Review

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

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An overview on Applications of Hesitant Fuzzy Linguistic Term Sets in Supply Chain Management: State of Art and Further 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 as a whole. 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 have been classified in accordance with a group of factors that are pertinent to the origins of these studies, SCM, HFLTSs, and decision-making. The results demonstrate 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 and Sustainable SCM and Green SCM strategies predominate in the analyzed studies. Even though most of the studies use techniques based on HFLTSs, we have identified applications of seven distinct HFLTS extensions, with Double Hierarchy Hesitant Fuzzy Linguistic Term Sets and Probabilistic Linguistic Term Sets being the most utilized. The identification of gaps in the literature presents avenues for future studies focused on innovative applications, integrations of techniques, comparisons of techniques, group decision-making, and validation procedures for new models. The results of this study offer a panorama of the state of the art in regard to this subject and can help researchers and practitioners develop new studies which involve the use of methods that employ HFLTSs and HFLTS extensions in SCM decision-making problems.

Keywords: hesitant fuzzy linguistic term sets; supply chain management; decision making; systematic literature review

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 look 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 more and more often in making decisions which 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 which 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 more and more attention, because they support complex modular linguistic expressions and provide support to DMs when they have hesitation in choosing 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 which 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 appropriate in helping DMs deal with uncertainty and hesitation, the use of HFLTS approaches frequently is justified by their ability to support group decision-making processes which are recurrent in SCM.

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], and supply chain performance evaluation models [6], 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 in 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 which cover 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 [11,12,20,21]. There is also a bibliometric review based on metadata from 1,080 studies of Hesitant Fuzzy Sets (HFSs) and their extensions [22]. Even though these studies are of great importance in summarizing theoretical knowledge about linguistic information modeling, they do not discuss HFLTS applications in practical problems. Moreover, the conducting of a systematic review of the literature focusing on HFLTS applications for SCM is justified for the following reasons:

i. There is a need to map the contexts where 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;
ii. It is important to investigate issues regarding SCM decision-making processes and methods, such as for example, the types of decision-making problems in which HFLTS techniques are applied, the most often used techniques, support for group decision making, and the way the application results are validated. 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 will be able to support managers in the decision-making processes which are inherent in SCM.

Table 1. Literature review studies which encompass HFLTS.

	Liao *et al.* [20]	**Morente-Molinera *et al.* [21]**	**Wang *et al.* [11]**	**Wang *et al.* [12]**	**Yu *et al.* [22]**
Focus	Survey of decision-making theory and HFLTS methodologies	Review of approaches to multi-granular fuzzy linguistic modeling	Recent review of HFLTS developments and their classification according to HFLTS computational strategies	Mapping of complex modeling techniques which employ linguistic expressions	Bibliometric analysis of 1,080 articles about HFSs and their extensions
Theories and/or approaches analyzed	HFLTSs, fusion theory, Hesitant Fuzzy Linguistic (HFL) measurement theory, HFL preference relationship theory, and HFL decision making	Approaches based on fuzzy membership functions, HFLTSs, 2-tuples, hierarchical trees, description spaces, and discrete fuzzy numbers		HFLTSs, EHFLTSs, linguistic HFSs, and 2-dimensional linguistic terms, among others.	Aggregation operators, decision making, information measures, preference relationships, and HFS extensions
Analysis of real applications	No	No	Identifies 20 applications in various areas and classifies them by the computational strategy adopted	No	No
Comparison between theories and/or 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 used to solve SCM decision-making problems in order to answer relevant research questions about this subject (which will be detailed in Section 3). The PRISMA™ (Preferred Reporting Items for Systematics Reviews and Meta-Analyses) 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 makes 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 describes the methodology for this systematic review of the literature; Section 4 will discuss the results; Section 5 presents recommendations for future studies; and Section 6 will consist of our conclusions and the limitations of this study.

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2. HFLTSs and HFLTS Extensions

Ever since it was proposed by Professor Lofti Zadeh [23], Fuzzy Set Theory has been applied successfully to various problems which involve imprecise, vague, and imperfect information [14,24]. 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 which are used by DMs to express their preferences [16,25].

Based on Fuzzy Set Theory, Torra [26] 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 [26], Rodríguez *et al*. [14] proposed HFLTS, 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 [27].

Considering a set of defined linguistic terms such as $S = \{s_{-\tau}, \cdots, s_0, \cdots, s_\tau\} = \{s_{-2}\text{: very low}, s_{-1}\text{: low}, s_0\text{: medium}, s_1\text{: high}, s_2\text{: very high}\}$, an HFLTS defined as $H_S(\vartheta)$= $\{ s_i \mid s_i \in S\}$ consists of a finite ordered subset of linguistic terms of S. Thus, $H_S(\vartheta)$= $\{s_{-2}$:very low, s_{-1}:low$\}$ and $H_S(\vartheta)$= $\{s_{-1}$:low, s_0:medium, s_1: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 judgement. Examples of linguistic expressions include "between very low and low" $\{s_{-2}, s_{-1}\}$, "at least high" $\{s_1, s_2\}$, "at most medium" $\{s_{-2}, s_{-1}, s_0\}$, and "lower than high" $\{s_2\}$ } [8,27]..

Based on the pioneering work of Rodríguez et al. [14], other authors proposed new operators for HFLTSs [28–30], measures of distance and similarity [31,32], techniques that support group decision making [18,19], and consistency and consensus methods for group decision making [33], among other advances. Extensions for HFLTSs also appeared, which opened new possibilities for modeling uncertainty in decision-making processes. Table 1 presents examples of the main HFLTS extensions which are described below:

Table 1. Summary of HFLTS extensions.

