteria and decision makers;

iii. At this stage, the model was applied to a case in order to demonstrate the applicability of the proposed model, considering a set of metrics and PDFS defined based on the studies in Table 1;

iv. Finally, the results were tabulated and analyzed, followed by the conclusion.

The method proposed by Osiro et al. (2018) was adopted in this study because it allows the evaluation of criteria, requirements, and PDFS in group decision-making processes, using hesitant linguistic judgments. In this method, to prioritize the requirements and criteria, the HFLTS distance measurement method is applied. It is also possible to consider different weights for the decision-makers' judgments (according to their level of experience and/or knowledge about the problem), in addition to being able to consider the degree of difficulty associated with data collection as a decision factor in choosing the criteria. According to Osiro et al. (2018), the four steps to implement the HFLTS-QFD approach are:

1. First step: decision makers, using the " *what* " matrix, establish a set of sustainability requirements that will be transformed into HFLTS, according to linguistic terms and expressions;
2. *how "* matrix , decision makers must define a set of criteria related to the requirements selected in step 1. Subsequently, they must evaluate the intensity of the relationship between the criteria and requirements;
3. Third stage: the degree of difficulty of data collection must be estimated to evaluate the alternatives in relation to each criterion, considering supplier acceptance, implementation cost and degree of difficulty of the technique;
4. Fourth step: finally, the final set of metrics in the matrix must be categorized and selected considering the results of steps 2 and 3, in order to select which ones will be used to evaluate suppliers.

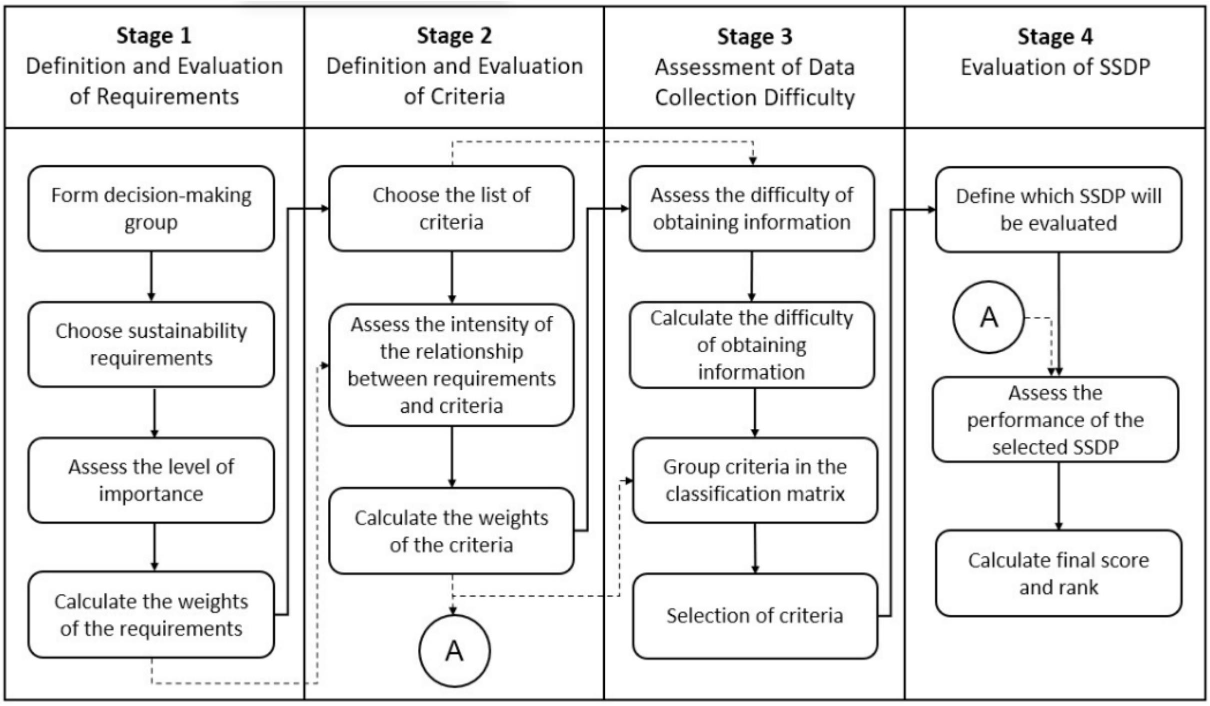
The equations used in this study are presented in detail in Osiro et al. (2018).

