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Review

An Overview of Applications of Hesitant Fuzzy Linguistic Term Sets in Supply Chain Management: The State of the Art and Future Directions

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Abstract: Supply chain management (SCM) encompasses a wide variety of decision-making problems that affect business and supply chain performance. Since most of these problems involve uncertainty and hesitation on the part of decision makers (DMs), various studies have emerged recently that present SCM applications of techniques based on Hesitant Fuzzy Linguistic Term Sets (HFLTSs) and HFLTS extensions. Given the relevance of this subject and the lack of literature review studies, this study presents a systematic review of HFLTS and HFLTS extension applications to SCM decision-making problems. In order to answer a set of research questions, the selected papers were classified in accordance with a group of factors that are pertinent to the origins of these studies, SCM, HFLTSs, and decision making. The results demonstrated that the Source and Enable processes have been studied with greater frequency, while the most common problems have to do with supplier selection, failure evaluation, and performance evaluation. The companies of the automotive sector predominated in the analyzed studies. Even though most of the studies used techniques based on HFLTSs, we identified applications of seven distinct HFLTS extensions. The main contribution of this study consists of presenting an overview of the use of HFLTSs and their extensions in practical examples of SCM, highlighting trends and research opportunities. It is the first study to analyze applications of decision-making techniques that deal with hesitation in SCM. Therefore, the results can help researchers and practitioners develop new studies that involve the use of HFLTSs and HFLTS extensions in decision-making problems, given that this study systematizes elements that should be considered in the modeling, application, and validation of these methods.

Keywords: multicriteria decision making; systematic literature review; operations management; fuzzy logic; group decision making

MSC: 90B50

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1. Introduction

The importance of SCM is recognized by researchers and practitioners as a way to ensure operational efficiency and seek global growth, increased profitability, and stakeholder satisfaction [1,2]. Various studies have corroborated the fact that company performance for supply chain members can be improved by better strategic management of the flow of goods, services, finance, and information throughout the supply chain as a whole [1,3]. In addition to seeking a reduction in costs and improved goods and services, current SCM practices frequently seek to help firms comply with socio-environmental requirements [4] and develop resilient capacities to prevent and/or overcome operational disruptions [2].

Given that SCM requires the integration and alignment of the activities of factories, suppliers, and distributors as well as other chain components, various challenges emerge and contribute to increasing complexity [3]. One of the main difficulties is related to making assertive decisions in the face of the uncertainties that frequently affect the business environment [2]. These uncertainties are due to a wide range of factors, including fluctuations in demand, changes in stakeholder requirements and competition, political conflicts, infectious diseases, and catastrophic events such as earthquakes and hurricanes [5]. As a consequence, the difficulty of obtaining reliable, complete, and updated information leads to many SCM decisions being made based on the knowledge of specialists (or decision makers (DMs)) [6]. In this scenario, quantitative decision-making techniques that use DM linguistic evaluations have been adopted increasingly often in making decisions that are inherent to SCM, such as supplier selection [7] supplier development [8], the selection of emergency logistic plans [9], and risk evaluations [10], among other issues.

The literature features a wide variety of approaches to modeling linguistic information that have been employed to support SCM, with those based on Fuzzy Set Theory (as well as the most recent extensions of this theory) playing a prominent role [11–13]. Among these extensions, Hesitant Fuzzy Linguistic Term Sets (HFLTSs) have been attracting increasing attention. In contrast to traditional decision-making methods, the use of HFLTSs supports complex linguistic expressions when DMs are hesitant to choose the linguistic terms that best represent their preferences [12]. Ever since HFLTSs were proposed by Rodríguez et al. [14], there have been various advances by other researchers that have led to the appearance of extensions such as Extended HFLTSs [15], Proportional HFLTSs [16], and Interval-Valued 2-Tuple HFLTSs [17]. In parallel, a wide array of decision-making processes based on a combination of HFLTSs and MCDM methods have appeared [18,19]. In addition to their being suitable in helping DMs deal with uncertainty and hesitation, the use of HFLTS approaches frequently is justified by their ability to support group decision-making (GDM) processes that are recurrent in SCM [14].

Given the relevance of SCM, there have been a variety of studies devoted to reviews of this subject's literature, including those focused on approaches to managing supply chain risks [2], SCM artificial intelligence techniques [13], SCM machine learning methods [5], supply chain performance evaluation models [6,13], and the application of fuzzy logic in supply chains [20,21], among other areas. However, to the best of our knowledge, there are no reviews of the literature focused on the application of HFLTS techniques to problems inherent to SCM.

Using searches of the ACM Digital Library, EBSCO, El Compendex, Emerald Insight, Google Scholar, IEEE Digital, Science Direct, Scopus, Springer, Taylor & Francis, Web of Science, and the Wiley Online Library databases, we found five literature review studies that covered HFLTSs. Based on Table 1, we may observe that most of the literature review studies that involve HFLTSs are devoted to compiling a comprehensive review of existing theoretical developments to compare linguistic information modeling approaches [11,12,22,23]. There is also a bibliometric review based on metadata from 1080 studies of Hesitant Fuzzy Sets (HFSs) and their extensions [24]. Even though these studies are of great importance in summarizing theoretical knowledge about linguistic information modeling, they do not discuss HFLTS applications to practical problems. Moreover, the conducting of a systematic review of the literature focusing on HFLTS applications for SCM is justified for the following reasons:

1. There is a need to map the contexts in which HFLTS techniques have been applied in order to identify which SCM processes have received the most attention, which are the most studied types of SCM strategies, and which economic sectors are represented by the participating companies in these studies. The realization of a systematic review of this subject has the potential to make a contribution for researchers and practitioners by indicating trends and opportunities for future study;
2. It is important to investigate issues regarding SCM decision-making processes and methods; for example, the types of decision-making problems in which HFLTS techniques are applied, the most often used techniques, and the way the application results are validated. Furthermore, since the use of criteria weights influences the results of

the decision-making problem, it is important to analyze how criteria weighting has been addressed in HFLTS applications and its extensions in SCM;

3. As decision-making processes in SCM usually involve a variety of actors inside and outside of companies, it is relevant to verify whether the adopted methods support GDM or not. In addition, it is important to analyze how they deal with weighting the opinion of decision-makers and whether they provide support for achieving consensus among DMs. Despite the importance of these issues, the factors related to GDM have been omitted in most literature reviews regarding decision making and SCM [6,11–13,22–24];
4. Furthermore, the literature lacks studies that map recent HFLTS extensions and discuss their applications. The present study made it possible to indicate which HFLTS extensions have been most studied in SCM and point out potential areas for the application of HFLTS extensions in future studies. In addition to contributing to the generation of knowledge related to the interface between SCM areas and decision making, the mapping of the state of the art of this subject will also indicate paths for the development of new computational tools that can support managers in SCM decision-making processes.

Table 1. Literature review studies that encompass HFLTSs.

	Liao et al. [22]	**Morente-Molinera et al. [23]**	**Wang et al. [11]**	**Wang et al. [12]**	**Yu et al. [24]**
Focus	Survey of decision-making theory and HFLTS methodologies	Review of approaches to multi-granular fuzzy linguistic modeling	Review of HFLTS developments and their classification according to computational strategies	Mapping of complex modeling techniques that employ linguistic expressions	Bibliometric analysis of 1080 articles about HFSs and their extensions
Approaches analyzed	HFLTSs, fusion theory, and Hesitant Fuzzy Linguistic preference relationship theory, among others	Fuzzy membership functions, HFLTSs, 2-tuples, and discrete fuzzy numbers, among others		HFLTSs, EHFLTSs, linguistic HFSs, and 2-dimensional linguistic terms, among others	Aggregation operators, information measures, preference relationships, and HFS extensions
Analysis of applications	No	No	Identifies 20 applications in various areas	No	No
Comparison between approaches	Yes	Yes	Yes	Yes	No

Given this information, this study will present a systematic review of the literature about HFLTS and HFLTS extension applications developed to solve SCM decision-making problems in order to answer relevant research questions about this subject (which will be detailed in Section 3). The Preferred Reporting Items for Systematics Reviews and Meta-Analyses (PRISMA) method was adopted to structure this study. The analyzed papers were selected from several databases and classified according to 17 factors. The mapping of these studies made it possible to identify a set of opportunities for the realization of future studies. In terms of the structure of the rest of this article, Section 2 will present a brief review of HFLTSs and HFLTS extensions, Section 3 will describe the methodology for this systematic review of the literature, Section 4 will discuss the results, Section 5 will present recommendations for future studies, and Section 6 will consist of our conclusions and the limitations of this study.

2. HFLTSs and HFLTS Extensions

Ever since it was proposed by Lofti [25], Fuzzy Set Theory has been applied successfully to various problems that involve imprecise, vague, and imperfect information [14,26]. This theory is also the foundation of new approaches to deal with decision-making problems under conditions of uncertainty. These approaches are based on various forms of representing information that are used by DMs to express their preferences [16,27].

Based on Fuzzy Set Theory, Torra [28] proposed Hesitant Fuzzy Set Theory, which provides a framework for supporting DMs in situations in which there are a set of possible values to define the membership of an element. Based on the work of Torra [28], Rodríguez et al. [14] proposed HFLTSs, which differ from previous approaches because they allow DMs to use more than one linguistic term and complex linguistic expressions to represent their preferences. In this manner, HFLTSs offer greater flexibility in eliciting linguistic preferences and at the same time support expressions that are closer to natural language [29].

Considering a set of defined linguistic terms such as $\mathrm{S} = \{\mathrm{s}_{-\tau}, \cdots, \mathrm{s}_0, \cdots, \mathrm{s}_\tau\} = \{\mathrm{s}_{-2} : \text{very low}, \mathrm{s}_{-1} : \text{low}, \mathrm{s}_0 : \text{medium}, \mathrm{s}_1 : \text{high}, \mathrm{s}_2 : \text{very high}\}$, as shown in Figure 1a, an HFLTS defined as $\mathrm{HS}(\vartheta) = \{\mathrm{s}_\mathrm{i} | \mathrm{s}_\mathrm{i} \in \mathrm{S}\}$ consists of a finite ordered subset of linguistic terms of S. Thus, $\mathrm{HS}(\vartheta) = \{\mathrm{s}_{-2} : \text{very low}, \mathrm{s}_{-1} : \text{low}\}$ (Figure 1b) and $\mathrm{HS}(\vartheta) = \{\mathrm{s}_{-1} : \text{low}, \mathrm{s}_0 : \text{medium}, \mathrm{s}_1 : \text{high}\}$ are examples of HFLTS. Any other HFLTS consists of at least one of the linguistic terms in S [14]. The HFLTS approach makes it possible for DMs to use linguistic expressions that employ more than one linguistic term simultaneously in each judgment. Examples of linguistic expressions include "at least high" $\{\mathrm{s}_1, \mathrm{s}_2\}$ (Figure 1c), "between very low and low" $\{\mathrm{s}_{-2}, \mathrm{s}_{-1}\}$, "at most medium" $\{\mathrm{s}_{-2}, \mathrm{s}_{-1}, \mathrm{s}_0\}$, and "lower than high" $\{\mathrm{s}_2\}$ [8,29]. Based on the pioneering work of Rodríguez et al. [14], other authors proposed new operators for HFLTSs [30–32], measures of distance and similarity [33,34], techniques that support GDM [18,19], and consistency and consensus methods for group decision making [35], among other advances. Extensions for HFLTSs also appeared, which opened new possibilities for modeling uncertainty in decision-making processes. Table 2 presents examples of the main HFLTS extensions that are described below:

1. Extended HFLTS (EHFLTS): this makes it possible to create sets of non-consecutive ordered terms based on a combination of HFTLSs given by a group of DMs. As indicated in Equation (1) (Table 1), $S = \{\mathrm{s}_{-\tau}, \cdots, \mathrm{s}_0, \cdots, \mathrm{s}_\tau\}$ represents the set of all possible linguistic terms that express the preferences of the DMs, and s_i indicates each of the linguistic terms chosen by them [15]. An EHFLTS can be especially useful in situations in which the DMs are divided into subgroups and there is no consensus among the DMs, which therefore leads to the need to represent evaluations in non-consecutive terms [44];
2. Hesitant Intuitionistic Fuzzy Linguistic Term Set (HIFLTS): this approach deals with situations in which the DMs evaluate each alternative using a possible linguistic interval and an impossible linguistic interval. As presented in Equation (2), each HIFLTS is composed of the functions h and h', which return finite ordered subsets of consecutive linguistic terms. $h(x)$ and $h'(x)$ indicate the respective possible membership degrees and non-membership degrees of element x and an HIFLTS [18];
3. Interval-Valued Hesitant Fuzzy Linguistic Set (IVHFLS): this is an HFLTS extension based on Interval-Valued HFSs. As shown in Equation (3), IVHFLSs incorporate the possible interval-valued membership degrees that an alternative has in relation to a linguistic term. These membership degrees are quantified by finite numbers of closed intervals that are defined in (0, 1] [36];
4. Proportional HFLTS (PHFLTS): this is formed by the union of the HFLTSs that correspond to the individual assessments of the DMs, which can contain consecutive or non-consecutive linguistic terms. It takes into account proportional information for each generalized linguistic term. As indicated in Equation (4), each linguistic term that makes up an PHFLTS is associated with a p_l value, which denotes the degree of possibility that the alternative carries an assessment value s_l provided by a group of DMs [16]. The values are computed as a function of the terms and values of p_l;
5. Probabilistic Linguistic Term Set (PLTS): this approach adds probability distributions to an HFLTS in order to prevent the loss of any linguistic information provided by the DMs. Thus, PLTSs allow DMs to attribute possible linguistic values to an alternative or criterion at the same time that they reflect the probabilistic information of a group of attributed values. In Equation (5), $\mathrm{L(k)(p(k))}$ is made up of the linguistic term

$L(k)$, which is associated with the probability $p(k)$, and $\#L(p)$ is the total number of different linguistic terms in $L(p)$ [37];