ID	Approaches	Author(s)	Mathematical representation	Example
i.	EHFLTS	Wang [15]	$\{ s_i \mid s_i \in S\}$	$\{s_2, s_4, s_5\}$
ii.	HIFLTS	Beg and Rashid [18]	$\{\langle x, h(x), h'(x)\rangle \mid x \in X\}$	$\langle(s_1, s_2, s_3)(s_3, s_4)\rangle$
iii.	IVHFLS	Wang *et al*. [34]	$\{\langle x, s_{\theta(x)}, \tilde{\Gamma}_A(x)\rangle \mid x \in X\}$	$\langle s_5, \{[0.4, 0.5], [0.6, 0.7]\}\rangle$
iv.	PHFLTS	Chen *et al*. [16]	$\{(s_i, p_i) \mid s_i \in S, i = 0,1, \ldots, g\}$	$\{(s_4, 0.2), (s_6, 0.6)\}$
v.	PLTS	Pang *et al*. [35]	$\left\{L^{(k)}(p^{(k)}) \mid L^{(k)} \in S, p^{(k)} \geq 0, k = 1,2, \ldots, \#L(p), \sum_{k=1}^{\#L(p)} p\right\}$	$\{s_4(0.1), s_5\ (0.65), s_6(0.2)\}$
vi.	IVDHFLTS	Qi *et al*. [36]	$\{\langle x, s_{\theta(x)}, \tilde{h}(x), \tilde{g}(x)\rangle \mid x \in X\}$	$\{s_3\{[0.4, 0.4], [0.5, 0.5]\}, \{[0.$
vii.	MHFLTS	Wang *et al*. [37]	$\{\langle x, h_{MS}(x)\rangle \mid x \in X\}$	$\{s_1, s_3, s_{54}\}$

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viii.	DHHFLTS	Gou *et al.* [38]	$S_o = \{S_{t<o_k>} \mid t = -\tau, \dots, -1,0,1, \dots, \tau; \ k = -\varsigma, \dots, -1, 0, 1, \dots, \varsigma\}$	$\{s_{2<o_1>}, s_{3<o_0>}\}$
ix.	HF2DLTS	Liu *et al.* [39]	$\{\langle x, \hat{h}_S(x)\rangle \mid x \in X\}$	$\{(\dot{s}_3, \ddot{s}_4), (\dot{s}_4, \ddot{s}_4), (\dot{s}_5, \ddot{s}_3)\}$
x.	PHILTS	Malik *et al.* [25]	$\{\langle x, l(x)p(x), \ l'(x)p'(x) \rangle \mid s_i \in S\}$	$\{s_2(0.4), s_3(0.1), s_4(0.35)\},$
xi.	IV2THFLTS	Si *et al.* [17]	$\{\langle x, h_s(x), \tilde{\Gamma}_A(x)\rangle \mid x \in X\}$	$\langle\{s_3, s_4\}, [0.7, 0.8]\rangle$
xii.	DHFLTS	Zhang *et al.* [40]	$\{\langle x_i, H_s(x_i), h_s(x_i), g_s(x_i)\rangle \mid x_i \in X\}$	$\{s_2\{0.7, 0.5, 0.3\}\{0.3, 0.2\}, s_3$
xiii.	HPFLTS	Yang *et al.* [41]	$\{\langle (s_i^k), (\mu_i^k, \eta_i^k, \nu_i^k)\rangle \mid i \in x\,(0,1, \dots, m); k = 1,2, \dots, \alpha\}$	$\{(s_2, (0.7, 0, 0)\}$

i. Extended HFLTS (EHFLTS): makes it possible to create sets of non-consecutive ordered terms based on a combination of HFTLS data for a group of DMs. The values are computed as a function of the possible terms in each group [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 [42];

ii. 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. 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]

iii. Interval-Valued Hesitant Fuzzy Linguistic Set (IVHFLS): is an HFLTS extension based on Interval-Valued HFSs. 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 which are defined in (0, 1] [34]

iv. Proportional HFLTS (PHFLTS): 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. This approach is different, because it takes into account proportional information for each generalized linguistic term. Each linguistic term which 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;

v. 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 each PLTS, $L(k)(p(k))$ 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 $L(p)$ [35];

vi. Interval-Valued Dual Hesitant Fuzzy Linguistic Set (IVDHFLTS): considers a function for the possible membership degrees and another function for the possible degrees which do not belong to the $s_{\theta(x)}$ terms selected by the DMs. $\tilde{h}(x)$ is a set of closed interval values defined in [0,1], which denote the possible membership degrees of $s_{\theta(x)}$; $\tilde{g}(x)$ is a set of closed interval values defined in [0,1] which represent the possible non-membership degrees [36];

vii. Multi-Hesitant Fuzzy Linguistic Term Set (MHFLTS): is an extension based on HFLTS and HFL elements, in which each set can contain repeated and non-consecutive linguistic terms. Considering the sets of terms $\hat{S} = \{ s_k \mid k \in [0,l]\}$ 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 [37];

viii. Double Hierarchy Hesitant Fuzzy Linguistic Term Set (DHHFLTS): is composed of two independent hierarchies of linguistic terms. Considering $S = \{s_t \mid t = -\tau, \dots, -1,0,1, \dots, \tau\}$ as the first hierarchy and $O = \{o_k \mid k = -\varsigma, \dots, -1, 0, 1, \dots, \varsigma\}$ as the second, $s_{t<o_k>}$ is defined as a

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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 "medium or between a little bad and very bad" [38];

ix. Hesitant Fuzzy 2-Dimension Linguistic Term Set (HF2DLTS): was proposed based on the concept of two-dimensional linguistic variables. Each set is made up of possible linguistic terms which represent a DM's assessment of an alternative, with each term having a degree of importance denoted by a linguistic term. If X is a fixed set and $S^{(1)} = \{\dot{s}_0, \dot{s}_1, \dot{s}_1, \ldots, \dot{s}_{g-1}\}$ and $S^{(2)} = \{\ddot{s}_0, \ddot{s}_1, \ddot{s}_1, \ldots, \ddot{s}_{t-1}\}$ two sets of linguistic terms, each HF2DLTS has a function $\hat{h}_s(x) = \bigcup_{(\dot{s}_a(x), \ddot{s}_b(x)) \in \hat{h}_s(x)} \{(\dot{s}_a(x), \ddot{s}_b(x))\}$, $\dot{s}_a(x)$ is a set of consecutive terms in $S^{(1)}$, and $\ddot{s}_b(x)$ is a two-dimensional piece of linguistic information which 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 ($\dot{s}_4$) is very good" [39];

x. Probabilistic Hesitant Intuitionistic Linguistic Term Set (PHILTS): arose from the combination of HIFLTS and PLTS to reflect the probabilities of DM assessments. Thus, 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 [25];