4 PROPOSED MODEL FOR PDF EVALUATION

The proposed model to support the evaluation process of sustainable supplier development programs (SDPs) consists of four stages, as illustrated in Figure 1. This model was developed based on the studies proposed by Rodriguez et al. (2012), Zimmer et al. (2016), Glock et al. (2017) and Osiro et al. (2018). In stage 1, decision makers will select among the sustainability requirements (economic, environmental and social requirements) which ones they wish to improve regarding their supplier(s). In stage 2, an intensity analysis is performed between the criteria listed in this stage and the requirements previously selected. In stage 3, the difficulty of obtaining information to evaluate the SDPs in each criterion is assessed, and which criteria will be considered in the evaluation are defined. Finally, in stage 4, the development programs are evaluated based on the selected criteria and, based on their overall score, they are ranked. Each stage of the proposed model will be described in more detail in the following application.

Figure 1

Proposed model for evaluating sustainable supplier development programs



Note: Solid arrows: sequence of activity execution; Dotted arrows: data flow between steps.

An illustrative application was developed considering the context of an automotive assembly company. This company needs to evaluate the PDFS that have already been or are being implemented at a supplier, in order to verify which of these is performing best and, from then on, make the next appropriate management decisions in each case. The programs that the company currently implements cover the three pillars of sustainability and are presented below:

1. PDFS $_1$: Board involvement in developing products with lower environmental impact and support for entering new markets (Finger & Lima, 2022);

2. PDFS $_2$: Creation of a product traceability system to identify batches with problems and improve internal and external logistics flow (Resende et al., 2019);
3. PDFS $_3$: Practices for increasing energy efficiency (Finger & Lima, 2022);
4. PDFS $_4$: Program to increase safety and hygiene in factories for workers and reduce work accidents (Resende et al., 2019);
5. PDFS $_5$: Financially support educational and cultural activities to improve the quality of life of local communities (Resende et al., 2019).

Following stage 1 of the model, three decision makers from the areas of research and development (R&D), social responsibility, and operations management were selected and tasked with determining the purchasing company's requirements regarding the capabilities that need to be improved in a supplier through the implementation of PDFS. The decision makers then assessed the level of importance of each of the requirements using a set of seven linguistic terms and linguistic expressions as presented in Rodriguez et al. (2012) and Finger & Lima (2022). The terms used in the four stages of the proposed model were s_0: Null (N), s_1: Very Low (MB), s_2: Low (B), s_3: Medium (M), s_4: High (A), s_5: Very High (MA), and s_6: Absolute (AB). The assessment made by the decision makers is presented in 2, already converted to the HFLTS format.

Table 2

Assessment of the level of importance of requirements

Requirements		D_1	D_2	D_3
R_{11}	Organization Management	[A, MA]	[M, A, MA]	[MA, AB]
R_{12}	Financial Performance	[M, A, MA]	[A, MA]	[A, MA]
R_{21}	Environmental Practices	[M, A, MA]	[A, MA, AB]	[A, MA, AB]
R_{22}	Environmental Performance	[M, A]	[A, MA]	[M, A, MA]
R_{32}	Social Performance	[A, MA, AB]	[M, A, MA]	[M, A, MA]
R_{33}	External Social Practices	[M, A, MA]	[THE]	[A, MA]

Source: Own authorship (2024).