6. Interval-Valued Dual Hesitant Fuzzy Linguistic Set (IVDHFLTS): this considers a function for the possible membership degrees and another function for the possible degrees that do not belong to the $s_{\theta(x)}$ terms selected by the DMs. In Equation (6), $\widetilde{h}(x)$ is a set of closed interval values defined in [0, 1], which denote the possible membership degrees of $s_{\theta(x)}$, and $\widetilde{g}(x)$ is a set of closed interval values defined in [0, 1] which represent the possible non-membership degrees [38];
7. Multi-Hesitant Fuzzy Linguistic Term Set (MHFLTS): this is an extension based on HFLTS and HFL elements in which each set can contain repeated and non-consecutive linguistic terms. As shown in Equation (7), considering the sets of terms $\hat{S} = \{s_k | k \in [0, l]\}$ and X as the reference set, an MHFLTS in X is represented by a function H_{MS}, which generates a finite ordered multi-subset of $\hat{S}$. $H_{MS}(x)$ indicates the possible membership degrees of element x in X [39];
8. Double Hierarchy Hesitant Fuzzy Linguistic Term Set (DHHFLTS): this is composed of two independent hierarchies of linguistic terms. As presented in Equation (8), considering $S = \{s_t | t = -\tau, \ldots, -1, 0, 1, \ldots, \tau\}$ as the first hierarchy and $O = \{o_k | k = -\varsigma, \ldots, -1, 0, 1, \ldots, \varsigma\}$ as the second, $s_{t<o_k>}$ is defined as a DHHFLTS in which o_k is the second term of the hierarchy when the first term is s_t. The use of this approach makes it possible for DMs to use expressions such as "very very good", "medium or just right", and "between a little bad and very bad" [40];
9. Hesitant Fuzzy 2-Dimension Linguistic Term Set (HF2DLTS): this was proposed based on the concept of two-dimensional linguistic variables. Each set is made up of possible linguistic terms that represent a DM's assessment of an alternative, with each term having a degree of importance denoted by a linguistic term. As represented in Equation (9), if X is a fixed set and $S^{(1)} = \left\{\dot{s}_0, \dot{s}_1, \dot{s}_1, \ldots, \dot{s}_{g-1}\right\}$ and $S^{(2)} = \left\{\ddot{s}_0, \ddot{s}_1, \ddot{s}_1, \ldots, \ddot{s}_{t-1}\right\}$ are two sets of linguistic terms, each HF2DLTS has a function $\hat{h}_s(x) = \bigcup_{(\dot{s}_a(x), \ddot{s}_b(x)) \in \hat{h}_s(x)} \left\{\left(\dot{s}_a(x), \ddot{s}_b(x)\right)\right\}$, $\dot{s}_a(x)$ is a set of consecutive terms in $S^{(1)}$, and $\ddot{s}_b(x)$ is a two-dimensional piece of linguistic information that expresses a DM's assessment of the importance of $\dot{s}_a(x)$. The adoption of this approach enables DMs to use linguistic expressions such as "it is certain ($\ddot{s}_4$) that ($\dot{s}_3$) is fair" and "it is uncertain ($\ddot{s}_2$) whether ($\ddot{s}_4$) is very good" [41];
10. Probabilistic Hesitant Intuitionistic Linguistic Term Set (PHILTS): this arose from the combination of HIFLTS and PLTS to reflect the probabilities of DM assessments. Thus, as shown in Equation (10), this approach takes into account membership probability data $(l(x)p(x))$ and non-membership probability data $(l'(x)p'(x))$, with these probabilities being considered independent [27];
11. Interval-Valued 2-Tuple HFLTS (IV2THFLTS): this is a combination of HFLTS with interval numbers. As presented in Equation (11), each IV2THFLTS has a function $\widetilde{I}_A(x)$, defined in a closed subinterval of [0, 1], which denotes the possible interval-valued membership degrees of x in $h_s(x)$. This approach helps DMs avoid a loss in information and improves the accuracy of the decision-making results [17];
12. Dual HFLTS (DHFLTS): this is the result of a combination of HFLTSs and Dual HFSs. As shown in Equation (12), DHFLTSs include the possible membership and non-membership degrees of hs(*xi*) in the set *S*. It is useful in very risky decision-making situations in which DMs consider not only the advantages of a decision but also the risks of making this decision [42];

13. Hesitant Picture Fuzzy Linguistic Set (HPFLTS): this is based on Picture 2-Tuple Linguistic Term Sets and arose to avoid the loss of DM information. In Equation (13), each term selected by the DM $\left(s_i^k\right)$ is accompanied by the crisp values of the positive membership degrees $\left(\mu_i^k\right)$, of the undetermined membership degrees $\left(\eta_i^k\right)$, and the negative membership degrees $\left(\nu_i^k\right)$ [43]. Another distinguishing characteristic is that this approach takes into account the refusal information concerning DMs for each assessment.

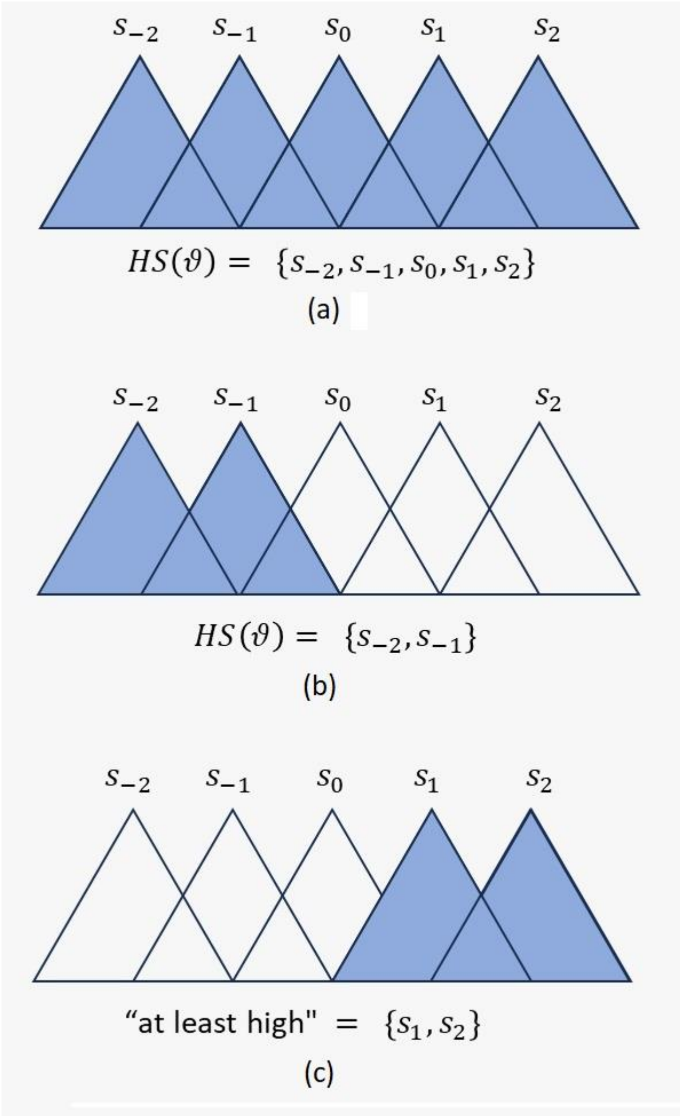


Figure 1. (**a**) Basic Set of Linguistic Terms, (**b**) Examples of Linguistic Terms, and (**c**) Linguistic expressions.

More information about HFLTS extensions can be consulted in the references indicated in Table 2. It is important to emphasize that even though the research presented in Table 2 provides an overview of HFLTS extensions, it is not exhaustive, given that there are other variations that have recently appeared based on the presented approaches.

The following section will present the methodological procedures adopted in this systematic review of the literature.

Table 2. Summary of HFLTS extensions.

ID	Approaches	Author(s)	Mathematical Representation		Example
1	EHFLTS	Wang [15]	$\{s_i \mid s_i \in S\}$	(1)	$\{s_2, s_4, s_5\}$
2	HIFLTS	Beg and Rashid [18]	$\{\langle x, h(x), h'(x)\rangle \mid x \in X\}$	(2)	$\langle (s_1, s_2, s_3)(s_3, s_4)\rangle$
3	IVHFLS	Wang et al. [36]	$\left\{\left\langle x, s_{\theta(x)}, \Gamma_A(x)\right\rangle \middle\| x \in X\right\}$	(3)	$\langle s_5, \{[0.4, 0.5], [0.6, 0.7]\}\rangle$
4	PHFLTS	Chen et al. [16]	$\{(s_i, p_i) \mid s_i \in S, i = 0, 1, \ldots, g\}$	(4)	$\{(s_4, 0.2), (s_6, 0.6)\}$
5	PLTS	Pang et al. [37]	$\left\{L^{(k)}\left(p^{(k)}\right) \middle\| L^{(k)} \in S, p^{(k)} \geq 0, k = 1, 2, \ldots, \#L(p), \sum_{k=1}^{\#L}(p)p\right\}$	(5)	$\{s_4(0.1), s_5(0.65), s_6(0.2)\}$
6	IVDHFLTS	Qi et al. [38]	$\left\{\left\langle x, s_{\theta(x)}, \tilde{h}(x), \tilde{g}(x)\right\rangle \middle\| x \in X\right\}$	(6)	$\{s_3\{[0.4, 0.4], [0.5, 0.5]\}, \{[0.3, 0.3], [0.4, 0.4]\}\}$
7	MHFLTS	Wang et al. [39]	$\{\langle x, h_{MS}(x)\rangle \mid x \in X\}$	(7)	$\{s_1, s_3, s_{54}\}$
8	DHHFLTS	Gou et al. [40]	$S_o = \{S_{t<o_k>} \mid t = -\tau, \ldots, -1, 0, 1, \ldots, \tau; k - \varsigma, \ldots, -1, 0, 1, \ldots, \varsigma\}$	(8)	$\{s_{2<o_1>}, s_{3<o_0>}\}$
9	HF2DLTS	Liu et al. [41]	$\left\{\left\langle x, \hat{h}_S(x)\right\rangle \middle\| x \in X\right\}$	(9)	$\{(\dot{s}_3, \ddot{s}_4), (\dot{s}_4, \ddot{s}_4), (\dot{s}_5, \ddot{s}_3)\}$
10	PHILTS	Malik et al. [27]	$\{\langle x, l(x)p(x), l'(x)p'(x)\rangle \mid s_i \in S\}$	(10)	$\{s_2(0.4), s_3(0.1), s_4(0.35)\}, \{s_4(0.3), s_5(0.4)\}$
11	IV2THFLTS	Si et al. [17]	$\left\{\left\langle x, h_s(x), \tilde{I}_A(x)\right\rangle \middle\| x \in X\right\}$	(11)	$\langle\{s_3, s_4\}, [0.7, 0.8]\rangle$
12	DHFLTS	Zhang et al. [42]	$\{\langle x_i, H_s(x_i), h_s(x_i), g_s(x_i)\rangle \mid x_i \in X\}$	(12)	$\{s_2\{0.7, 0.5, 0.3\}\{0.3, 0.2\}, s_3\{0.6, 0.4\}\{0.4, 0.2\}\}$
13	HPFLTS	Yang et al. [43]	$\left\{\left\langle \left(s_i^k\right), \left(\mu_i^k, \eta_i^k, \nu_i^k\right)\right\rangle \middle\| i \in x(0, 1, \ldots, m); k = 1, 2, \ldots, \alpha\right\}$	(13)	$\{(s_2, (0.7, 0, 0)\}$

3. Methodological Procedures

This systematic review of the literature was developed using the PRISMA methodology. According to Page et al. [45], literature review studies "can provide a synthesis of the status of knowledge in a field, from which future priorities can be identified". The PRISMA methodology provides a guide for the preparation of transparent, complete, and concise reviews. It provides an evidence-based minimum set of items that help ensure the robustness and reliability of systematic literature review studies [45].

Figure 2 illustrates the steps of the research method adopted in this study. Stage 1 encompassed the conception and planning of the present study. Stage 2 involved searching, selecting, and ranking studies, while Stage 3 focused on reporting results and identifying opportunities for further research. In Stage 1, based on the analysis of the literature related to SCM and HFLTS (Step 1.1), we identified the need to carry out a systematic review concerning HFLTSs and HFLTS extension applications in SCM (Step 1.2).

Then, we developed the research protocol (Step 1.3) presented in Table 3 based on the PRISMA methodology. For this protocol, the Population, Intervention, Comparison, and Outcome (PICO) were initially specified according to PRISMA [45]. A set of research questions was defined by the authors based on the motivations presented in topics 1 to 4 of the fifth paragraph of Section 1. The research questions RQ1.1 to RQ1.4 dealt with information related to the origin of the selected studies, RQ2.1 to RQ2.4 investigated questions related to SCM, and RQ3.1 to RQ3.8 were focused on questions regarding HFLTSs and decision making. The investigation of these research questions made it possible to provide an overview of the use of HFTLS and HFLTS extension techniques in SCM.

Table 3. Research Protocol Developed for this Study.

Stages	Research Elements	Description
1. Conception and planning	Population	Studies that present decision-making problems in SCM.
	Intervention	HFLTS and HFLTS extension techniques.
	Comparison	Factors related to the origin of these studies, SCM, HFLTSs, and decision making.
	Outcome	- Mapping of the use of HFLTS-based techniques in SCM problems. - Identification of research trends and gaps. - Proposal of directions for future studies.
	Research questions	RQ1.1. What has been the trend in terms of the number of publications since 2012? RQ1.2. Which countries stand out in terms of the production of articles on this subject? RQ1.3. Which journals have published more studies about this subject? RQ1.4. Which are the most cited studies? RQ2.1. What has been the focus of HFLTS techniques in SCM-related problems? RQ2.2. Which SCM processes have received the most attention among the analyzed studies? RQ2.3. With what frequency are these studies devoted to specific types of SCM strategies? RQ2.4. Which economic sectors have received the greatest attention among the identified applications? RQ3.1. Which types of decision-making problems have been addressed by the analyzed studies? RQ3.2. Which HFLTS extension are most frequently used? RQ3.3. How often are techniques integrated in the same problem? What is the frequency of the use of each identified technique? RQ3.4. How are the criteria weights defined? RQ3.5. With what frequency do applications support group decision making? RQ3.6. The weighting of the DMs is considered in which applications? How are these weights defined? RQ3.7. In terms of applications that deal with group decision making, do they use methods to obtain a consensus among the DMs and/or do they perform aggregation operations? RQ3.8. How were the application results validated?
	Keywords	- Hesitant Fuzzy Linguistic Terms Set — Synonyms: HFL and Hesitant Fuzzy Linguistic.

Table 3. *Cont.*

Stages	Research Elements	Description
1. Conception and planning	Keywords	- Supply Chain Management: Synonyms: supply chain, customer relationship management, customer service management, demand, distribution, location selection, logistics provider, manufacturing flow, order fulfilment, partner selection, procurement, product development, risk, stock, supplier development, supplier evaluation, supplier selection, and transport.
	Databases	- ACM Digital Library, EBSCO, El Compendex, Emerald Insight, the Google Scholar tool, IEEE Digital, Science Direct, Scopus, Springer, Taylor & Francis, the Web of Science, and the Wiley Online Library.
	Time frame	2012–2023
	Language	- English
	Inclusion criteria	- Studies in English that feature real HFLTS and/or HFLTS extension applications in SCM problems and are approved or published in a peer-reviewed journal.
	Exclusion criteria	- Studies that realize simulated applications of HFLTSs and/or HFLTS extensions in SCM problems. - Studies about SCM decision-making that do not apply HFLTSs or HFLTS extensions; - Studies that apply HFLTSs in problems outside of SCM; - Systematic literature review studies; or - Gray literature.
2. Conducting	Search string	(“Hesitant fuzzy linguistic” OR “HFL”) AND (“supply chain” OR “customer relationship management” OR “customer service management” OR “demand “ OR “logistic provider” OR “manufacturing flow” OR “stock “ OR “supplier development” OR “supplier evaluation” OR “supplier selection” OR “location selection” OR “order fulfilment” OR “risk” OR “partner selection” OR “distribution” OR “procurement” OR “product development” OR “transport”)
	Filters	Exhibits only journal-published articles in its results; and exhibits articles published in 2012 or later.
	Study selection	- Realized by the two authors in an independent manner through reading titles, keywords, and abstracts.
	Quality assessment	- Realized by the two authors through a complete reading of the article to confirm whether the study performed a real application, was in English, and was peer-reviewed.
	Data extraction	- Performed by the two authors with the help of the Parsifal software through a complete reading of the articles. The factors considered in the data extraction are presented in Table 4. The data generated in this step were exported into MS Excel 2021 (Redmond, WA, USA).
3. Reporting	Classification of the studies	- The classification was performed in accordance with the factors and categories displayed in Table 4.
	Visualization and analysis of results	- Creation of graphs and a publication map using MS Excel 2021; - Creation of tables using MS Word; - Analysis of HFLTS approaches and the problems addressed over the years.
	Summary of the information	- Analysis and summary of the results; - Summary of the results and answers to the research questions; - Comparison with other systematic literature reviews; - Identification of research gaps and proposed recommendations for future studies; and - Conclusion, contributions and limitations.