xi. Interval-Valued 2-Tuple HFLTS (IV2THFLTS): is a combination of HFLTS with interval numbers. Each IV2THFLTS has a function $\tilde{I}_A(x)$, 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 of information and improves the accuracy of the decision-making results [17];

xii. Dual HFLTS (DHFLTS): is the result of a combination of HFLTSs and Dual HFSs. DHFLTS includes the possible membership and non-membership degrees of $h_s(x_i)$ 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 taking this decision [40];

xiii. Hesitant Picture Fuzzy Linguistic Set (HPFLTS): is based on Picture 2-Tuple Linguistic Term Sets and arose to avoid the loss of DM information. In this representation, each term selected by the DM (s_i^k) is accompanied by the crisp values of the positive membership degrees (μ_i^k), of the undetermined membership degrees (η_i^k), and the negative membership degrees (ν_i^k) [41]. Another distinguishing characteristic of it is that this approach takes into account the refusal information concerning DMs for each assessment.

More information about HFLTS extensions can be consulted in the references indicated in Table 1. It is important to emphasize that even though the research presented in Table 1 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.

3. Methodological Procedures

This systematic review of the literature was developed using the PRISMA™ methodology. According to Page et al. [43], 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 which help ensure the robustness and reliability of systematic literature review studies [43]

Table 3 presents the research protocol developed based on the PRISMA™ methodology used to conduct this study. The Parsifal software was used to support the planning and conducting steps. Later, during the reporting step, MS Excel software was used to prepare our graphs to summarize the findings. A set of research questions was defined by the authors to present information which makes it possible to provide an overview of the use of HFTLS and HFLTS extension techniques in SCM. The research questions RQ1.1 to RQ1.4 deal with information related to the origin of the selected studies, while RQ2.1 to RQ2.4 investigate questions related to SCM, and RQ3.1 to RQ3.8 are focused on questions about HFLTSs and decision making.

The keywords used in the search string were defined to cover studies which involve 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, 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 about HFLTS dates from 2012 [14]. The searches were performed in March 2023. During the selection of our study sample, we only included journal articles published in English which presented real HFLTS or HFLTS extension applications used in SCM problems. 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 which were not within the scope of this review of the literature. In addition to the cited databases, we also selected studies using citation searching and searches of the Research Gate website (https://www.researchgate.net/).

Table 3. Research Protocol Developed for this Study.

Steps	Research elements	Description
Planning	Population	Studies which 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?

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		RQ3.7. In terms of applications that deal with group decision making, do they use methods to obtain a consensus among the DMs 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.
		- 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, Web of Science, and the Wiley Online Library.	
	Time frame	2012-2023	
	Language	- English	
	Inclusion criteria	- Studies in English which feature real HFLTS and/or HFLTS extension applications in SCM problems, approved or published in a peer-reviewed journal.	
	Exclusion criteria	- Studies which 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 which apply HFLTSs in problems outside of SCM; - Systematic literature review studies; or - Gray literature.	
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 was exported into MS Excel.	
Reporting	Classification of the studies	- The classification was performed in accordance with the factors and categories displayed in Table 4.	

Summary of the information	- Creation of graphs using MS Excel; - Analysis and summary of the results; and - Identification of research gaps and proposed recommendations for future studies.

Figure 1 presents the results obtained through the search and selection of articles from the databases. In Step 1, using the search string in our database search we obtained a total of 1,085 results. 173 duplicates were excluded. Considering the remaining 912 studies, the initial selection was performed by the two authors in an independent manner by reading the titles, keywords, and abstracts. The goal of this step was to only select articles which are within the scope of this review. Later, in the evaluation of the quality of the articles, the two authors read the complete articles to confirm that they perform real applications, are written in English, and have been peer-reviewed. After the eligibility criteria were applied and after the quality evaluation, we included 28 studies from these databases. In Step 2, several more studies were collected through a search of the Research Gate website and a search for citations referenced in the studies selected in Step 1. These studies were also evaluated in terms of their eligibility and quality, which made it possible to identify 6 studies which were included in our review. Thus, a total of 34 studies were included.