Thus, the positive (SIP) and negative (SIN) ideal solutions were calculated. For SIP, we have x^+ = [[AB] [AB] [AB]], and for SIN, we obtained x^- = [[M] [M] [M]]. It was considered that the judgments of each of the decision makers have the same weight (0.333). The distances between the requirements scores and the ideal solutions were calculated ($d(x_i, x^+)$ and $d(x_i, x^-)$) . Once the distance values were defined and the decision makers' risk preference parameter θ= 0.5 (in this case representing a neutral view), the degree of satisfaction of each of the requirements ($\eta(x_i)$) was calculated and normalized ($v(x_i)$). Table 3 presents the values calculated for each of the requirements evaluated by the decision makers. The results indicate that the priority requirement is organization management (R_{11}), which is related to the economic dimension of sustainability. The second most important requirement refers to environmental practices (R_{21}), followed by social performance (R_{32}).

Table 3

Result of calculation of requirement weights

ID	$d(x_i, x^+)$	$d(x_i, x^-)$	$\eta(x_i)$	$v(x_i)$	Classification
R_{11}	0.228	0.269	0.541	0.1955	1°
R_{21}	0,233	0,274	0,540	0,1949	2°
R_{32}	0,274	0,233	0,460	0,1663	3°
R_{12}	0,256	0,213	0,454	0,1639	4°
R_{33}	0,276	0,187	0,405	0,1462	5°
R_{22}	0,305	0,178	0,369	0,1332	6°

Source: Own authorship (2024).

In step 2, decision makers defined a set of criteria related to the requirements from the previous step and assessed the degree of relationship between each of the criteria and the requirements. These assessments were converted to HFLTS format, as shown in Table 4. The calculations of the criteria weights followed the same logic as the calculations in step 1. However, the normalized weights of the requirements were used to weight the values of the intensity of the relationship between requirements and criteria. The results are presented in Table 5 , in which $w(x_i)$ indicates the normalized weights of the criteria . The criteria with the highest weight were organizational strategy (C_{11}), social responsibility (C_{39}), employee training (C_{36}), and environmental management (C_{22}).

Table 4

Converting Relationship Intensity to HFLTS Format

Criteria	R_{11}	R_{12}	R_{21}	R_{22}	R_{32}	R_{33}
C_{11} Organization Strategy	[MA, AB]	[MA, AB]	[M, A]	[B, M]	[MB, B]	[MB, B]
C_{12} Internal Management	[A, MA, AB]	[M, A]	[B, M]	[MB, B]	[B, M]	[MB]
C_{15} Costs	[I, A]	[A, MA]	[N]	[MB]	[MB, B]	[MB]
C_{16} Financial situation	[A, MA]	[A, MA]	[MB, B]	[N, MB]	[N, MB]	[N, MB]
C_{21} Environmental Commitment	[B, M]	[MB, B]	[MA, AB]	[A, MA]	[MB, B]	[MB]
C_{22} Environmental Management	[MB, B]	[N, MB]	[MA, AB]	[MA, AB]	[B]	[B]
C_{27} Water consumption	[N]	[N]	[A, MA]	[A, MA]	[MB]	[N, MB]
C_{34} Health and Safety	[MB, B, M]	[MB, B]	[MB, B]	[MB, B]	[A, MA]	[A, MA]
C_{36} Employee Training	[MB, B, M]	[MB, B]	[B, M]	[B, M]	[A, MA]	[A, MA, AB]
C_{39} Social Responsibility	[MB]	[MB]	[M, A]	[M, A]	[A, MA]	[MA, AB]

Source: Own authorship (2024).

Table 5

Results of calculating the weights of the PDFS evaluation criteria

ID	$d(x_i, x^+)$	$d(x_i, x^-)$	$\eta(x_i)$	$w(x_i)$	Classification
C_{11}	0.194	0.307	0.612	0.8481	1°
C_{39}	0.237	0.252	0.515	0.7136	2°
C_{36}	0.232	0.217	0.483	0,6557	3°
C_{22}	0,289	0,241	0,455	0,6023	4°
C_{21}	0,271	0,223	0,451	0,5941	5°
C_{12}	0,251	0,202	0,446	0,5841	6°
C_{34}	0,285	0,192	0,402	0,4941	7°
C_{16}	0,377	0,165	0.304	0.3023	8°
C_{15}	0.390	0.133	0.254	0.2224	9°
C_{27}	0.457	0.142	0.237	0.1997	10°

Source: Own authorship (2024).