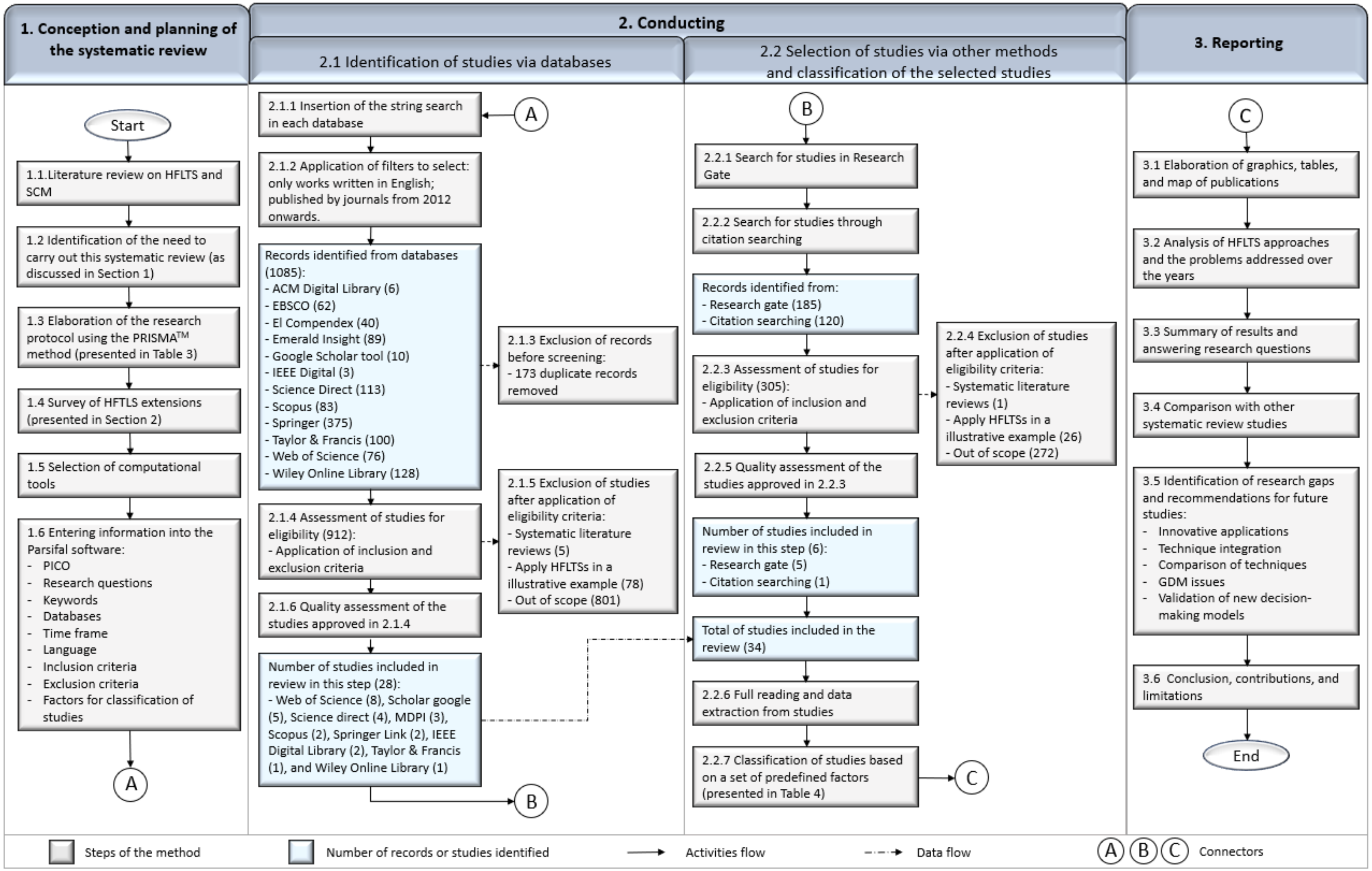


Figure 2. Research Method Adopted for the Systematic Review.

The keywords used in the search string were defined to cover studies that involved the application of HFLTSs in various subareas of SCM. The databases utilized were the ACM Digital Library, EBSCO, El Compendex, Emerald Insight, the Google Scholar tool, IEEE Digital, Science Direct, Scopus, Springer, Taylor & Francis, the Web of Science, and the Wiley Online Library. The time frame considered in our search ranged from 2012 to 2023, given that the first publication concerning HFLTSs dates from 2012 [14]. To generate a reliable and interpretable sample of studies, we only included studies in English that featured real HFLTS and/or HFLTS extension applications in SCM problems that had been approved or published in a peer-reviewed journal.

A survey of HFLTS extensions was carried out in Step 1.4 through searches in the databases indicated in Table 2. The studies shown in Table 1 were also used in this step. The results of this stage provided a theoretical basis for the analysis and classification of studies in the subsequent steps, as discussed in Section 2. The main extensions identified are described in Section 2. In Step 1.5, we chose our computational tools. The Parsifal software was selected to support the selection, assessment, and classification of the studies (in Steps 2.1.3 to 2.1.6 and Steps 2.2.3 to 2.2.7). MS Excel software was chosen to prepare our graphs and a publication map to summarize the findings (in Steps 3.1 to 3.2).

At the end of Stage 1 (Step 1.6), the research protocol information was entered into the Parsifal software to facilitate the selection and classification of studies in Stage 2. The study searches were performed in March 2023. Using the search string in our database search (Step 2.1.1) and after applying the filters (Step 2.1.2) described in Figure 1, we obtained a total of 1085 results. Metadata from these studies were imported into the Parsifal software. Thus, in Step 2.1.3, 173 duplicates were excluded.

When considering the remaining 912 studies, the initial selection was performed in Step 2.1.4 by both authors in an independent manner by reading the titles, keywords, and abstracts. The goal of this step was to only select articles that were within the scope of this review. We excluded books, book chapters, proceedings, literature review articles, and works that did not present real HFLTS applications in SCM, as well as other studies that were not within the scope of this literature review. In total, 884 articles were excluded in the Step 2.1.5 because they did not meet the inclusion criteria. Later, in the assessment of the quality of the articles (2.1.6), both authors read the complete articles to confirm that they performed real applications, were written in English, and had been peer-reviewed. After the quality evaluation, we included 28 studies from these databases.

In Step 2.2, several more studies were collected through a search of the Research Gate (Step 2.2.1) website and a search for the referenced citations (Step 2.2.2) in the studies selected in Step 2.1.6. These studies were also evaluated in terms of their eligibility and quality (Steps 2.2.3 to 2.2.5), which made it possible to identify 6 studies that were included in our review. Thus, a total of 34 studies were included. In Steps 2.2.6 and 2.2.7, all of the selected studies were read in pairs and classified according to the factors presented in Table 4. These factors were defined based on systematic literature reviews focused on SCM [6,13], supplier selection [7], supply management [46], GDM [47], and the modeling of complex linguistic expressions [12]. The categories related to each factor were defined initially based on these studies. Then, the categories were reviewed and updated according to the findings based on a thorough reading of the selected articles.

After the data were extracted and the studies were classified according to Table 4, a set of graphs and tables was prepared to better visualize the results in Step 3.1. The analysis of the frequency of decision-making problems and HFLTSs and the approaches addressed over the years was performed in Step 3.2. In Step 3.3, the obtained information was summarized to answer the research questions presented in Table 3. The obtained results were compared with other systematic review studies regarding this subject in Step 3.4. A framework with recommendations for future research was proposed in Step 3.5 based on the identified research gaps. Finally, the conclusion, contributions and limitations were discussed in Step 3.6.

Table 4. Factors Considered in the Classification of the Selected Studies.

	Factors		Categories	References
Information about the origin of the studies	Year of publication: classified the selected studies by year of publication and analyzes trends over the years.	-	Frequency of publications per year.	Lima-Junior and Carpinetti [6] Resende et al. [7], and Zimmer et al. [46]
	Country: classified the selected studies according to the country of the first author's affiliated institution.	-	Frequency of publications per journal.	
	Journal: classified the studies according to the journals in which they were published in order to find the journals that published the most on this subject.	-	Frequency of publications by country as defined based on the affiliation of the authors of each study.	
	Number of citations: identified the most cited articles based on information from Google Scholar.	-	Total citations of each study in Google Scholar.	
Factors related to SCM	Application objective: classified the selected studies based on the main objective of the decision-making problem in question.	-	Failure evaluation, risk evaluation, performance evaluation, supplier selection, and logistics service provider selection, among others.	Riahi et al. [13], Zimmer et al. [46], Lima-Junior and Carpinetti [6]
	SCM processes: based on the application objective, the studies were classified into one of the six main SCM processes.	-	Source, Plan, Make, Delivery, Return, and Enable.	SCC [48] and Riahi et al. [13]
	Type of SCM strategy: grouped the studies according to the SCM strategy adopted by the participating company in the application.	-	Agile, digital, flexible, green, lean, resilient, or sustainable.	Lima-Junior and Carpinetti [6] and Resende et al. [7]
	Sector	-	Automotive, electro-electronics, energy, construction, food, and health, among others.	Riahi et al. [13]
Factors related to decision making and HFLTS	Type of problem: classifies the studies based on the type(s) of decision-making problems in question.	-	Choice, ordering, or categorization.	Zimmer et al. [46]
	Type of HFLTS approach: identified the frequency of applications of HFLTSs and HFLTS extensions over the years.	-	HFLTS, EHFLTS, HIFLTS, IVHFLS, PHFLTS, PLTS, IVDHFLTS, MHFLTS, DHHFLTS, HF2DLTS, PHILTS, IV2THFLTS, DHFLTS, and HPFLTS.	Wang et al. [12]
	Combination of techniques: identified the frequency with which HFLTSs and HFLTS extensions have been integrated with other techniques.	-	Frequency of isolated applications and combined applications.	Lambert and Enz [1], Lima-Junior. and Carpinetti [6], and Riahi et al. [13]
	Frequency of use of each technique: identified the frequency of use of each the techniques that have been integrated with HFLTSs or HFLTS extensions.	-	Frequency of the applications for each technique.	

Table 4. *Cont.*

	Factors	Categories	References
Factors related to decision making and HFLTS	Criteria weights: identified whether the selected studies provided support for criteria weights. When they did, it mapped how the criteria weights were defined.	- Enabled the use or non-use of weights for criteria; - Weights attributed directly by the DMs or calculated weights; - Method(s) adopted for the weight calculations.	Kabak [47]
	Group decision making: investigated whether the selected studies supported group decision-making processes.	- Focused on individual or GDM; - Number of DMs who participated in the application.	Kabak [47]
	Weights for DMs: analyzed whether the selected studies consider weights for the DMs. When they did, it analyzed how these weights were defined.	- Considered or ignored the weights for the DMs; - Weights attributed by DMs or calculated by some method.	Kabak [47]
	Consensus among DMs: identified whether the selected studies performed aggregation operations and whether they used methods to obtain a consensus among the DMs.	- Frequency of the use of aggregation methods for the DMs' preferences and the techniques used to obtain consensus in GDM.	Kabak [47]
	Validation: classified the approaches used for validation of the results for each selected study.	- Based on sensitivity analysis, the application of statistical techniques, and comparisons with other methods or real data.	Lima-Junior and Carpinetti [6]

4. Results and Discussion

4.1. Presentation of the Selected Studies

4.1.1. HFLTS-Based Studies

This section presents the selected studies that were based on HFLTS applications. Among them, there were six studies that proposed models focused on supply management. Liao et al. [49] combined HFLTSs with the Best Worst Method (BWM) and Additive Ratio Assessment (ARAS) methods to support supplier selection in a digital supply chain. Dolatabad et al. [50] also proposed a supplier selection model for a digital supply chain; however, they used a fuzzy cognitive map combined with the HFLTS-VIKOR (Vlsekriterijumska Optimizacija I KOmpromisno Resenje in Serbian) method. Liu et al. [51] developed a method that combined HFLTS with Dempster–Shafer evidence theory to achieve consensus in GDM problems. The application was realized in a supplier selection problem for chemical products in a retail supermarket. Lima-Junior and Hsiao [52] developed a model to monitor supplier performance in an automobile factory. In this study, the HFLTS-TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) method was utilized to classify suppliers in a two-dimensional matrix based on operational performance and supply costs.

Another HFLTS-TOPSIS model based on a bi-dimensional matrix was proposed by Borges et al. [4] to support the segmentation of sustainable suppliers. In this study, the application involved the classification of suppliers in a hydroelectric plant. Finger and Lima-Junior [8] developed an approach based on Quality Function Deployment (QFD) and HFLTS to support decision making during the elaboration of programs to develop sustainable suppliers. The application took place in an automotive firm while considering criteria related to the economic, environmental, and social performance of the suppliers. In addition to the studies by Borges et al. [4] and Finger and Lima-Junior [8], we identified two other studies focused on the promotion of sustainable supply chains. Osiro et al. [19] proposed a method that combined HFLTS with QFD to select evaluation measures for sustainable supply chains. Erol et al. [53] applied the HFLTS-QFD, HFLTS-Delphi, HFLTS-ANP (Analytic Network Process), and HFLTS-TOPSIS methods to analyze barriers to the adoption of circular economics.

There were four studies that involved the application of HFLTSs to performance management. Tüysüz and Şimşek [54] applied an HFLTS-based Analytic Hierarchy Process (AHP) to evaluate the factors that affected the performance of a transport company's affiliates. Pérez-Domínguez et al. [55] evaluated the impact of using lean tools for organizational performance using a combination of AHP and HFLTS-TOPSIS methods. Through a combination of the HFLTS-AHP and HFLTS-MULTIMOORA (Multi-Objective Optimization on the basis of Ratio Analysis Multiplicative Forms) methods, Büyüközkan and Güler [56] created a methodology to support managers in evaluating supply chain analytics tools. Zheng et al. [57] presented a Hesitant Fuzzy Linguistic Decision-Making Trial and Evaluation Laboratory (DEMATEL) model to evaluate the importance of critical success factors in a health company.

In terms of risk management in supply chains, we found three related applications. Wu et al. [58] presented a new approach to risk evaluation in supply chains that integrated HFLTSs, the fuzzy synthetic method, and the eigenvalue method. A pilot application of this approach was realized to evaluate risks in electric vehicle supply chains. Chang et al. [59] combined the Failure Mode and Effect Analysis (FMEA), DEMATEL, and HFLTS methods to analyze risks that failures would occur in an electronic company's production processes. More recently, Qin et al. [9] integrated the swaps method based on the prospect theory with HFLTS. The objective of the application of this proposal was to help select emergency logistics plans during the COVID-19 pandemic.

Finally, we identified two studies related to location selection, one for human resources management and another for packaging design selection. More recently, Wu et al. [60] developed a new method that combined HFLTSs, TODIM (Tomada de Decisão Interativa Multicritério in Portuguese), and DEA. The method was applied for the selection of the most appropriate location a new health management center. Another model for location selection was developed by Ren et al. [35] based on Incomplete Hesitant Fuzzy Linguistic Preference Relations that was applied to selecting the location of hydroelectric plants. Yalçın and Pehlivan [61] proposed a personnel selection model for a manufacturing company. The use of the Fuzzy Combinative Distance-Based Assessment (CODAS) Method based on fuzzy envelopes for HFLTS proved effective in dealing with this problem.