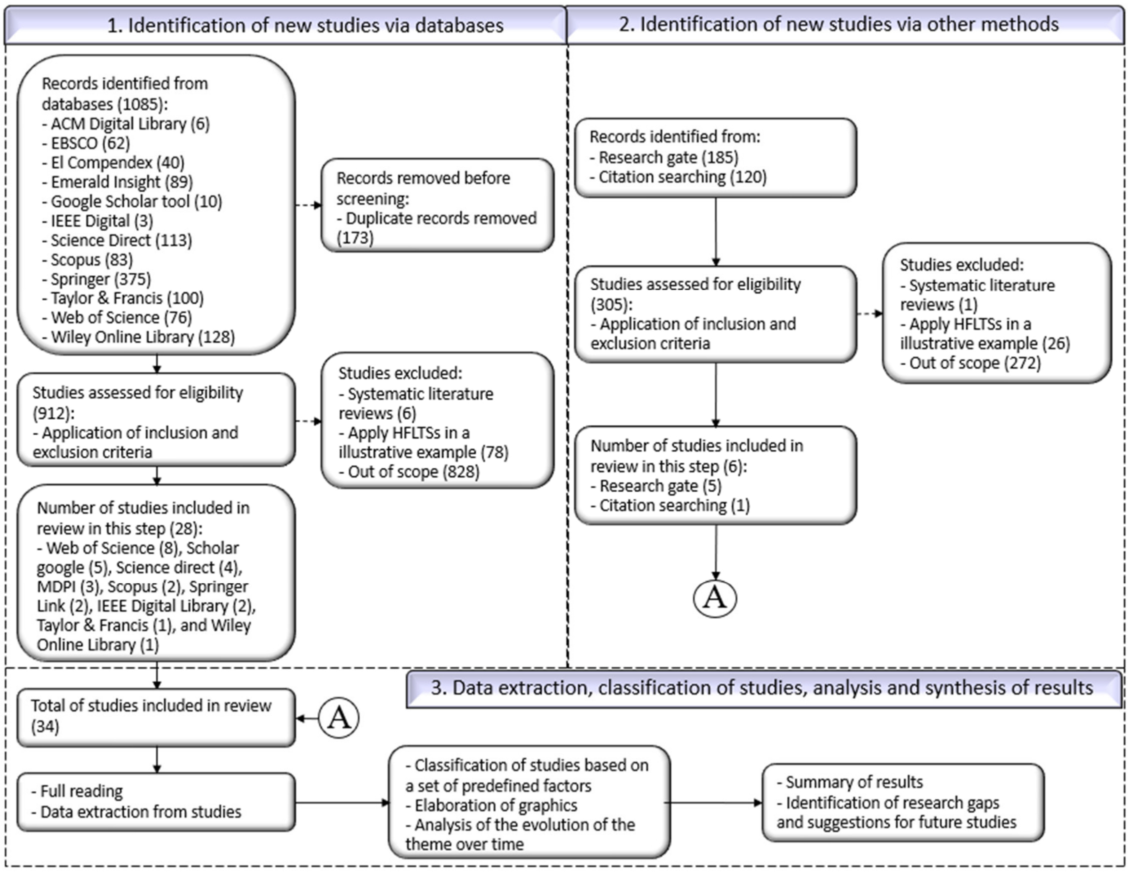

Figure 1. Search, Selection and Classification Procedures for these Studies.

In Step 3 in Figure 1, the studies were classified according to the factors and categories presented in Table 4. These factors were defined based on systematic literature review studies dealing with SCM [6,13], supplier selection [7], supply management [44], group decision making [45], and the modeling of complex linguistic expressions [12]. The categories related to each factor were defined initially based on the such studies. Then the categories were reviewed and updated according to the findings based on a thorough reading of the selected articles. After the extraction of the data and the classification of the studies in accordance with Table 4, a set of graphs was prepared to better visualize

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the results. Finally, the information was summarized to answer the research questions presented in Table 2 and identify research gaps and opportunities in terms of this subject.

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

	Factors	Categories	References
Information about the origin of the studies	Year of publication	- Frequency of publications per year;	Lima-Junior and Carpinetti [6] Resende et al. [7], and Zimmer et al. [44]
	Journal	- Frequency of publications per journal;	
	Country	- Frequency of publications by country, defined based on the affiliation of the authors of each study;	
	Number of citations	- Total citations of each study in Google Scholar,	
Factors related to SCM	Application objective	- Failure evaluation; - Risk evaluation; - Performance evaluation; - Supplier selection; - Logistics service provider selection; and - Location selection; - Among others.	Riahi et al. [13], Zimmer et al. [44], Lima-Junior and Carpinetti [6]
	SCM Processes	- Source, plan, make, delivery, return, and enable.	SCC [46], and Riahi et al. [13]
	Type of SCM Strategy	- 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	- Selection, ordering, or categorization.	Zimmer et al. [44]
	Type of HFLTS approach	- HFLTS, EHFLTS, HIFLTS, IVHFLS, PHFLTS, PLTS, IVDHFLTS, MHFLTS, DHHFLTS, HF2DLTS, PHILTS, IV2THFLTS, DHFLTS, and HPFLTS.	Wang et al. [12]
	Combination of techniques	- Frequency of isolated applications and combined applications.	Lambert and Enz [1], Lima-Junior. and Carpinetti

	Frequency of use of each technique	- Frequency of applications for each technique (in isolation or in combination with others).	[6], and Riahi et al. [13]
	Criteria weights	- Enable 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 [45]
	Group decision making	- Focused on individual or group decision making; - Number of DMs who participated in the application.	Kabak [45]
	Weights for DMs	- Considers or ignores the weights for the DMs; - Weights attributed by DMs or calculated by some method.	Kabak [45]
	Consensus among DMs	- Frequency of the use of aggregation methods for the DM preferences and the techniques used to obtain consensus in group decision making.	Kabak [45]
	Validation	- 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 which are based on HFLTS applications. Among them, there are six studies which proposed models focused on supply management. Liao et al. [47] 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. [48] 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. [49] developed a method which combines HFLTS with Dempster–Shafer evidence theory to achieve consensus in group decision making problems. The application was realized in a supplier selection problem for chemical products in a retail supermarket. Lima-Junior and Hsiao [50] 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 bi-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 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 which combines HFLTS with QFD to select evaluation measures for sustainable supply chains. Erol et al. [51] 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 are four studies which involve the application of HFLTSs to performance management. Tüysüz and Şimşek [52] applied HFLTS-based AHP (Analytic Hierarchy Process) to evaluate the factors which affect the performance of a transport company's affiliates. Pérez-Domínguez et al. [53] 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 [54] created a methodology to support managers in evaluating supply chain analytics tools. Zheng et al. [55] present a Hesitant Fuzzy Linguistic DEMATEL (Decision Making Trial and Evaluation Laboratory) 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. [56] presented a new approach to risk evaluation in supply chains which integrates 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. [57] combined the Failure Mode and Effect Analysis (FMEA), DEMATEL and HFLTS methods to analyze risks that failures will 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. [58] developed a new method that combines HFLTS, 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. [33] based on Incomplete Hesitant Fuzzy Linguistic Preference Relations, which was applied to selecting the location of hydroelectric plants. Yalçın and Pehlivan [59] 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 which combines HFLTS, AHP, QFD, and Preference Ranking Organization Method for Enriched Evaluation (PROMETHEE) for packaging design selection. The application 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 have identified the use of seven distinct approaches. The use of DHHFLTS has predominated, and it is present in seven of these studies. Krishankumar et al. [60] 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. [61] proposed a DHHFLTS-based framework for green supplier selection with partial weight information. Krishankumar et al. [62] 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 [63] evaluated the risk of logistics firms based on a combination of DHHFLTS and FMEA. Dai et al. [64] evaluated the risk of failures in an electronic products firm utilizing DHHFLTS, FMEA, and the K-means algorithm. Similarly, Duan et al. [65]

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combined DHHFLTS, FMEA, and the K-means algorithm to analyze the risk of failures in a firm in the energy sector. Finally, we have a study which uses DHHFLTS and ORESTE (*Organísation, Rangement et Synthèse de Données Relarionnelles*, in French) to evaluate traffic congestion [66].