In step 3, the difficulty in collecting data on supplier performance that would allow the evaluation of the results of the ongoing PDFS was assessed. This assessment is based on three aspects with the same weight (0.333): the availability of information, the human capital and time required to obtain the data, and the need for additional resources. The calculations in step 3 followed the same procedures as in steps 1 and 2. Table 6 presents a summary of the judgments collected and the results obtained, in which $c(x_i)$ is the standardized degree of difficulty in collecting data. Environmental management (C_{22}), employee training (C_{36}), and financial situation (C_{16}) obtained the highest scores in relation to the difficulty of collecting data, which indicates that these criteria are the most difficult to assess.

Table 6

Judgments on the difficulty of collecting data converted to HFLTS

ID	Information available	Human rec. and time	Additional Resources	$d(x_i, x^+)$	$d(x_i, x^-)$	$\eta(x_i)$	$c(x_i)$	Classif.
C_{11}	[M, A]	[M, A]	[MB]	0,245	1,010	0,805	0,899	1°
C_{12}	[M, A]	[B, M]	[MB]	0,548	0,787	0,590	0,702	2°
C_{15}	[MB, B]	[B]	[M, A]	0,632	0,748	0,542	0,637	3°
C_{16}	[M, A]	[M, A]	[B, M]	0,735	0,583	0,442	0,487	4°
C_{21}	[M, A]	[B, M]	[B, M]	0,787	0,616	0,439	0,482	5°
C_{22}	[M, A]	[M, A]	[A, MA]	0,872	0,600	0,408	0,434	6°
C_{27}	[B]	[MB, B]	[MB, B]	0,906	0,548	0,377	0,388	7°
C_{34}	[B, M]	[B, M]	[B, M]	0.787	0.424	0.350	0.349	8°
C_{36}	[M, A]	[M, A]	[B, M]	0.825	0.400	0.327	0.317	9°
C_{39}	[B, M]	[M, A]	[B, M]	0.959	0.283	0.228	0.201	10°

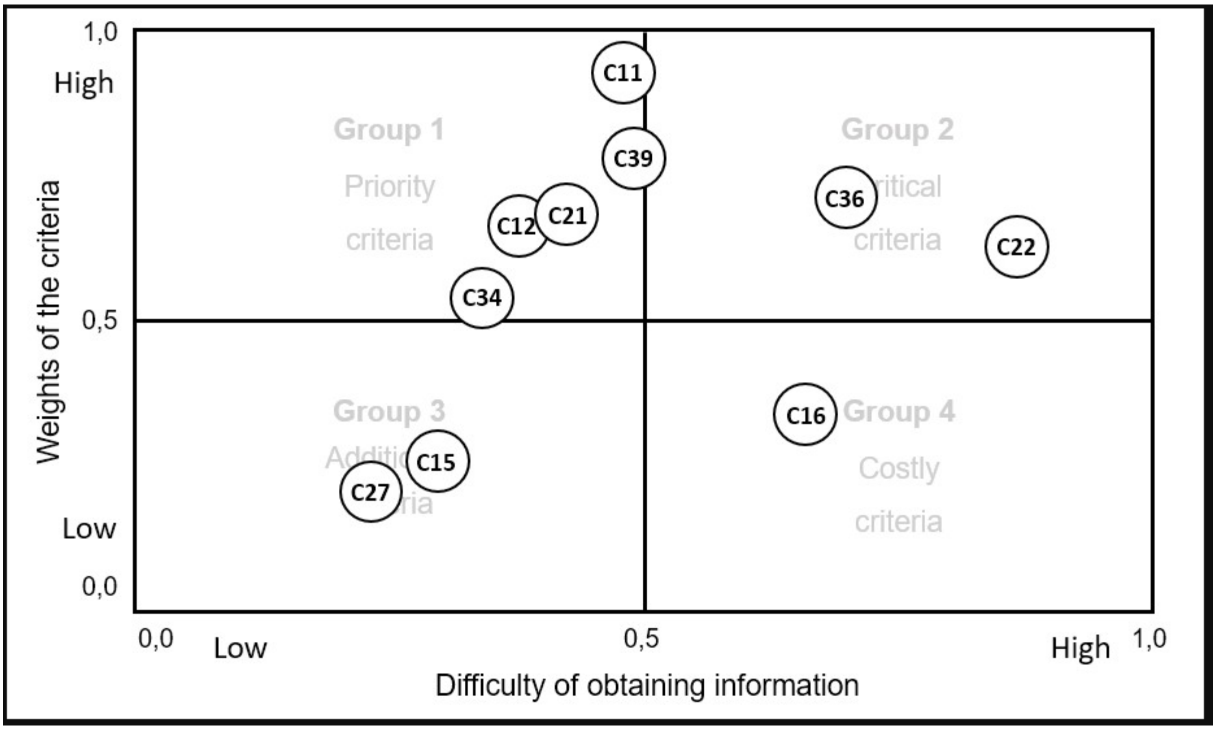
Source: Own authorship (2024)