Lima et al. [8] developed a method that combined HFLTS, AHP, QFD, and the Preference Ranking Organization Method for Enriched Evaluation (PROMETHEE) for packaging design selection. This method was applied in an automotive firm, and the results were compared with other multicriteria decision methods.

4.1.2. Studies Based on HFLTS Extensions

Among the 15 studies based on extensions of HFLTS, we identified the use of seven distinct approaches. The use of DHHFLTS predominated, and it was present in seven of these studies. Krishankumar et al. [62] presented a framework for supplier selection based on DHFLTS, which is focused on situations in which the weights of the criteria are unknown. Krishankumar et al. [63] proposed a DHHFLTS-based framework for green supplier selection with partial weight information. Krishankumar et al. [64] applied DHHFLTS to generate a ranking of sustainable suppliers.

In addition to these three studies regarding supply management, we found three applications of DHHFLTS for risk analysis. Shen and Liu [65] evaluated the risk of logistics firms based on a combination of DHHFLTS and FMEA. Dai et al. [66] evaluated the risk of failures in an electronic products firm utilizing DHHFLTS, FMEA, and the K-means algorithm. Similarly, Duan et al. [67] combined DHHFLTS, FMEA, and the K-means algorithm to analyze the risk of failures in a firm in the energy sector. Finally, Wang et al. [68] proposed a study that used DHHFLTS and ORESTE (Organísation, Rangement et Synthèse de Données Relarionnelles in French) to evaluate traffic congestion.

The use of PLTSs has also emerged in SCM problems. Li et al. [69] developed a methodology that integrated PLTS with DEMATEL to evaluate sustainable recycling partners. Zhang et al. [70] proposed the use of PLTSs to deal with sustainable logistics suppliers. Zhang et al. [71] applied PLTSs to supplier selection for a construction company. In this application, the authors also used the BWM and Combined Compromise Solution (CoCoSo) methods based on rough boundary intervals.

The other identified extensions appeared in only one application apiece. Wang et al. [72] proposed an MHFLTS model to support the outsourcing of logistics services, which is especially useful in situations in which the weight information for the criteria is incomplete. Based on the performance indicators of the Supply Chain Operations Reference (SCOR) model, Divsalar et al. [73] created a model to evaluate supply chain performance that integrates the EHFLTS-VIKOR, Fuzzy Delphi, Interval-valued Hesitant Fuzzy, and DANP (DEMATEL-ANP) methods. A distinguishing characteristic of this model was that it combined criteria, paradigms, and Lean, Agile, Resilient, and Green (LARG) practices to improve supply chain performance.

Qu et al. [74] developed a stochastic method based on DHFLTSs and HFLTSs for sustainable supplier selection in a high-tech manufacturing center. Wu et al. [75] combined HPLTSs with the Weighted Cross-Entropy TOPSIS method to support the decision-making process for personnel selection in a firm in the automotive sector. Zolfaghari and Mousavi [75] created a risk evaluation methodology based on FMEA, MULTIMOORA, the Technique of Precise Order Preference (TPOP), and IVHFLTS. A pilot application of this methodology was created to manage failures in a healthcare company.

Based on the characterizations of the studies presented in Sections 4.1.1 and 4.1.2, it was possible to answer the research questions displayed in Table 3. Sections 4.2–4.4 will discuss the obtained results.

4.2. Information about the Origins of These Studies

This section is dedicated to answering the research questions RQ1.1 to RQ1.4 and presenting the classification results for these studies in terms of year of publication, journal, country, and most cited articles. Figure 3 presents the distribution of the number of articles by year of publication (RQ1.1). This figure demonstrates that our subject is quite emergent in the literature, given that the first publication we found occurred in 2017. Roughly 58.8% of the studies were published within the past three years (beginning with 2021). In addition, the trend line of Figure 3 indicates a growth trend in terms of the number of publications about this subject. It is important to mention that the results displayed in the last column of the graph only include studies published in the first few months of 2023, given that our study sample was selected in March 2023.

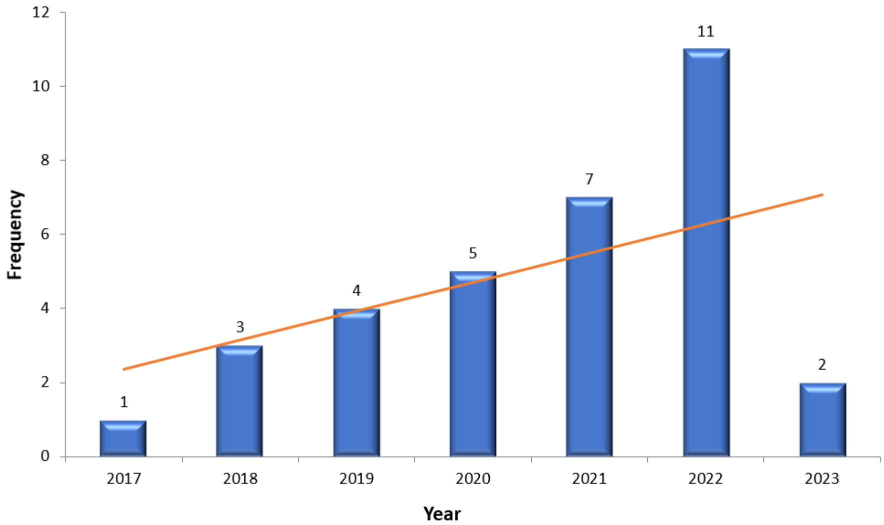


Figure 3. Frequency of Articles Published by Year.

Figure 4a presents the distribution of publications classified according to the country of the first author's affiliated institution for each study (RQ1.2). China had the largest number of publications with 17 studies, which represented 50% of our analyzed sample. It was followed by Brazil (five studies), Turkey (four studies), India (three studies), and Iran (three studies). As shown in Figure 4b, production related to this subject was concentrated in Asia (24 studies), South America (5 studies), and Europe (4 studies).

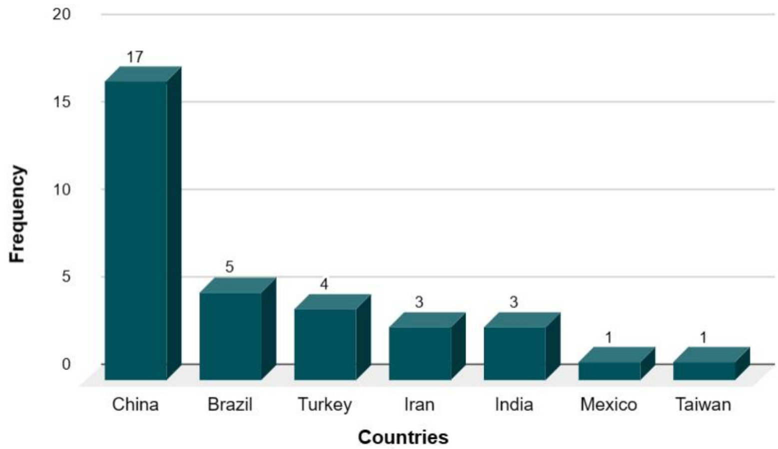
Table 5 presents the journals in which the selected studies were published (RQ1.3). A wide variety of journals published articles about this subject: there was a total of 27 distinct journals. The journal with the most published articles on this subject was *IEEE Transactions on Engineering Management*. Following it, there was a tie between the journals *Applied Soft Computing*, *Computers and Industrial Engineering*, *Environmental Science and Pollution Research*, *the Journal of Intelligent & Fuzzy Systems*, and *Symmetry*, each with two publications. The other 21 journals had 1 publication apiece.

Table 5. Distribution of Published Articles by Journal.

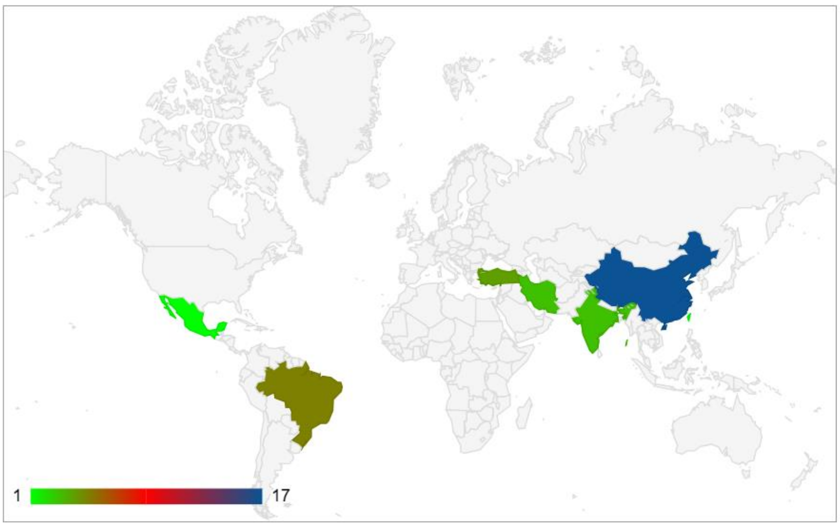
Journal	2017	2018	2019	2020	2021	2022	2023	Total
IEEE Transactions on Engineering Management						3		3
Applied Soft Computing				1	1			2
Computers and Industrial Engineering						2		2
Environmental Science and Pollution Research						1	1	2
Journal of Intelligent & Fuzzy Systems		1				1		2
Symmetry			1			1		2
Applied Sciences			1					1
Aslib Journal of Information Management							1	1

Table 5. *Cont.*

Journal	2017	2018	2019	2020	2021	2022	2023	Total
Complex & Intelligent Systems	1							1
Complexity				1				1
DYNA					1			1
Energy			1					1
Fuzzy Optimization and Decision Making				1				1
Int. J. of Computational Intelligence Systems				1				1
Int. J. of Environmental Research and Public Health				1				1
Int. J. of Information Technology & Decision Making					1			1
Int. J. of Production Economics						1		1
Int. J. of Strategic Property Management				1				1
Int. Transactions in Operational Research		1						1
J. of Cleaner Production		1						1
J. of Contemporary Administration						1		1
J. of Mathematics					1			1
J. of the Operational Research Society						1		1
Knowledge-Based Systems					1			1
Kybernetes					1			1
Neural Computing & Applications					1			1
Technological and Economic Development of Economy			1					1



(a)



(b)

Figure 4. (**a**) Distribution of the Publications by Country and (**b**) a Map of the Publications.

By collecting the number of citations in Google Scholar, it was possible to identify the most influential articles. Table 6 presents the number of citations received by the 11 most cited studies within our analyzed sample (RQ1.4). The article that had the greatest number of citations was Osiro et al. [19] with a total of 86 citations. The works of Wang et al. [72], Yalçın and Pehlivan [72], Tüysüz and Şimşek [54], and Liu et al. [51] followed with 84, 72, 71, and 65 citations, respectively.

Table 6. List of the Most Cited Articles.

Rank	Author(s)	Number of Citations
1st	Osiro et al. [19]	86
2nd	Wang et al. [72]	84
3rd	Yalçın and Pehlivan [61]	72
4th	Tüysüz and Şimşek [54]	71
5th	Liu et al. [51]	67
6th	Wu et al. [58]	56
7th	Wang et al. [68]	56
8th	Liao et al. [49]	41
9th	Duan et al. [67]	32
10th	Erol et al. [53]	28
10th	Chang et al. [59]	28

4.3. Aspects Related to SCM

To answer the research questions RQ2.1 to RQ2.4, this section presents the results regarding the objectives of HFLTS applications in SCM processes, their industrial sector, and the company's type of SCM strategy. In order to identify the most common decision-making problems in SCM that have been addressed using HFLTSs and HFLTS extensions, the selected studies were classified based on the application objective. Based on this, to elucidate which SCM processes received the greatest attention in these applications, each study was classified as dealing with one of the following SCM processes: Source, Plan, Make, Deliver, Return, and Enable. These are the six main SCM processes according to the Supply Chain Operations Reference (SCOR) model, which is an SCM reference that has been widely adopted by practitioners and researchers [48]. Table 7 displays the results of the classification of our studies in terms of the objectives of their applications and the associated SCM processes (RQ2.1). Studies dealing with supplier selection were the most frequent, totaling 23.5% of the sample. They were followed by failure evaluations (11.8%) and performance evaluations (8.8%). Figure 5 exhibits the frequency of application objectives over the years. This figure indicates the dominant relevance of the supplier selection problem over the years.

According to the results displayed in Figure 6a, the Source process had the most associated applications and represented 38.2% of the studies. This process is dedicated to acquiring goods and hiring external services that are necessary to meet actual or planned demand. It was followed by the Enable process with 29.4% of the studies. The high frequency of applications related to the Source process seemed to be related to the fact that this process requires decision-making processes that affect several areas of the business. The main one is supplier selection, which determines part of the supply chain structure and also influences production costs, product quality, and customer satisfaction. Similarly, the Enable process encompasses other decision-making processes that are essential for supply chain structuring and operation, such as personnel selection, location selection, performance evaluation, and risk assessment [48].

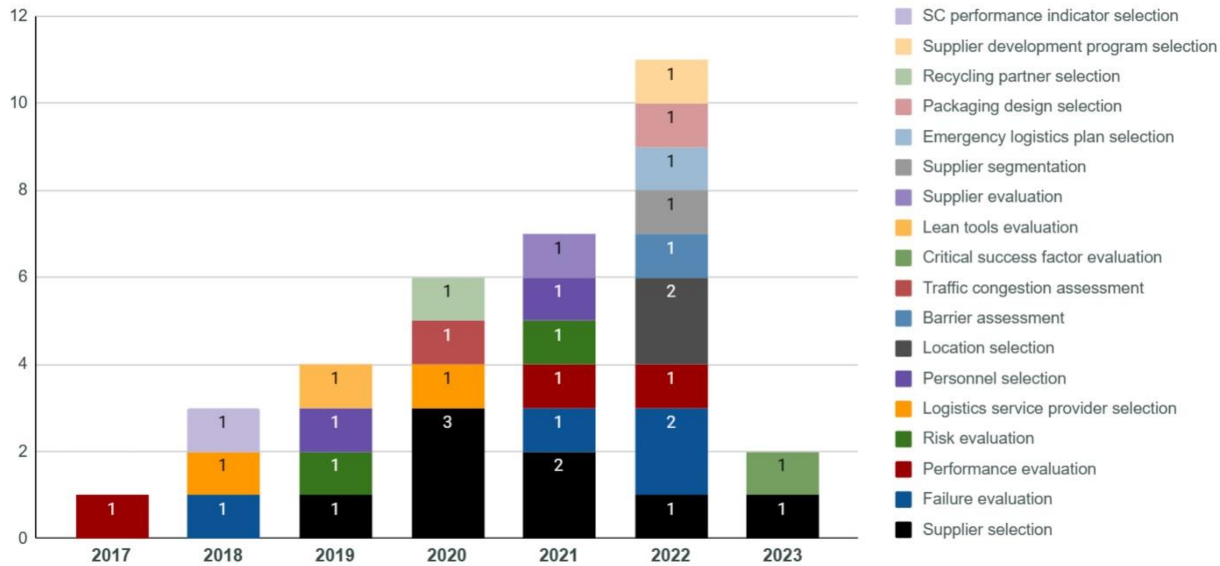


Figure 5. Frequency of Application Objectives over the Years.