The use of PLTSs has also emerged in SCM problems. Li et al. [67] developed a methodology which integrates PLTS with DEMATEL to evaluate sustainable recycling partners. Zhang et al. [68] proposed the use of PLTSs to deal with sustainable logistics suppliers. Zhang et al. [69] 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 appear in only one application apiece. Wang et al. [70] 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. [71] created a model to evaluate the supply chain performance which integrates the EHFLTS-VIKOR, Fuzzy Delphi, Interval-valued Hesitant Fuzzy, and DANP (DEMATEL-ANP) methods. A distinguishing characteristic of this model is that it combines criteria, paradigms and LARG (Lean, Agile, Resilient, and Green) practices to improve supply chain performance.

Qu et al. [72] developed a stochastic method based on DHFLTS and HFLTS for sustainable supplier selection in a high-tech manufacturing center. Wu et al. [73] 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 [73] created a risk evaluation methodology based on FMEA, MULTIMOORA, 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 2. Sections 4.2 to 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, presenting the classification results for these studies in terms of year of publication, journal, country, and most cited articles. Figure 2 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 2 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.

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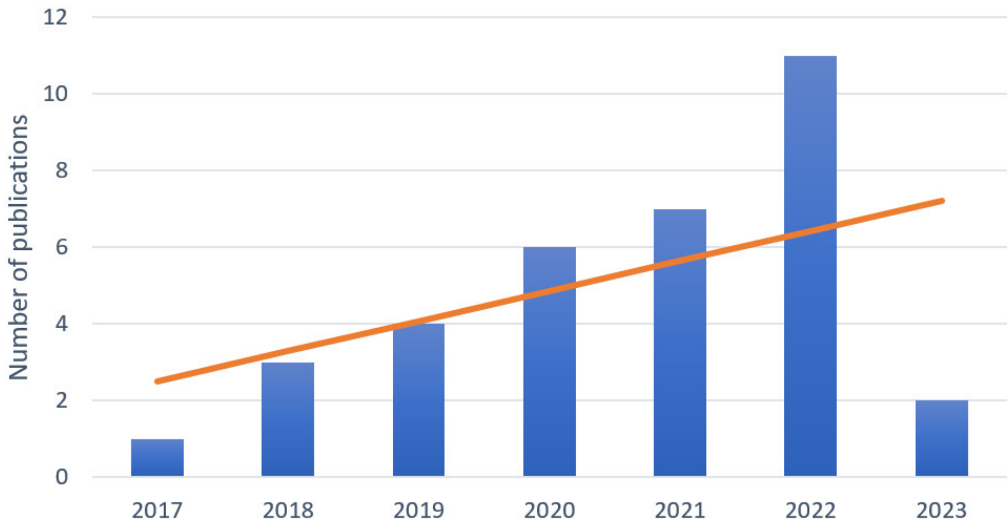
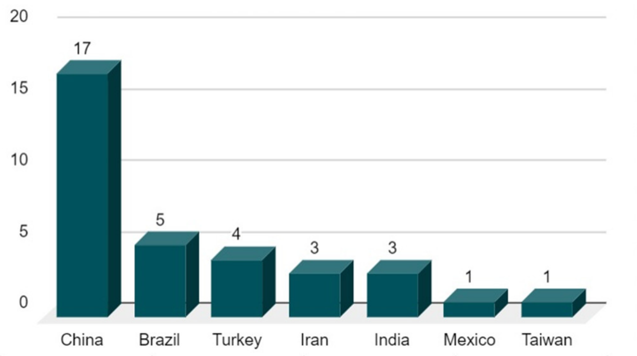
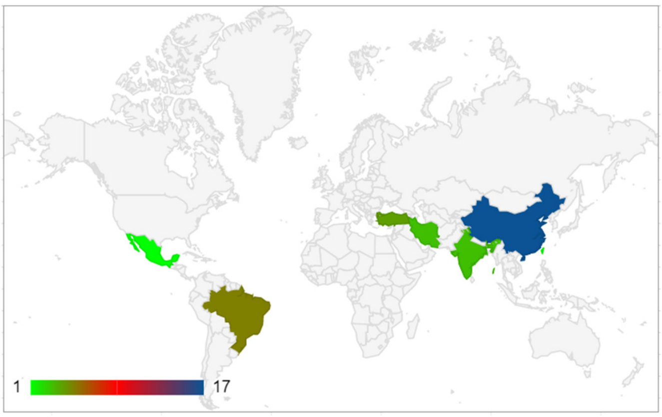


Figure 2. Frequency of Articles Published by Year.

Figure 3a presents the distribution of publications classified according to the first author's affiliated institution for each study (RQ1.2). China has the largest number of publications with 17 studies, which represented 50% of our analyzed sample. It was followed by Brazil (5 studies), Turkey (4 studies), India (3 studies), and Iran (3 studies). As shown in Figure 3b, production related to this subject was concentrated in Asia (24 studies), South America (5 studies), and Europe (4 studies).



(a)



(b)

Figure 3. Distribution of the Publications by Country of Origin (**a**) and a Map of the Publications (**b**).

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Table 4 presents the journals in which the selected studies were published (RQ1.3). A wide variety of journals published articles about this subject, with there being a total of 27 distinct journals. The journal which 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 & Industrial Engineering*, *Environmental Science and Pollution Research*, the *Journal of Intelligent & Fuzzy Systems*, and *Symmetry*, each with two publications. The other 21 journals had one publication apiece.

Table 4. 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 & 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
Complex & Intelligent Systems	1							1
Complexity				1				1
DYNA					1			1
Energy			1					1
Fuzzy Optimization and Decision Making				1				1
International Journal of Computational Intelligence Systems				1				1
International Journal of Environmental Research and Public Health				1				1
International Journal of Information Technology & Decision Making					1			1
International Journal of Production Economics						1		1
International Journal of Strategic Property Management				1				1
International Transactions in Operational Research		1						1
Journal of Cleaner Production						1		1
Journal of Contemporary Administration						1		1
Journal of Mathematics					1			1
Journal of the Operational Research Society						1		1
Knowledge-Based Systems					1			1
Kybernetes					1			1
Neural Computing & Applications					1			1

Journal	2017	2018	2019	2020	2021	2022	2023	Total
Technological and Economic Development of Economy			1					1

By collecting the number of citations in Google Scholar, it was possible to identify the most influential articles. Table 5 presents the number of citations received by the 11 most cited studies within our analyzed sample (RQ1.4). The article which had the greatest number of citations was Osiro et al. [19], with a total of 86 citations. The works of Wang et al. [70], Yalçın and Pehlivan [70], Tüysüz and Şimşek [52], and Liu et al. [49] followed with 84, 72, 71, and 65 citations respectively.