The resulting values were grouped into a classification matrix together with the criteria weights calculated in step 2. This matrix is divided into four quadrants: priority criteria (group 1), critical (group 2), complementary (group 3) and costly (group 4). Furthermore, the threshold defined between the quadrants is 0.5, i.e., if the normalized value obtained from the calculations is equal to or greater than 0.5, the corresponding criterion will be categorized into one of the upper or right quadrants of the matrix, indicating that the criterion has a high weight and/or high difficulty in data collection.

Figure 2 illustrates the matrix with the results obtained for this case. Based on the classification obtained, the decision makers decided to select all the criteria from group 1 and discard the criteria from group 4. Regarding groups 2 and 3, it was decided to select criteria C_{36} (employee training) and C_{15} (costs) and exclude criteria C_{27} (water consumption) and C_{22} (environmental management).

Figure 2

Criteria ranking matrix



Source: Own authorship (2024)

In step 4, the decision makers evaluated a set of PDFS already implemented by the company, considering the criteria selected in step 3. Table 7 presents the decision makers' judgments regarding the performance of the PDFS, already converted to HFLTS. Next, the same calculation sequence performed in steps 1, 2 and 3 was applied. The ideal solutions were found x^+ = [[AB] [A] [A] [MA] [MA] [A] [AB]] and x^- = [[MB] [N] [MB] [N] [N] [N] [N]].

Table 7

Evaluation of PDFS converted to HFLTS

ID	C_{11}	C_{12}	C_{15}	C_{21}	C_{34}	C_{36}	C_{39}
$PDFS_1$	[MA, AB]	[M, A]	[M, A]	[MB, B]	[N]	[MB, B]	[N]
$PDFS_2$	[M, A]	[M, A]	[M, A]	[MB]	[N]	[N]	[N]
$PDFS_3$	[MB, B]	[B, M]	[B, M]	[A, MA]	[MB]	[MB, B]	[M, A]
$PDFS_4$	[MB]	[M, A]	[MB, B]	[N, MB]	[A, MA]	[M, A]	[A, MA]
$PDFS_5$	[MB, B]	[N, MB]	[MB, B]	[MB, B]	[B, M]	[M, A]	[MA, AB]

Source: Own authorship (2024)

THE Table 8 shows the main results of the PDFS evaluation. After applying the four steps, it was concluded that the best-ranked programs according to the proposed model are PDFS $_4$ and PDFS $_5$, followed by PDFS $_1$, PDFS $_3$ and PDFS $_2$. In view of this, it is recommended to continue the PDFS $_4$ and PDFS $_{5\ \text{programs}}$, since they obtained the highest final scores. It is also possible to try to improve or reformulate the programs that obtained intermediate scores (such as PDFS $_1$ and PDFS $_3$); and eliminate PDFS $_2$, since it obtained the worst performance among those evaluated.