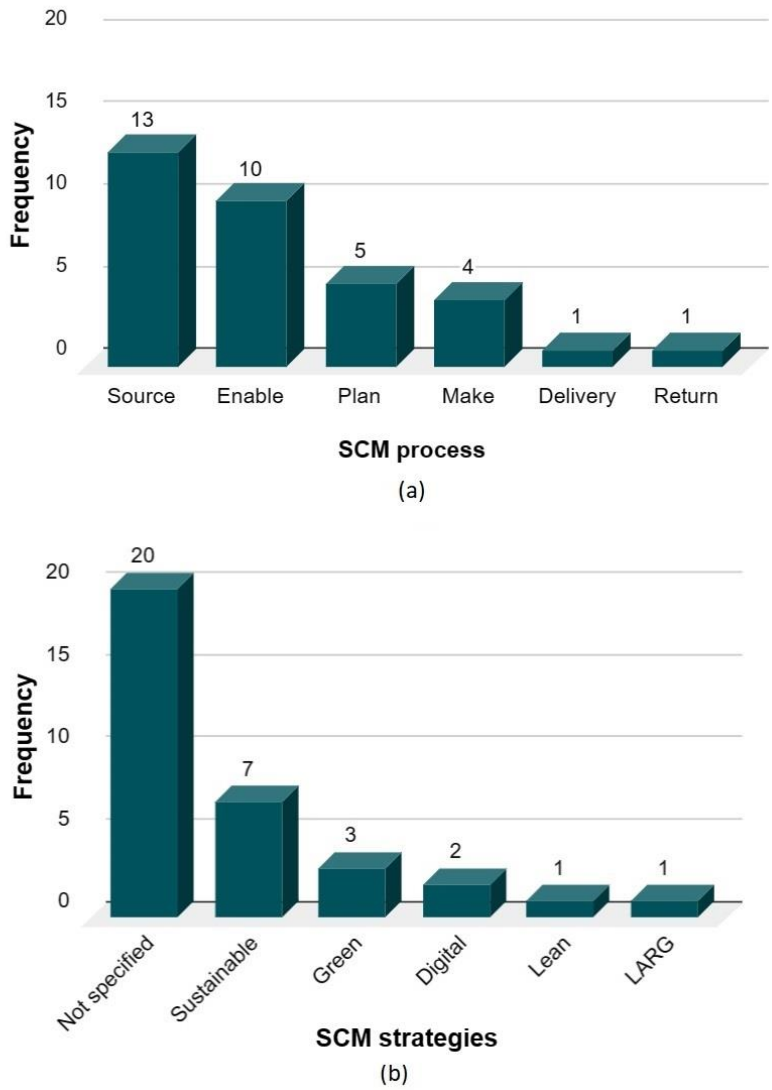


Figure 6. (**a**) SCM Process Results and (**b**) Types of SCM Strategies.

The Plan process appeared in 14.7% of the applications. This process encompasses planning activities to create the actions that will best achieve the requirements of the Make, Delivery, and Return processes. The studies dealing with the Make process totaled 11.8% of the sample, including activities dealing with the transformation of products or the execution of services. Finally, the Delivery process, which involves order, transportation, and distribution management, appeared in just one application (2.9%). Similarly, the Return process, which is related to receiving products that are returned for any reason [48], was also associated with just a single application.

Figure 6b displays the results of the classification of these studies by the type of SCM strategy adopted by the company where the model was applied (RQ2.3). While 58.8% of the studies did not clearly identify the type of SCM strategy employed, 20.6% of the studies involved companies that adopted a Sustainable strategy. In general, sustainable SCM studies are based on triple-bottom-line dimensions and include decision-making criteria related to economic, environmental, and social aspects. Applications in companies employing green supply chains represented 8.8% of the sample and were oriented toward minimizing environmental pollution and improving the environmental performance of products and processes. They were followed by 5.9% of the companies with digital (or smart) supply chains, which are focused on promoting digitalization, automation, and the integration of operations throughout the supply chain. The Lean strategy, which focuses on a reduction in costs and the elimination of waste, was represented by one application (2.9%). Similarly, the LARG strategy, which combines aspects of the Lean, Agile, Resilient, and Green strategies, was also represented by just one application. We did not find applications devoted exclusively to agile or resilient supply chains.

The predominance of applications in sustainable and green SCM is due to the importance that environmental management and social responsibility have achieved in recent decades. Companies began adapting to deal with stricter regulations and customers who were more concerned about the socio-environmental impacts of business activities [8,76]. As the use of environmental and social performance indicators is relatively recent in most companies and these indicators usually involve qualitative aspects or variables for which there is no performance history, the use of HFLTS techniques and HFLTS extensions is quite appropriate [19].

Table 7. Classification of the Studies according to their Application Objectives.

Application Objective	Author(s)	SCM Process	Total
Supplier selection	Liao et al. [49]; Zhang et al. [71]; Krishankumar et al. [77]; Krishankumar et al. [78]; Liu et al. [49]; Dolatabad et al. [50]; Qu et al. [74]; Krishankumar et al. [64].	Source	8
Failure evaluation	Chang et al. [59]; Zolfaghari and Mousavi [79]; Dai et al. [66]; Duan et al. [67].	Make	4
Performance evaluation	Tüysüz and Şimşek [54]; Büyüközkan and Güler [56]; Divsalar et al. [73].	Enable	3
Risk evaluation	Wu et al. [58]; Shen and Liu [65].	Enable	2
Logistics service provider selection	Wang et al. [72]; Zhang et al. [70].	Source	2
Personnel selection	Wu et al. [75]; Yalçın et al. [61].	Enable	2
Location selection	Wu et al. [80]; Ren et al. [81].	Enable	2
Barrier assessment	Erol et al. [53].	Plan	1
Traffic congestion assessment	Wang et al. [68].	Delivery	1
Critical success factor evaluation	Zheng et al. [57].	Plan	1
Lean tools evaluation	Pérez-Domínguez et al. [55].	Plan	1
Supplier evaluation	Lima-Junior and Hsiao [52].	Source	1
Supplier segmentation	Borges et al. [4]	Source	1
Emergency logistics plan selection	Qin et al. [9].	Plan	1
Packaging design selection	Lima et al. [82].	Plan	1
Recycling partner selection	Li et al. [69].	Return	1
Supplier development program selection	Finger and Lima-Junior [8].	Source	1
SC performance indicator selection	Osiro et al. [19].	Enable	1

Finally, Figure 7 displays the classification of these studies according to the sector of the participating company (RQ2.4). The automotive sector stood out with 10 applications (29.4%). It was followed by the health and electro-electronic sectors with five and four applications, respectively. The food, glass, high-technology, infrastructure, manufacturing, retail, and transportation sectors were represented by just one application apiece. Five of the studies did not specify the company's sector. The large number of company applications seemed to be related to the fact that these chains are of great economic importance and have a complex structure. Assembly companies purchase many components externally, for which there is often more than one supplier. Moreover, many automotive companies have traditionally been among the early adopters of management tools and practices [83,84].

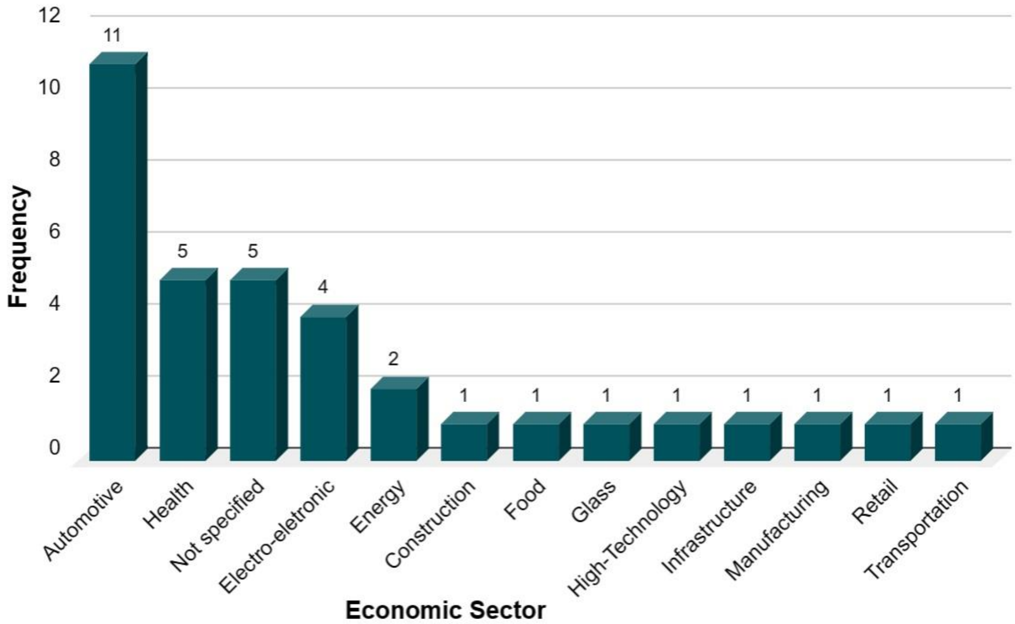


Figure 7. Classification of the Studies according to Economic Sector.

4.4. Aspects Related to Decision Making and HFLTSs

This section deals with subjects related to research questions RQ3.1 to RQ3.8. In the graph displayed in Figure 8, the selected studies are classified according to the main decision-making problem that they dealt with (RQ3.1). The results indicated that half of the applications were devoted to ranking problems, or in other words, problems with ranking alternatives by global preference. This was followed by 32.4% of the applications, which dealt with choice problems, in which there was a desire to choose a subgroup of alternatives within the available options. Finally, in 17.6% of the applications, we found studies that dealt with sorting issues, or in other words, problems in which the objective was to classify each alternative in a predetermined category.

In Figure 9, the studies were classified according to the adopted HFLTS approach (RQ3.2). The HFLTS approach was used in 23 studies (67.6%), while 15 studies (44.1%) adopted an HFLTS extension. Among the 13 HFLTS extensions discussed in Section 2, we found applications based on just 7 of them: DHHFLTS (7 studies); PLTS (3 studies); and DHFLTS, EHFLTS, HPFLS, IVHFLTS, and MHFLTS (with 1 study apiece). Four studies combined HFLTSs with an HFLTS extensions such as PLTSs and DHFLTSs.

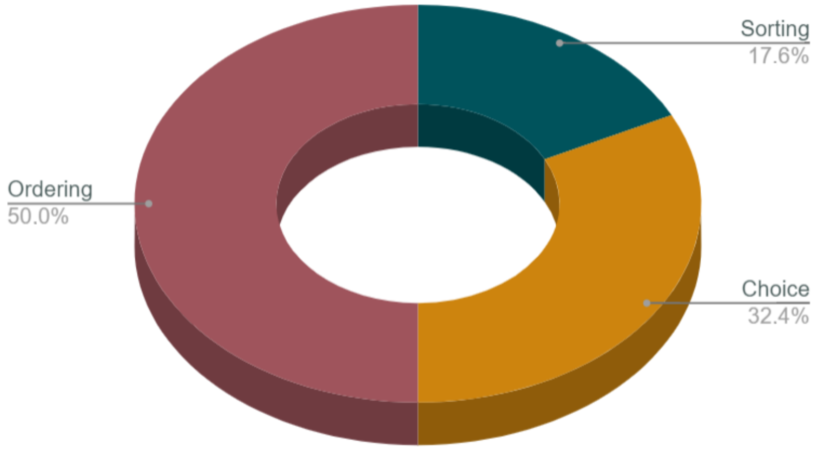


Figure 8. Classification of the Studies by Type of Decision-Making Problem.

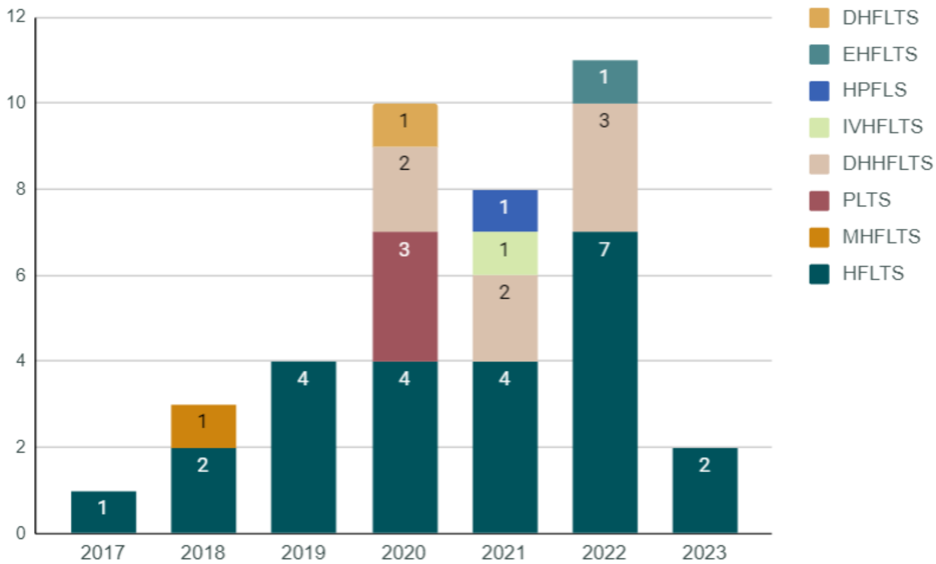


Figure 9. Frequency of Use of HFLTSs and HFLTS Extensions.

The great frequency of the HFLTS approach originally proposed by Rodríguez et al. [14] may be related to its ease of use by DMs and the ease of calculations. Meanwhile, the use of DHHFLTSs may be associated with the possibility of using complex linguistic expressions, which combine two scales of linguistic terms in each judgment. In addition to increasing the flexibility of DM preferences, the use of DHHFLTSs increases the possibilities of values that can be attributed to the evaluated object [40]. Furthermore, the interest of using PLTSs lies in the fact that this approach takes into account a possibility degree for each linguistic term selected by a DM. For each judgment provided by a DM, the sum of the possibility degrees must be equal to 1. For example, if a DM selects only the term "s_3: Medium" without hesitation, their judgment will be quantified as (s_3, 1.0). When selecting "between s_4: good and s_6: extremely good", the DM's judgment will be quantified as (s_4, 0.33; s_5, 0.33; s_6, 0.33). Since the values of the degrees of possibility act as weighting factors for the linguistic terms, the terms chosen in situations of greater hesitation will have less influence on the final result [37].

Table 8 displays the techniques that were applied in each of the analyzed studies. It also describes how the criteria weights were determined and which techniques were employed in calculating these weights. In terms of research question RQ3.3, we verified that all of the studies proposed the integration of HFLTS or HFLTS extension techniques with other techniques, which included Multicriteria Decision-Making (MCDM) methods, quality management, and statistical techniques. Integration occurred through the hybridization or sequential application of these techniques.

Table 8. Decision-Making Techniques in Each Study.