Table 5. List of the Most Cited Articles.

Rank	Author(s)	Number of citations
1st	Osiro et al. [19]	86
2nd	Wang et al [70]	84
3rd	Yalçın and Pehlivan [59]	72
4th	Tüysüz and Şimşek [52]	71
5th	Liu et al. [49]	67
6th	Wu et al. [56]	56
7th	Wang et al. [66]	56
8th	Liao et al. [47]	41
9th	Duan et al. [65]	32
10th	Erol et al. [51]	28
10th	Chang et al. [57]	28

4.3. Aspects Related to SCM

To answer the research questions RQ2.1 to RQ2.4**,** this section will present 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 what has been the focus of HFLTS and HFLTS extension techniques as applied to SCM problems, the selected studies have been organized in accordance with the objective of the application. Based on this, to elucidate which SCM processes have received the greatest attention in these applications each study has been 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 SCOR model (Supply Chain Operations Reference), which is an SCM reference that has been widely adopted by practitioners and researchers [46]. Table 6 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 have been the most frequent, totaling 23.5% of the sample. It has been followed by failure evaluations (11.8%) and performance evaluations (8.8%).

Table 6. Classification of the Studies according to the Application Objective.

Application objective	Author(s)	SCM process	Total
Supplier selection	Liao et al. [47]; Zhang et al. [69]; Krishankumar et al. [74]; Krishankumar et al. [75]; Liu et al. [47]; Dolatabad et al. [48]; Qu et al. [72]; Krishankumar et al. [62].	Source	8

Failure evaluation	Chang et al. [57]; Zolfaghari and Mousavi [76]; Dai et al. [64]; Duan et al. [65].	Make	4
Performance evaluation	Tüysüz and Şimşek [52]; Büyüközkan and Güler [54]; Divsalar et al. [71].	Enable	3
Risk evaluation	Wu et al. [56]; Shen and Liu [63].	Enable	2
Logistics service provider selection	Wang et al. [70]; Zhang et al. [68].	Source	2
Personnel selection	Wu et al. [73]; Yalçın et al. [59].	Enable	2
Location selection	Wu et al. [77]; Ren et al. [78].	Enable	2
Barrier assessment	Erol et al. [51].	Plan	1
Traffic congestion assessment	Wang et al. [66].	Delivery	1
Critical success factor evaluation	Zheng et al. [55].	Plan	1
Lean tools evaluation	Pérez-Domínguez et al. [53].	Plan	1
Supplier evaluation	Lima-Junior and Hsiao [50].	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. [79].	Plan	1
Recycling partner selection	Li et al. [67].	Return	1
Supplier development program selection	Finger and Lima-Junior [8].	Source	1
SC performance indicator selection	Osiro et al. [19].	Enable	1

According to the results displayed in Figure 4a, 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 which are necessary to meet actual or planned demand. It was followed by the enable process with 29.4% of the studies. This process involves activities related to managing supply chain structure, such as risk and performance management, defining its locations, and personnel selection, among other activities [46]. 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 appears with just one application (2.9%). Similarly, the return process, related to receiving products that are returned for any reason [46], was also associated with just a single application.

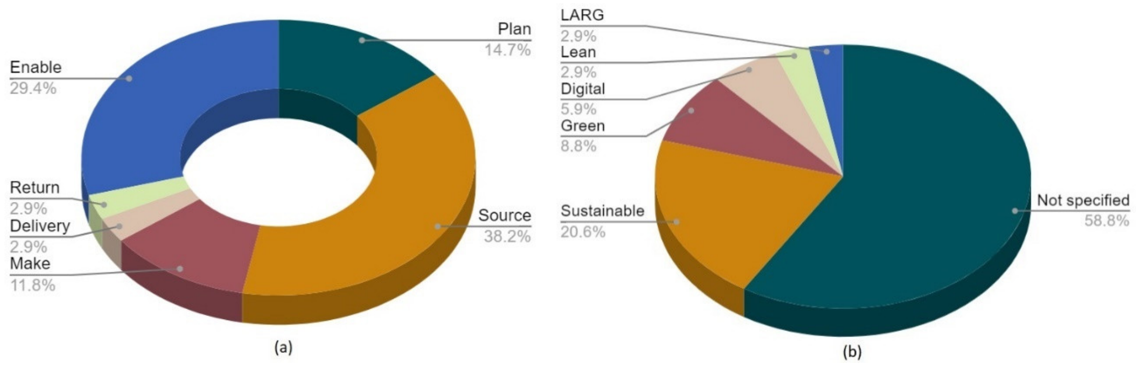

Figure 4. SCM Process Results (**a**) and Types of SCM Strategies (**b**).

Figure 4b 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 which 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 are oriented towards 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 the reduction of 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.

Finally, Figure 5 displays the classification of these studies according to the sector of the participating company (RQ2.4). The automotive sector stands out with 10 applications (29.4%). It was followed by the health and electro-electronic sectors with 5 and 4 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.