Table 8

Classification of evaluated PDFs

ID	$d(x_i, x^+)$	$d(x_i, x^-)$	$\eta(x_i)$	$v(x_i)$	Classification
PDFS $_4$	0.351	0.388	0.526	0.2333	1st
PDFS $_5$	0.365	0.355	0.493	0.2189	2nd
PDF $_1$	0.417	0.335	0.445	0.1977	3rd
PDFS $_3$	0.370	0.291	0.440	0.1955	4th
PDFS $_2$	0.468	0.250	0.348	0.1546	5th

Source: Own authorship (2024).

5 CONCLUSION

This study proposed a decision support model for evaluating sustainable supplier development programs by combining HFLTS with the QFD method. Unlike previous similar studies, which focus on economic aspects, this study considers the three dimensions of sustainability together, incorporating requirements and criteria related to environmental and social aspects into the evaluation process. The developed model presents four logical steps that allow evaluating a set of sustainable supplier development programs considering multiple criteria, whose weights are defined based on the performance aspects that the supplier needs to improve (requirements). The criteria are selected using a classification matrix based on their weights and the degree of difficulty in obtaining information to evaluate the PDFS in each metric. These steps serve as guidance to assist decision makers in managing programs already implemented, based on factors related to the performance of each program.

Unlike the models presented by Bai and Sarkis (2010), Routroy and Pradhan (2014), Dou et al. (2015) and Pradhan and Routroy (2018), the proposed model supports group decision-making, since in the PDFS evaluation process it is necessary to take into account the opinions of decision makers from different areas of the company. In addition, the model allows different weights to be given to the judgments, according to the experience and technical knowledge of the decision makers. Furthermore, unlike previous models that allow decision-makers to use only one linguistic term to evaluate the performance of a PDFS in a given criterion (Bai & Sarkis, 2011; Routroy & Pradhan, 2014; Dou et al., 2015; Routroy et al., 2016; Kumar & Routroy, 2017b; Forooresh & Tavakkoli-Moghaddam, 2018; Pourjavad & Shahin, 2020), the proposed model allows the use of linguistic expressions to represent judgments, as well as the use of two or more linguistic terms simultaneously.

However, this study has certain limitations. One of them is that the use of an illustrative application may limit the perception and understanding of the advantages, difficulties and implications of using the model. Another difficulty may be related to the need to obtain consensus among decision makers. Finally, it is suggested that future studies apply the model to different types of supply chains in order to verify the usability of the model, as well as the frequency with which the model should be used. Another suggestion is the application of the HFLTS-QFD method in other areas of supply chain management that require support in terms of multicriteria decision making.

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REFERENCES

Araz, C., & Ozkarahan, I. (2007) Supplier evaluation and management system for strategic sourcing based on a new multicriteria sorting procedure. *International Journal of Production Economics*, 106 (2), 585-606.

Awasthi, A., & Kannan, G. (2016). Green supplier development program selection using NGT and VIKOR under fuzzy environment. *Computers & Industrial Engineering*, *91*, 100-108.

Bai, C., & Sarkis, J. (2010). Green supplier development: analytical evaluation using rough set theory. *Journal of cleaner production*, 18(12), 1200-1210.

Bai, C., & Sarkis, J. (2011). Evaluating supplier development programs with a grey based rough set methodology. *Expert Systems with Applications*, 38(11), 13505-13517.

Dou, Y., Zhu, Q., & Sarkis, J. (2014). Evaluating green supplier development programs with a grey-analytical network process-based methodology. *European Journal of Operational Research*, *233*(2), 420-431.