	Proposed By	Decision Technique(s)	Method for Obtaining Criteria Weights	Method for Calculating Criteria Weights
Hybrid techniques (13)	Tüysüz & Şimşek [54]	HFLTS-AHP	Weights not applied	N/A
	Osiro et al. [19]	HFLTS-QFD	Calculation	HFLTS-QFD
	Yalçın et al. [61]	HFLTS-CODAS	Calculation	HFLTS-CODAS
	Qu et al. [74]	DHFLTS, HFLTS, and Regret and Rejoice Theory	Calculation	HFLTS and Regret and Rejoice Theory
	Ren et al. [81]	Programming models based on Incomplete Hesitant Fuzzy Linguistic Preference Relation	Calculation	Programming models
	Wang et al. [68]	DHHFLTS-ORESTE	Calculation	DHHFL-ORESTE
	Zhang et al. [70]	HFLTS-PLTS and Ratio Index-Based Probabilistic Linguistic Ranking Method	Calculation	CoCoSo
	Liu et al. [51]	HFLTS and Dempster–Shafer Theory	Assigned by DMs	N/A
	Lima-Junior & Hsiao [52]	HFLTS-TOPSIS	Assigned by DMs	N/A
	Borges et al. [4]	HFLTS-TOPSIS	Calculation	HFLTS-TOPSIS
	Finger and Lima-Junior [8]	HFLTS-QFD	Calculation	HFLTS-QFD
	Qin et al. [9]	HFLTS and Swaps Method	Calculation	HFLTS, and Swaps Method
	Zheng et al. [57]	HFLTS-DEMATEL	Calculation	HFLTS-DEMATEL
Combined techniques (21)	Chang et al. [59]	HFLTS-FMEA, DEMATEL, and Ordered Weighted Geometric Average (OWGA)	Calculation	OWGA
	Wang et al. [20,72]	MHFLTES, Heronian Mean (HM), and Prioritized Average Operator	Calculation	MHFLTE and HM
	Liao et al. [59]	HFLTS-BMW and HFLTS-ARAS	Calculation	HFLTS-BWM
	Pérez-Domínguez et al. [55]	AHP and HFLTS-TOPSIS	Calculation	AHP
	Wu et al. [58]	HFLTS, Fuzzy Synthetic Method, Eigenvalue Method, and Triangular Fuzzy Number (TFN)	Calculation	Eigenvalue Method
	Zhang et al. [71]	HFLTS, PLTS, Modified BWM, and CoCoSo	Calculation	HFLTS-BWM
	Krishankumar et al. [77]	DHHFLTS, Generalized Maclaurin Symmetric Mean (GMSM), and Borda Method	Calculation	DHHFLTS and SV
	Li et al. [69]	HFLTS, PLTS, TFN, DEMATEL and Generalized Weighted Ordered Weighted Average (GWOWA)	Calculation	PLTS-DEMATEL
	Büyüközkan and Güler [56]	HFLTS-AHP and HFLTS-MULTIMOORA	Calculation	HFLTS-AHP

Table 8. *Cont.*

	Proposed By	Decision Technique(s)	Method for Obtaining Criteria Weights	Method for Calculating Criteria Weights
Combined techniques (21)	Shen and Liu [65]	DHHFLTS-FMEA, DHHFLTS-COPRAS, and Kemeny Median Method (KEM)-SWARA	Calculation	KEM-SWARA
	Krishankumar et al. [78]	DHHFLTS, GMSM, TODIM, and Cronbach's Alpha Coefficient	Calculation	Mathematical model
	Wu et al. [75]	HPFLS-TOPSIS and Weighted Cross-Entropy	Calculation	HPFLS-TOPSIS, and Weighted Cross-Entropy
	Zolfaghari and Mousavi [79]	IVHFLS-FMEA, MULTIMOORA, and TPOP	Calculation	MULTIMOORA
	Duan et al. [67]	DHHFLTS-FMEA, K-Means Clustering, and Maximizing Deviation Method	Calculation	Maximizing Deviation Method
	Dai et al. [66]	DHHFLTS-FMEA, K-Means Clustering, and Entropy Weight Method	Calculation	K-means Clustering
	Divsalar et al. [73]	Fuzzy Delphi, EHFLTS-VIKOR and IVHF-DANP	Calculation	IVHF-DANP
	Erol et al. [53]	HFLTS-QFD, HFLTS-Delphi, HFLTS-ANP, and HFLTS-TOPSIS	Calculation	HFLTS-ANP
	Krishankumar et al. [64]	DHHFLTS combined with the Attitudinal-CRITIC (Criteria Importance Through Intercriteria Correlation) Approach and the Weighted Distance Approximation (WDA) Algorithm	Calculation	Attitudinal-CRITIC Approach
	Wu et al. [80]	HFLTS and the DEA-Based TODIM Method	Calculation	DEA-Based TODIM Method
	Lima et al. [82]	HFLTS-AHP, HFLTS-QFD, and HFLTS-PROMETHEE	Calculation	HFLTS-AHP
	Dolatabad et al. [50]	HFLTS-VIKOR and Fuzzy Cognitive Map	Calculation	Fuzzy Cognitive Map

Figure 10 presents the frequency with which each technique was utilized in the integrated methods. We identified 36 distinct techniques. The most frequently utilized methods were FMEA and TOPSIS, which were present in five of the studies. These were followed by AHP, DEMATEL, and QFD with four applications apiece.

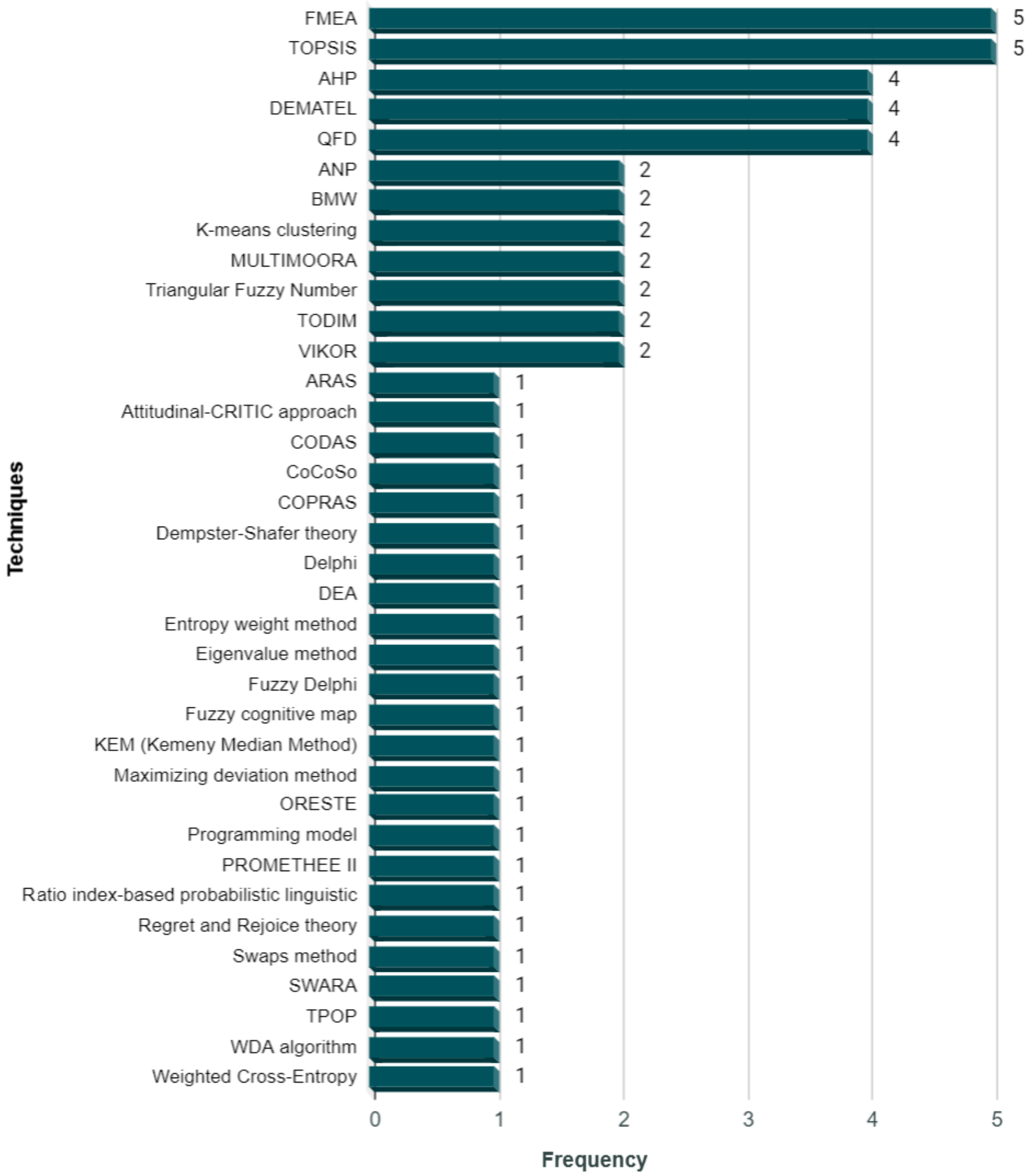


Figure 10. Frequency of Techniques that have been Integrated with HFLTSs and Extensions.

Table 9 describes the techniques that were found in at least two applications. In this table, the techniques are positioned according to their frequency of use. We believe that the great frequency of the use of FMEA is related to the fact that this method is recognized worldwide as an efficient risk evaluation tool. Combining it with HFLTS techniques makes it possible to overcome deficiencies in the original version of FMEA, such as the inability to attribute weights to the criteria and the need to review occasional erroneous evaluations of failures utilizing exact numerical values [65]. On the other hand, the methods resulting from the combination of TOPSIS and HFLTS approaches provide greater flexibility to the alternative evaluation process [4].

Table 9. Description of the Techniques that are Most Frequently Combined with HFLTSs and HFLTS Extensions.

Technique	Description
FMEA	A risk analysis method that is traditionally used to prioritize failure modes. Each failure mode receives a numerical value based on the "Severity", "Occurrence" and "Detection" criteria. In traditional FMEA, the values range from 0 to 10, and the criteria weights are not considered. Combining FMEA with HFLTSs or HFLTS extensions enables DMs to use linguistic expressions to evaluate failures. It also makes it possible to consider criteria weights and support group decision making under conditions of uncertainty and hesitation [65].
TOPSIS	An MCDM method that ranks alternatives according to their proximity to the ideal solutions. While the positive ideal solution is formed by the highest numerical values achieved by the alternatives in each criterion, the negative ideal solution consists of the lowest numerical values for each criterion. The traditional version of TOPSIS only uses numerical values and is not appropriate for decision making under conditions of uncertainty. On the other hand, combining TOPSIS with HFLTSs or HFLTS extensions enables DMs to use linguistic expressions to evaluate alternatives and in some cases criteria weights as well [4].
AHP	An MCDM method in which decision-making problems are represented as a hierarchy composed of the problem objective, the criteria, and the alternatives. The criteria weights and the values for the alternatives are defined based on pairwise comparisons conducted by the DMs. This method requires the verification of the consistency of the DM judgments and also requires a greater number of judgments than TOPSIS and VIKOR [54,56].
DEMATEL	A very useful technique for identifying the cause-and-effect relationships among a group of system elements. In the decision-making area, this method is often used to identify the inter-relationships among the criteria. The evaluations of the individual relationships between the elements serve as the inputs for this method. The main output is a structural model that provides a global view of the inter-relationships among the criteria, which makes it possible to discover which of them are the most influential [57].
QFD	A quality management method traditionally applied to the product development area. It is made up of a "what" matrix that contains the prioritization of the customer requirements and a "how" matrix that relates the requirements to the desirable technical characteristics of the product. While traditional QFD uses numerical values, the versions based on HFLTSs and HFLTS extensions use linguistic terms and expressions provided by the DMs. There are also versions of HFLTS-QFD that can take into account the degree of risk in the decision-making problem [8,19].
ANP	An MCDM method based on AHP. The decision-making problem is represented by a network composed of various nodes. Like AHP, comparisons between pairs of alternatives and criteria serve as the input data for this method. ANP also requires the verification of the consistency of the DMs' paired judgments. A distinguishing characteristic of ANP is that this method takes into account the inter-relationships among decision-making criteria [53]
BWM	An MCDM method that ranks alternatives from the best to the worst solution. Initially, the DMs should indicate which are the most important and least important criteria. The other criteria are compared in terms of the best and worst criteria. The same principle is applied in the evaluation of the alternatives. In addition to requiring fewer comparisons than AHP, the BWM method presents an advantage in that it does not require tests to verify its consistency [59,71].
K-Means Clustering	An unsupervised learning technique which makes it possible to partition n observations into k groups. Initially, this method randomly selects k alternatives and associates each alternative with a cluster. For each remaining alternative, the similarity is calculated between the analyzed alternative and the center of each cluster (centroid). Then, each alternative is associated with the closest cluster. The centroids of the clusters are updated and the alternatives are reclassified until they achieve the convergence of the algorithm [66,67].
MULTI-MOORA	A compensatory method that works with independent criteria and does not use the weights of these criteria. This method seeks to simultaneously optimize two or more objectives while taking into account a group of restrictions. The output of MULTIMOORA is a ranking obtained through the aggregation of the results of the following methods: the Ratio System, the Reference Point Approach, and the Full Multiplicative Form [56,79].
TFNs	Triangular Fuzzy Numbers are used to represent imprecise numerical values or qualitative linguistic evaluations. Each TFN is made up of a triangular membership function in which the central vertex indicates the value with the greatest membership degree, while the vertices of the extremities indicate values of lesser membership degrees. One of the main advantages of TFNs is the simplicity of the calculations and the low computational complexity involved in manipulating their values [58,69].
TODIM	An MCDM method that is based on prospect theory. TODIM works with quantitative criteria as well as qualitative criteria. It measures the dominance degree of each alternative over the other alternatives based on the value overall. TODIM presents resources to eliminate inconsistencies in the DM judgments. A distinguishing characteristic of this method is that it tests more specific forms of profit and loss functions [78].
VIKOR	An MCDM method for determining a compromise solution that is closer to the ideal solution. One benefit of the VIKOR method is its capacity to generate rankings that consider judgments related to all of the criteria (group utility) or the criteria that have the worst evaluations (individual regret) [50,73].

In addition to the approaches used to model DM preferences, another factor that directly influences decision making is the weights (degrees of relative importance) attributed to the criteria. The definition of these weights allows DMs to decide which aspects should have priority in evaluating alternatives for the solution of a problem. The literature features various ways of obtaining the values of criteria weights. As shown in Table 8, in most of the studies (31), the weights were calculated by a decision-making technique or an aggregation operator based on the DM judgments (RQ3.4). The most often applied techniques to accomplish this were HFLTS-QFD, HFLTS-AHP, and HFLTS-BWM. In two studies, the weights were attributed directly by the DMs. One study did not attribute weights to the criteria.

Table 10 presents the classification of the studies based on factors related to their support of GDM (RQ3.5). We found that all of the studies applied methods to support GDM, even though the application presented by Finger and Lima-Junior [8] considered only one DM. Figure 11 presents the frequency of given numbers of participating DMs in the analyzed applications. The average number of participating DMs in the analyzed applications was 6.4 and the mode was 3. Applications with three or four participating DMs have been also quite frequent. In nine studies (26.5%), the weights of the DMs were taken into account in obtaining the results (RQ3.6). Among these, seven studies (20.6%) used methods to calculate the weight values of the DMs, and in two studies (5.9%) numerical values were attributed directly to weight the DM opinions.