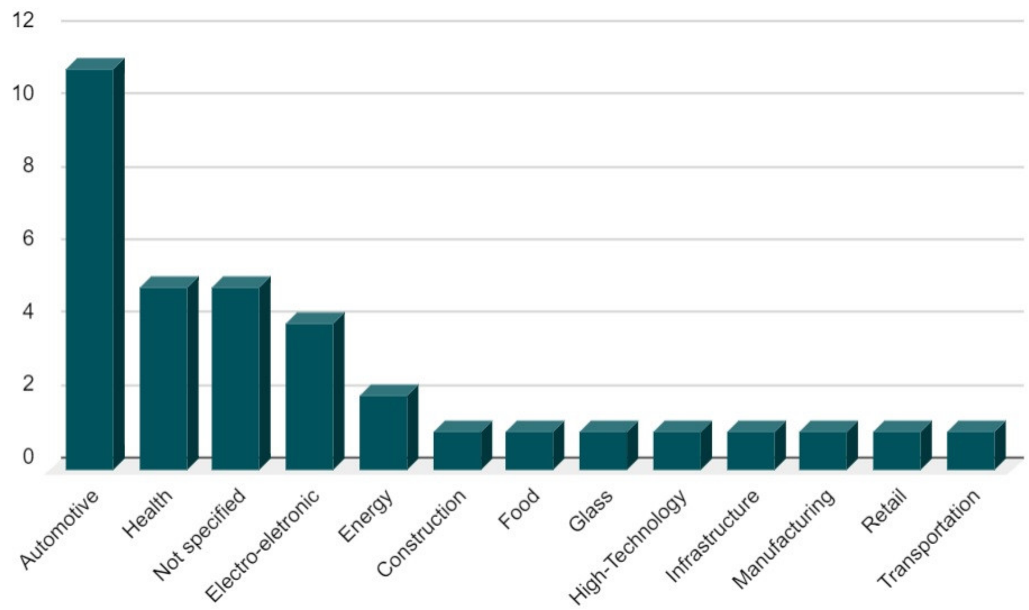

Figure 5. Classification of the Studies according to Economic Sector.

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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 6, the selected studies are classified according to the main decision-making problem that they deal with (RQ3.1). The results indicate that half of the applications are 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 deal with choice problems, in which there is a desire to choose a subgroup of alternatives within the available options. Finally, with 17.6% of the applications, we have studies which deal with sorting issues, or in other words, problems in which the objective is to classify each alternative in a predetermined category.

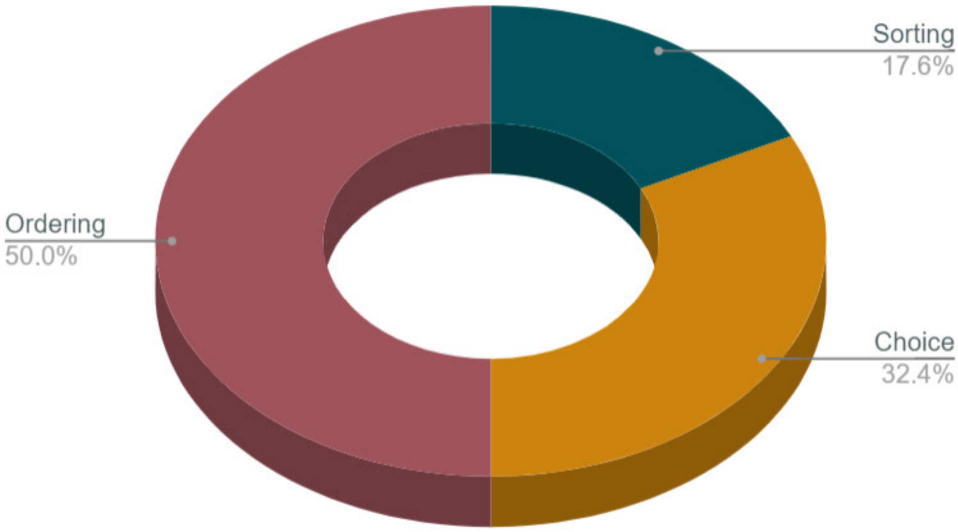

Figure 6. Classification of the Studies by Type of Decision-Making Problem.

In Figure 7a the studies are 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 displayed in Table 1, we found applications based on just seven of them: DHHFLTS (seven studies), PLTS (three studies), and DHFLTS, EHFLTS, HPFLS, IVHFLTS, and MHFLTS (with one study apiece). Four studies combined HFLTSs with an HFLTS extensions, such as PLTSs and DHFLTSs. These results underline the fact that this subject is emergent and presents many opportunities for research. 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 judgement. 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.

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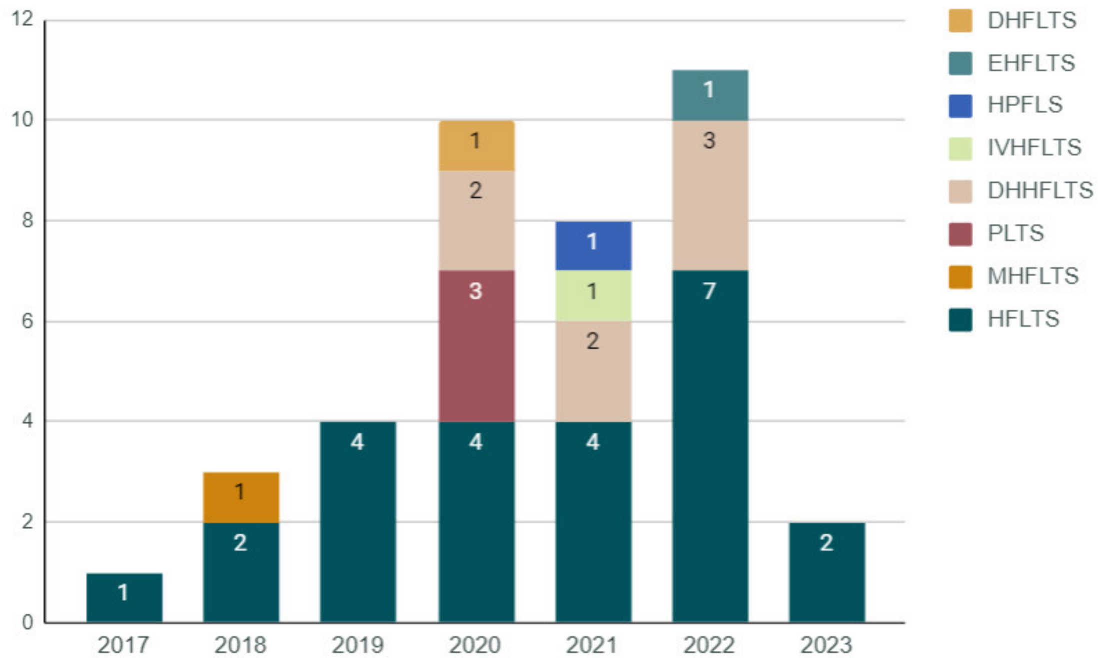

Figure 7. Frequency of Use of HFLTSs and HFLTS Extensions.