Dou, Y., Zhu, Q., & Sarkis, J. (2015). Integrating strategic carbon management into formal evaluation of environmental supplier development programs. *Business Strategy and the Environment*, *24*(8), 873-891.

Finger, G. S. W., & Lima Junior, F. R. (2022). A hesitant fuzzy linguistic QFD approach for formulating sustainable supplier development programs. *International Journal of Production Economics, 247*, 108428.

Foroozesh, N., & Tavakkoli-Moghaddam, R. (2018). Assessment of green supplier development programs by a new group decision-making model considering possibilistic statistical uncertainty. *Journal of Quality Engineering and Production Optimization*, *3*(2), 1-10.

Fu, X., Zhu, Q., & Sarkis, J. (2012). Evaluating green supplier development programs at a telecommunications systems provider. *International Journal of Production Economics*, *140*(1), 357-367.

Glock, C. H., Grosse, E. H., & Ries, J. M. (2017). Decision support models for supplier development: Systematic literature review and research agenda. *International Journal of Production Economics*, 193, 798-812.

Kumar, C. S., & Routroy, S. (2017a). Analyzing a manufacturer’s returns from supplier development programs. *Materials Today: Proceedings*, *4*(2), 2255-2262.

Kumar, C. S., & Routroy, S. (2017b). Performance analysis of supplier development programs. *Benchmarking: An International Journal*, 24(2), 488-510.

Lima Junior, F. R., Oliveira, M. E. B., & Resende, C. H. L. (2023). An overview of applications of hesitant fuzzy linguistic term sets in supply chain management: The state of the art and future directions. *Mathematics,* 11(13).

Omurca, S.I. (2013). An inteligente supplier evaluation, selection and development system. *Applied Soft Computing*, 13(1), 690–697.

Osiro, L., Lima-Junior, F. R., & Carpinetti, L. C. R. (2018). A group decision model based on quality function deployment and hesitant fuzzy for selecting supply chain sustainability metrics. *Journal of Cleaner Production*, *183*, 964-978.

Pourjavad, E., & Shahin, A. (2020). Green supplier development programmes selection: a hybrid fuzzy multi-criteria decision-making approach. *International Journal of Sustainable Engineering*, 1-10.

Pradhan, S. K., & Routroy, S. (2018). Improving supply chain performance by Supplier Development program through enhanced visibility. *Materials Today: Proceedings*, *5*(2), 3629-3638.

Resende, C. H. L., Lima Junior, F. R., & Carpinetti, L. C. R. (2023). Decision-making models for formulating and evaluating supplier development programs: A state-of-the-art review and research paths. *Transportation Research Part E: Logistics and Transportation Review, 180*.

Rezaei, J., & Ortt, R. (2013) Supplier segmentation using fuzzy logic. *Industrial Marketing Management*, 42(4), 507–517.

Rodriguez, R. M., Martinez, L., & Herrera, F. (2012). Hesitant fuzzy linguistic term sets for decision making. *IEEE Transactions on Fuzzy Systems*, 20,1,109–119.

Routroy, S., & Pradhan, S. K. (2014). Analyzing the performance of supplier development: a case study. *International Journal of Productivity and Performance Management*, 63(2), 209-233.

Routroy, S., Pradhan, S. K., & Kumar, C. S. (2016). Evaluating the implementation performance of a supplier development program. *Asia Pacific Journal of Marketing and Logistics*, 28(4), 663-682.

Sarkar, A., & Mohapatra, P.K.J. (2006) Evaluation of supplier capability and performance: a method for supply base reduction. *Jornal Purchasing and Supply Management*, 12(3), 148–163.

Schmidt, C. G., Foerstl, K., & Schaltenbrand, B. (2017). The supply chain position paradox: green practices and firm performance. *Journal of Supply Chain Management*, 53(1), 3-25.

Zimmer, K., Fröhling, M., & Schultmann, F. (2016). Sustainable supplier management–a review of models supporting sustainable supplier selection, monitoring and development. *International Journal of Production Research*, 54(5), 1412-1442.