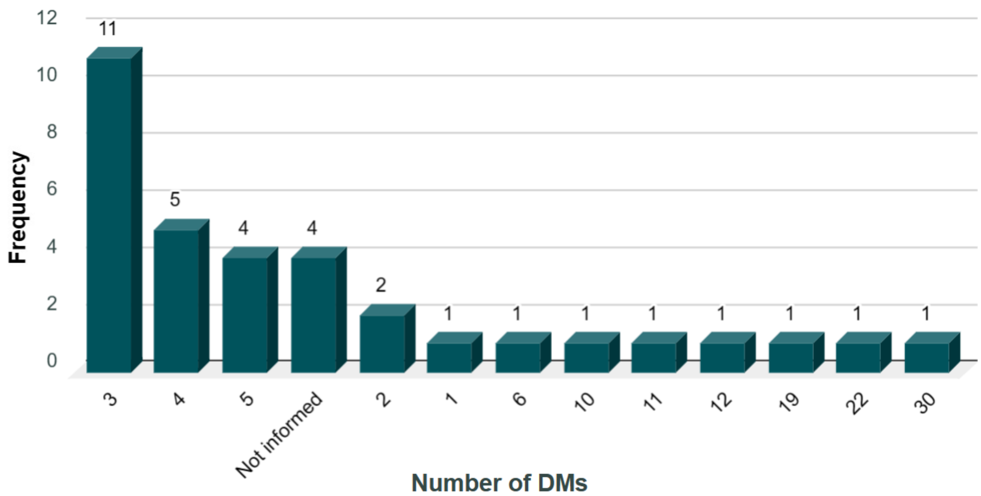


Figure 11. Frequency of Studies with Given Numbers of DMs in the Analyzed Applications.

In terms of the approaches adopted to manipulate the individual preferences of the DMs (RQ3.7), 31 (88.2%) applied a decision-making technique or a mathematical operator to aggregate DM preferences; for example, VHFLPWA, Interval Weighed Geometric Aggregation (IWGA), OWA, HFLWA, DHHLWA, GWOWA, and GMSM. Three studies (11.8%) presented a decision-making matrix obtained by consensus without specifying how this consensus among the various DM evaluations was achieved. Only four studies (11.8%) applied iterative methods in the search for consensus. These methods made it possible to suggest modifications to the DM evaluations by calculating measures of consensus during the evaluation rounds. Examples of iterative methods seeking consensus were presented in Liu et al. [51], Wu et al. [75], Divsalar et al. [73], and Erol et al. [53].

Table 10. Classification of the Studies in terms of Group Decision-Making (GDM).

Author(s)	Supports GDM?	Number of DMs	Allows Weighting of DM Opinions?	How Were DM Weights Assigned?	Method Used to Calculate DM Weights	Aggregates DM Opinions?	Procedure Used to Aggregate DM Opinions	Applies Iterative Consensus Method?
Tüysüz and Şimşek [54]	Yes	3	No	N/A	N/A	Yes	HFLTS-AHP	No
Osiro et al. [19]	Yes	3	Yes	N/A	N/A	Yes	HFLTS-QFD	No
Wang et al. [11]	Yes	3	No	N/A	N/A	Yes	HM	No
Chang et al. [59]	Yes	4	No	N/A	N/A	Yes	OWGA	No
Wu et al. [58]	Yes	30	No	N/A	N/A	Yes	Fuzzy arithmetic mean	No
Liao et al. [49]	Yes	4	Yes	Attributed numeric values	N/A	Yes	IWGA	No
Pérez-Domínguez et al. [55]	Yes	6	No	N/A	N/A	Yes	HFLTS-TOPSIS	No
Yalçın et al. [61]	Yes	5	No	N/A	N/A	Yes	Ordered Weighted Average (OWA)	No
Krishankumar et al. [77]	Yes	3	No	N/A	N/A	Yes	GMSM	No
Li et al. [69]	Yes	5	No	N/A	N/A	Yes	GWOWA	No
Qu et al. [74]	Yes	3	No	N/A	N/A	Yes	Degree of group satisfaction and the regret theory	No
Wang et al. [68].	Yes	Not informed	No	N/A	N/A	Yes	DHHFLTS-ORESTE	No
Ren et al. [81]	Yes	4	No	N/A	N/A	Yes	Programming model	No
Zhang et al. [70]	Yes	Not informed	No	N/A	N/A	Yes	Ratio index-based probabilistic linguistic	No
Zhang et al. [71]	Yes	5	No	N/A	N/A	Yes	HFLTS-BWM	No
Krishankumar et al. [78]	Yes	3	Yes	Calculated	Mathematical model	Yes	GMSM	No
Liu et al. [51]	Yes	4	Yes	Attributes numeric values	N/A	Yes	Based on degrees of hesitancy and similarity	Yes
Büyüközkan and Güler [56]	Yes	3	No	N/A	N/A	Yes	AHP and OWA	No
Lima-Junior and Hsiao [52]	Yes	2	No	N/A	N/A	Yes	HFLTS-TOPSIS	No
Zolfaghari and Mousavi [79]	Yes	3	No	N/A	N/A	Yes	Interval-valued Hesitant Fuzzy Linguistic Prioritized Weighted Average	No

Table 10. *Cont.*

Author(s)	Supports GDM?	Number of DMs	Allows Weighting of DM Opinions?	How Were DM Weights Assigned?	Method Used to Calculate DM Weights	Aggregates DM Opinions?	Procedure Used to Aggregate DM Opinions	Applies Iterative Consensus Method?
Shen and Liu [65]	Yes	Not informed	No	N/A	N/A	Yes	DHHFLTS-COPRAS	No
Wu et al. [75]	Yes	10	No	N/A	N/A	No	N/A	Yes
Finger and Lima-Junior [8]	Yes	1	No	N/A	N/A	Yes	HFLTS-QFD	No
Erol et al. [53]	Yes	19	No	N/A	N/A	Yes	HFLTS-Delphi and HFLTS-ANP	Yes
Qin et al. [9]	Yes	Not informed	No	N/A	N/A	No	N/A	No
Divsalar et al. [73]	Yes	12	No	N/A	N/A	No	N/A	Yes
Borges et al. [4]	Yes	2	No	N/A	N/A	Yes	HFLTS-TOPSIS	No
Duan et al. [67]	Yes	5	Yes	Calculated	Non-linear programming and genetic algorithm	Yes	Double Hierarchy Hesitant Linguistic Weighted Average (DHHLWA)	No
Dai et al. [66]	Yes	3	Yes	Calculated	Entropy Weight Method	Yes	Entropy Weight Method	No
Wu et al. [80]	Yes	3	Yes	Calculated	Optimization model	Yes	Optimization model	No
Lima et al. [82]	Yes	4	No	N/A	N/A	Yes	HFLTS-AHP and OWA	No
Krishankumar et al. [64]	Yes	3	Yes	Calculated	WDA algorithm	Yes	Attitudinal-CRITIC approach	No
Dolatabad et al. [50]	Yes	11	Yes	Calculated	Method not defined	Yes	Hesitant Fuzzy Linguistic Weighted Average (HFLWA)	No
Zheng et al. [57]	Yes	22	Yes	Calculated	Maximizing consensus approach	Yes	HFLTS-DEMATEL	No

Finally, another important aspect of these applications has to do with how their results were validated. As presented in Figure 12, the results in 12 studies (35.3%) were validated by comparing them with the results of other decision-making methods applied to the same problem (RQ3.8). In general, this comparison is based on the ranking or categorization (sorting) supplied for each analyzed method. In 11 studies (23.5%), the authors compared the obtained results with those furnished by other methods and also conducted sensitivity analysis tests. Sensitivity analyses were utilized in an isolated manner in four studies (11.8%). The main purpose of sensitivity analyses is to verify alterations in the outputs furnished by the model when the input parameter values are varied. In three studies (8.8%), the results were validated through a combination of sensitivity analysis, comparisons with other methods, and statistical tests. In addition, three studies featured just one application without specifying how the results were validated. Just one study validated the results by comparing them with real data.

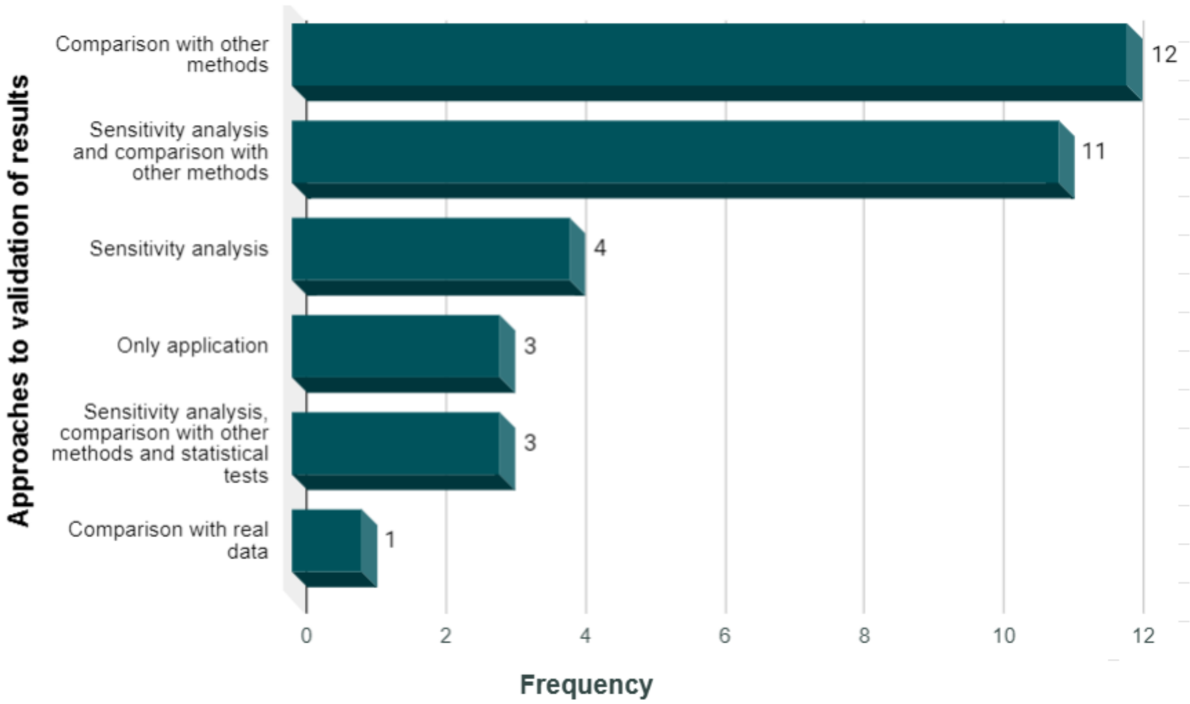


Figure 12. Approaches Utilized to Validate the Analyzed Study Results.

4.5. Comparison of the Results of Previous Studies

The results of this study were compared to those of previous literature review studies on subjects related to our objective. Thus, as in Yu et al. [24], which analyzed 1080 studies based on HFS and HFS extensions, this study found that the HFLTS approach proposed by Rodríguez et al. [14] was the most utilized in the analyzed studies. In terms of the type of SCM strategy, our results were similar to the study by Lima-Junior and Carpinetti [6], which investigated decision-making models to evaluate supply chain performance. Both studies indicated the predominance of sustainable and green supply chains. In terms of the procedures adopted to validate their results, Lima-Junior and Carpinetti [6] related the prevailing use of sensitivity analysis followed by statistical techniques and comparisons with other methods, while our study concluded that comparisons with other methods have been the most utilized validation procedure followed by sensitivity analysis combined with comparisons with other methods.

The results of this study indicated that the most frequently adopted techniques in integrated models have been TOPSIS, FMEA, AHP, DEMATEL, and QFD; while in Lima-Junior and Carpinetti's study [6], the AHP and Data Envelopment Analysis (DEA) techniques and linear programming predominated. In terms of the SCM processes that had the most applications, in analyzing artificial intelligence techniques in SCM, Yang et al. [5] found that the Return and Make processes had fewer applications, while our study found that the least studied processes have been Return and Delivery. On the other hand, while Yang et al. [5] found that the Enable and Plan processes had the most applications, this study found that the Source and Enable processes have had the most applications.

Finally, in terms of the economic sectors of the participating companies that have received these applications, Yang et al.'s study [5] noted the predominance of retail, food, and manufacturing; while our study showed a prevalence in the automotive, health, and electro-electronic industries. These results were somewhat similar to those found by Lima-Junior and Carpinetti [6], who related that the sectors that received the most applications of decision-making models were the automotive, food, and electro-electronic industries.

5. Recommendations for Future Research

The results of our systematic review of the literature identified various research gaps in this subject. Based on such gaps, as well as those in SCC [48], Lima-Junior and Carpinetti [6], Wang et al. [11], Kabak [47], and Yang et al. [5], we proposed a framework that seeks to help researchers and managers develop future studies on this subject. The framework presented in Figure 13 encompasses pertinent recommendations regarding the following topics: innovative applications of techniques; new combinations of decision-making techniques; comparative studies of decision-making techniques; GDM issues; and validation procedures for new decision-making support models.

As indicated in Figure 13, we recommend taking into account the participating economic sector and the type of SCM strategy of the company participating in the application for various types of future studies, since this has a strong influence on the choice of criteria and the assessment of their weights. Since there is no single decision-making method, each technique has benefits and limitations that depend on the context of the application [26]. Thus, the choice of MCDM methods to be applied must take into account aspects such as: the purpose of the application; the type of decision-making problem; the number of alternatives, the criteria, and the DMs involved; the nature of the criteria; the format for representing DM preferences; and the need to weigh DM opinions among other factors. Thus, choosing a suitable decision-making method requires a detailed analysis of the features of the techniques and the problem in question. Proposing new hybrid techniques has the potential to bring together the benefits of HFLTS approaches with techniques traditionally used in companies, which will thus generate more appropriate solutions for each context.

5.1. Innovative Applications

The results of this study indicated that the use of HFLTS and HFLTS extension techniques has still not been tested in various decision-making problems that are important to ensure effective SCM. Problems related to the delivery and return processes have been less studied until now. There are also various types of industries that have not participated in HFLTS and HFLTS extension applications.

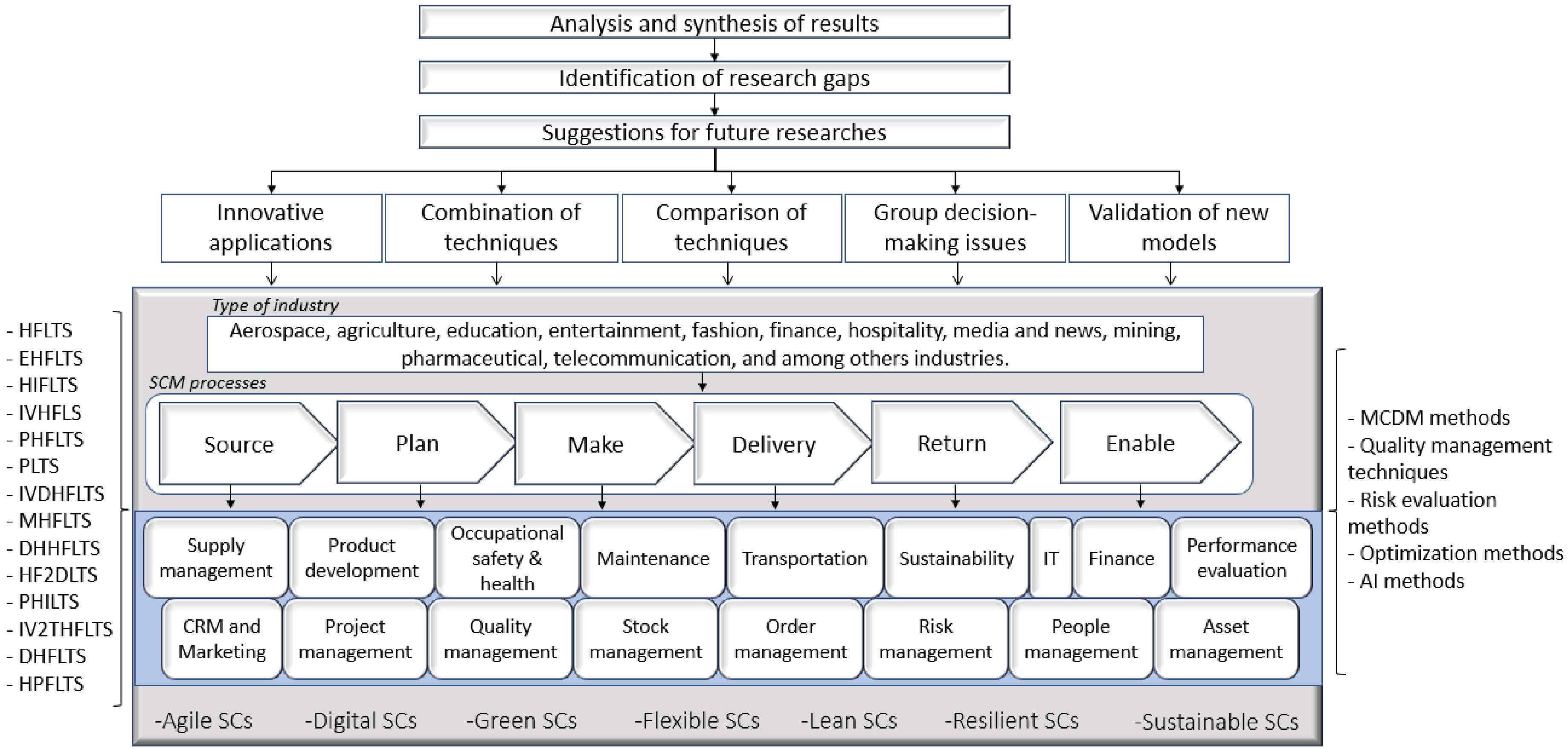


Figure 13. Framework to Guide the Development of Future Studies on this Subject.

As Figure 13 illustrates, SCM processes span various business areas that present multiple-criteria decision-making problems for which few or no applications have been applied. The use of HFLTS and HFLTS extension techniques has great potential to contribute to applications dealing with these problems due to the capacity of these techniques to provide support for GDM under conditions of uncertainty. Based on the research opportunities that we have identified, below is a list of SCM problems that involve selecting, ordering, and categorizing that can be explored in future works. It includes problems associated with various business areas that involve strategic, tactical, and/or operational decision making:

1. Asset management: prioritization of asset management investments, strategic asset allocation, selecting the location of new installations, and layout selection;
2. Customer relationship management (CRM) and marketing: marketplace selection, marketing strategy selection, market segmentation, customer satisfaction analysis, and customer relationship management software selection;
3. Finance: credit risk evaluation, corporate financial performance analysis, investment appraisal, budget allocations, and the evaluation of financial plans;
4. Information technology (IT): information system selection, computer workstation selection, software quality evaluation, IT service provider selection, and disruptive Industry 4.0 technology evaluation;
5. Maintenance: maintenance strategy selection, maintenance service provider selection, maintenance machine selection, and the prioritization of maintenance activities;
6. Occupational safety and health: accident risk evaluation, the selection of key indicators for improving the occupational safety system, the prioritization of emergency plans, individual protection equipment selection, and system reliability evaluation;
7. Order management: prioritization of production orders, order delivery evaluation, and the prioritization of plans to improve order management;
8. Product development: product development strategy selection, new product material selection, prototype evaluation, and product portfolio evaluation;
9. Project management: project proposal selection, project risk evaluation, project performance indicator selection, project management practice maturity evaluation, and program and/or project success evaluation;
10. Quality management: Six Sigma project selection, benchmarking, product or service requirement prioritization, selection of the certifying body for the implementation of ISO 9001 certification, and prioritization of continual improvement actions;
11. Risk management: risk evaluation tool selection, organizational risk evaluation, and supply chain risk evaluation;
12. Stock management: stock management strategy selection, ABC classification of stocks, warehouse location selection, and warehouse structure selection;
13. Supply management: make or buy, supplier performance monitoring, supplier segmentation, and supplier development program evaluation;
14. Personnel management: organizational climate evaluation, personnel selection, position evaluation, and skills and qualifications evaluation;
15. Sustainability: waste treatment alternative evaluation, prioritization of sanitary landfill location selection actions, prioritization of actions designed to promote sustainability, evaluation of the barriers to the adoption of sustainable practices, and product lifecycle evaluation;
16. Transportation: route selection, modes of transport evaluation, logistics service provider selection, vehicle selection, and geographic information system selection.

The suggested applications open a gamut of possibilities for new studies. On one hand, one can explore problems that still have not been addressed with applications, such as those related to asset management, finance, IT, maintenance, marketing, occupational safety and health, order management, and stock management, among other areas. On the other hand, one can test the use of techniques that still have not been applied to problems that have received more attention, such as supplier selection, failure evaluation, and performance evaluation. These applications can involve companies in sectors that have not been very studied until now or firms in sectors that have not had any applications, such as aerospace, agriculture, education, entertainment, fashion, finance, hospitality, media and news, mining, pharmaceuticals, and telecommunications. It is also important to take SCM strategies into account in each case. Applications related to agile, flexible, and resilient supply chains have received less attention in recent studies. Different combinations of SCM strategies could also be studied in future studies.

5.2. Technique Integration

The results indicated that the choice, ordering, or sorting of alternatives has rarely been conducted using HFLTSs or one of their extensions alone. Instead, HFLTSs and HFLTS extensions have usually been combined with other methods. However, there are various combinations of HFLTS and HFLTS extension techniques and other types of methods that still have not been tested in SCM problems.

Although HFLTSs and their extensions can be used to calculate criteria weights, in many cases techniques based on paired comparisons have been used. The most frequent of these is the AHP method, which requires a greater amount of judgment from DMs and also requires consistency tests. Therefore, there are several opportunities for using HFLTS approaches in defining criteria weights and evaluating possible inter-relationships between criteria. The use of HFLTS extensions in these cases can bring greater flexibility to representing criteria weights and avoid a loss of information in the initial stages of the decision-making problem.

Given the low frequency of applications that employed the DHFLTS, EHFLTS, HPFLS, IVHFLTS, and MHFLTS techniques, as well as the absence of applications based on HIFLTS, PHFLTS, IVDHFLTS, HF2DLTS, PHILTS, IV2THFLTS techniques, future studies could test new combinations of these approaches with MCDM methods, quality management techniques, risk evaluation techniques, optimization methods, and/or artificial intelligence techniques.

Although the EHFLTS and MHFLTS approaches are especially useful for GDM problems in which it is necessary to aggregate the preferences of several DMs, repeated linguistic terms of the global set of evaluations are not accounted for, which can lead to a loss of information. In view of this, the adoption of PHFLTSs, PLTSs, and PHILTSs is more appropriate because they take into account each term that appears in the individual or subgroup evaluation of the DMs and at the same time assign greater weights to the terms that appear more frequently.

Since HIFLTSs, IVDHFLTSs, DHFLTSs, and HPFLTSs take into account the number of membership and non-membership degrees, these approaches can be applied in GDM that involves high complexity and risk. On the other hand, IVHFLSs are appropriate when the group's opinion is given according to the limits of the valued intervals and are not appropriate for preserving the individual preferences of the DMs. Thus, IVHFLSs can be used in problems with more homogeneous groups and are not suitable for situations in which there is no consensus.

New hybrid methods can be created based on MCDM methods, which have great potential for integration with HFLTS approaches but have rarely or never been used, such as ORESTHE, ARAS, CODAS, CoCoSo, Delphi, ELECTRE (ÉLimination Et Choix Traduisant la REalité in French), Measurement of Alternatives and Ranking according to Compromise Solution (MARCOS), Measuring Attractiveness by a Categorical Based Evaluation Technique (MACBETH), ORESTE, PROMETHEE, the Qualitative Flexible Multiple Criteria Method (QUALIFLEX), the Simple Multi-Attribute Rating Technique (SMART), and SWARA.

There are also quality management techniques such as QFD, Service Quality Measurement (SERVQUAL), and the GUT matrix (a process prioritization matrix based on Gravity, Urgency, and Tendency) that are multicriteria in nature and can be integrated with HFLTS extensions to create new MCDM methods. Similarly, FMEA, risk matrix, and fault tree analysis can be combined with these approaches to generate new methodologies for risk evaluation.

In cases in which a problem step seeks to order, select, or sort alternatives while another step seeks to optimize resources, one can use combinations with optimization methods such as linear programming, non-linear programming, stochastic programming, and dynamic programming. On the other hand, for problems that seek to classify patterns or predictions and/or group values and/or require the analysis of a large quantity of data, HFLTS approaches can be combined with AI methods such as artificial neural networks, neuro-fuzzy systems, genetic algorithms, and case-based logic.

5.3. Comparison of Techniques

The results of our study also demonstrated the need to conduct comparative studies involving MCDM techniques based on HFLTSs and HFLTS extensions. Even though some of the analyzed studies compared the numeric outputs of distinct techniques when applied to the same problem, the literature offered few comparative studies that discussed the benefits and limitations of HFLTS and HFLTS extension techniques in specific problem domains.

The realization of these comparative studies would contribute to a greater understanding of the technical characteristics being compared and could assist researchers and practitioners in choosing the most appropriate techniques for given SCM problems. In addition to comparing the outputs generated by each technique, it is recommended that these studies take into account comparison factors such as computational complexity, limitations in terms of the number of input variables, the effect of variations in criteria and alternatives, support for GDM, and agility in the decision-making process [26].

The realization of studies that compare various HFLTS extensions could also be valuable in mapping the advantages in use as well as the similarities and differences among these approaches. These comparative studies could take into account factors such as the complexity of modeling and processing, the effect of differences in the representation of DM preferences, and the appropriateness of each approach in dealing with various types of uncertainty. The behavior of various aggregation operators for HFLTS and HFTLS extension information could also be analyzed.

5.4. GDM Issues

There are some topics related to GDM in SCM that have been little studied and deserve more attention. Even though all of the analyzed studies provided support for GDM, we verified that there are few methods that make it possible to attribute weights to the DMs. This may be especially useful when one wants to weight the opinion of DMs based on their level of experience, positions, and/or knowledge of a problem. In addition, since methods that allow the attribution of weights to DMs using linguistic expressions were not found, we suggest the development of methods that make this possible to deal appropriately with uncertainty in the definition of DM weights.

An important emergent research topic is large GDM problems. These problems are a special case in terms of GDM processes in which the opinions of a large number of people are collected. There are various large GDM problems inherent to SCM that could be investigated in future works; for example, strategic decisions that involve DMs from various departments or organizations or product or service evaluations conducted by a gamut of customers. In cases in which the number and diversity of DMs are large, we recommend the adoption of EHFLTS techniques, which make it possible to organize DMs in subgroups and avoid losses of information in situations in which there is no consensus among the DMs.

Finally, another relevant topic regarding GDM that requires more investigation has to do with models based on the consensus-reaching process. There are a variety of opportunities to develop new models of this type that can be explored through a combination of iterative methods with HFLTS and/or HFLTS extension techniques. One of them consists of the development of new approaches that combine the Delphi method with HFLTS extensions. In addition, it would be interesting to test new consensus models that propose modifications to DM preferences as well as models based on adaptive consensus strategies that automatically update DM weights with each iteration.

5.5. Validation of New Decision-Making Models

Future studies could use validation procedures that have been little explored to evaluate the reliability of the results of new decision-making models. Given that most studies currently conduct sensitivity analysis tests and compare their results with other methods, it is plausible to adopt statistical techniques such as hypothesis tests, variance analysis, and error measurements that analyze the obtained results. The use of similarity measures is also a useful way to compare the results generated by different techniques. In addition, the realization of factor analysis experiments would make it possible to identify which input variables have the greatest influence on the results.

To verify the consistency of the obtained results, it is important to conduct tests that consider a larger number of application cases in order to evaluate the performance of these techniques under distinct scenarios while varying the number of alternatives, criteria, and linguistic terms. We also recommend verifying the usability of HFLTS and HFLTS extension techniques by users who are not specialists in dealing with these techniques. To accomplish this, we suggest that future studies develop software with graphical interfaces based on these techniques to verify their usability in various organization areas.

6. Conclusions

This study presented a systematic review of the literature on applications of HFLTS and HFLTS extension techniques in SCM decision-making problems. In order to answer a series of research questions regarding this subject, the selected studies were characterized in accordance with a group of factors related to their origin, SCM, HFLTSs, and decision making. The results demonstrated that this research subject is quite recent and that there has been substantial growth in the number of publications about this topic. The applications we identified provide support for a wide variety of decision-making problems; their main focuses were on supplier selection, failure evaluation, and performance evaluation. The results reinforced the high applicability of HFLTSs and their extensions to business practices, since companies from any economic sector can adopt these techniques in their decision-making processes no matter whether they are strategic, tactical, or operational.

We verified the predominance of the use of HFLTS, TOPSIS, and FMEA techniques. Among HFLTS extensions, we can highlight DHHFLTS and PLTS applications. Applications in automotive firms and sustainable supply chains have received the most attention. It was confirmed that all of the analyzed models are appropriate for providing support for GDM, even though few of them permit the attribution of distinct weights to DMs. There were also few models designed to obtain a consensus among DMs. The results of this study demonstrated that even though there is a wide variety of HFLTS extensions, we did not find SCM applications for around half of them. There are also various types of SCM strategies, industries, and decision-making problems that deserve greater attention from researchers and practitioners. A challenge for real applications is to computationally implement HFLTS techniques and their extensions, since decision-making software products based on these techniques are still rare. Although most of them can be implemented using spreadsheet software such as MS Excel, the development of new forms of software with a graphical interface can simplify their use and contribute to the greater adoption of these techniques by users who are not specialists in HFLTSs.

The main contribution of this study consists of presenting an overview of the use of HFLTSs and HFLTS extensions in SCM in practice, highlighting trends and research opportunities. Our study presented a wide array of directions for future studies that encompass topics related to innovative applications, combinations of techniques, comparisons of techniques, GDM issues, and validation procedures for new decision-making models. To our knowledge, this was the first study to present a systematic review that focused on real applications of HFLTS and HFLTS extension techniques. It was also the first study to analyze applications of decision-making techniques that deal with hesitation in SCM. The analyzed techniques can be applied to various fields in SCM. That being said, we believe that this study can contribute to the dissemination of the use of HFLTSs and HFLTS extensions to minimize the effects of uncertainty on the results.

Finally, a limitation of this study was that there may be works that present HFLTS or HFLTS extension applications that were not identified in our searches. Even though we consulted various databases, this list was not exhaustive. In addition, we opted to include only articles in English and did not include gray literature or non-realistic numerical applications. Future studies can complement the results of this systematic review of the literature by including new works in the study sample. Other reviews can also be conducted that consider applications of techniques derived from HFSs and HFS extensions in various areas of knowledge such as the engineering, health, construction, and energy fields.

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