Table 7 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 propose the integration of HFLTS or HFLTS extension techniques with other techniques, which include Multicriteria Decision-Making (MCDM) methods, quality management, and statistical techniques. Integration occurs through the hybridization or sequential application of these techniques.

Figure 8 presents the frequency with which each technique was utilized in the integrated methods. We identified 36 distinct techniques. The most frequently utilized methods are FMEA and TOPSIS, which are present in five of the studies. These are followed by AHP, DEMATEL and QFD with four applications apiece. 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. In FMEA, failures are prioritized according to the criteria of gravity, occurrence, and detection. 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 [63]. The TOPSIS method, on the other hand, is a multicriteria decision method which is well-known for its simplicity and versatility. This method classifies the alternatives according to their proximity to the positive and negative ideal solutions. The methods resulting from the combination of TOPSIS and HFLTSs and HFLTS extensions made it possible to deal with different types of uncertainty offering greater flexibility to the alternative evaluation process [4].

Table 7. Decision-Making Techniques in Each Study.

Proposed by	Decision technique(s)	How to get the criteria weights	Method for calculating criteria weights
Tüysüz & Şimşek [52]	HFLTS-AHP	Weights not applied	N/A

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Hybrid techniques (13)	Osiro et al. [19]	HFLTS-QFD	Calculation	HFLTS-QFD
	Yalçın et al. [59]	HFLTS-CODAS	Calculation	HFLTS-CODAS
	Qu et al. [72]	DHFLTS, HFLTS, and Regret and Rejoice theory	Calculation	HFLTS and Regret and Rejoice theory
	Ren et al. [78]	Programming models based on Incomplete Hesitant Fuzzy Linguistic Preference Relations	Calculation	Programming models
	Wang et al. [66]	DHHFLTS-ORESTE	Calculation	DHHFL-ORESTE
	Zhang et al. [68]	HFLTS-PLTS, and ratio index-based probabilistic linguistic ranking method	Calculation	CoCoSo
	Liu et al. [49]	HFLTS, and Dempster-Shafer theory	Assigned by DMs	N/A
	Lima-Junior & Hsiao [50]	HFLTS-TOPSIS	Assigned by DMs	N/A
	Borges et al. [4]	HFLTS-TOPSIS	Calculation	HFLTS-TOPSIS
	Finger & Lima-Junior [8]	HFLTS-QFD	Calculation	HFLTS-QFD
	Qin et al. [9]	HFLTS, and Swaps method	Calculation	HFLTS, and Swaps method
	Zheng et al. [55]	HFLTS-DEMATEL	Calculation	HFLTS-DEMATEL
Combined techniques (21)	Chang et al. [57]	HFLTS-FMEA, DEMATEL and Ordered Weighted Geometric Average (OWGA)	Calculation	OWGA
	Wang et al. [70]20	MHFLTES, Heronian Mean (HM), and Prioritized average operators	Calculation	MHFLTE, and HM
	Liao et al. [57]	HFLTS-BMW and HFLTS-ARAS	Calculation	HFLTS-BWM
	Pérez-Domínguez et al. [53]	AHP and HFLTS-TOPSIS	Calculation	AHP
	Wu et al. [56]	HFLTS, Fuzzy synthetic method, Eigenvalue method, and Triangular Fuzzy Number (TFN)	Calculation	Eigenvalue method
	Zhang et al. [69]	HFLTS, PLTS, modified BWM, and CoCoSo	Calculation	HFLTS-BWM
	Krishankumar et al. [74]	DHHFLTS, Generalized Maclaurin Symmetric Mean (GMSM), and Borda method	Calculation	DHHFLTS and SV
	Li et al. [67]	HFLTS, PLTS, TFN, DEMATEL and Generalized Weighted Ordered Weighted Average (GWOWA)	Calculation	PLTS-DEMATEL

Büyüközkan & Güler [54]	HFLTS-AHP, and HFLTS-MULTIMOORA	Calculation	HFLTS-AHP
Shen & Liu [63]	DHHFLTS-FMEA, DHHFLTS-COPRAS, and Kemeny Median Method (KEM)-SWARA	Calculation	KEM-SWARA
Krishankumar et al. [75]	DHHFLTS, GMSM, TODIM, and Cronbach's alpha coefficient	Calculation	Mathematical model
Wu et al. [73]	HPFLS-TOPSIS, and Weighted Cross-Entropy	Calculation	HPFLS-TOPSIS, and Weighted Cross-Entropy
Zolfaghari & Mousavi [76]	IVHFLS-FMEA, MULTIMOORA, and TPOP	Calculation	MULTIMOORA
Duan et al. [65]	DHHFLTS-FMEA, k-means clustering, and maximizing deviation method	Calculation	Maximizing deviation method
Dai et al. [64]	DHHFLTS-FMEA, k-means clustering, and entropy weight method	Calculation	K-means clustering
Divsalar et al. [71]	Fuzzy Delphi, EHFLTS-VIKOR, and IVHF-DANP	Calculation	IVHF-DANP
Erol et al. [51]	HFLTS-QFD, HFLTS-Delphi, HFLTS-ANP, and HFLTS-TOPSIS	Calculation	HFLTS-ANP
Krishankumar et al. [62]	DHHFLTS combined with attitudinal-CRITIC (Criteria Importance Through Intercriteria Correlation) approach, and Weighted Distance Approximation (WDA) algorithm	Calculation	Attitudinal-CRITIC approach
Wu et al. [77]	HFLTS, and DEA-based TODIM method	Calculation	DEA-based TODIM method
Lima et al. [79]	HFLTS-AHP, HFLTS-QFD, and HFLTS-PROMETHEE	Calculation	HFLTS-AHP
Dolatabad et al. [48]	HFLTS-VIKOR, and Fuzzy Cognitive Map	Calculation	Fuzzy Cognitive Map

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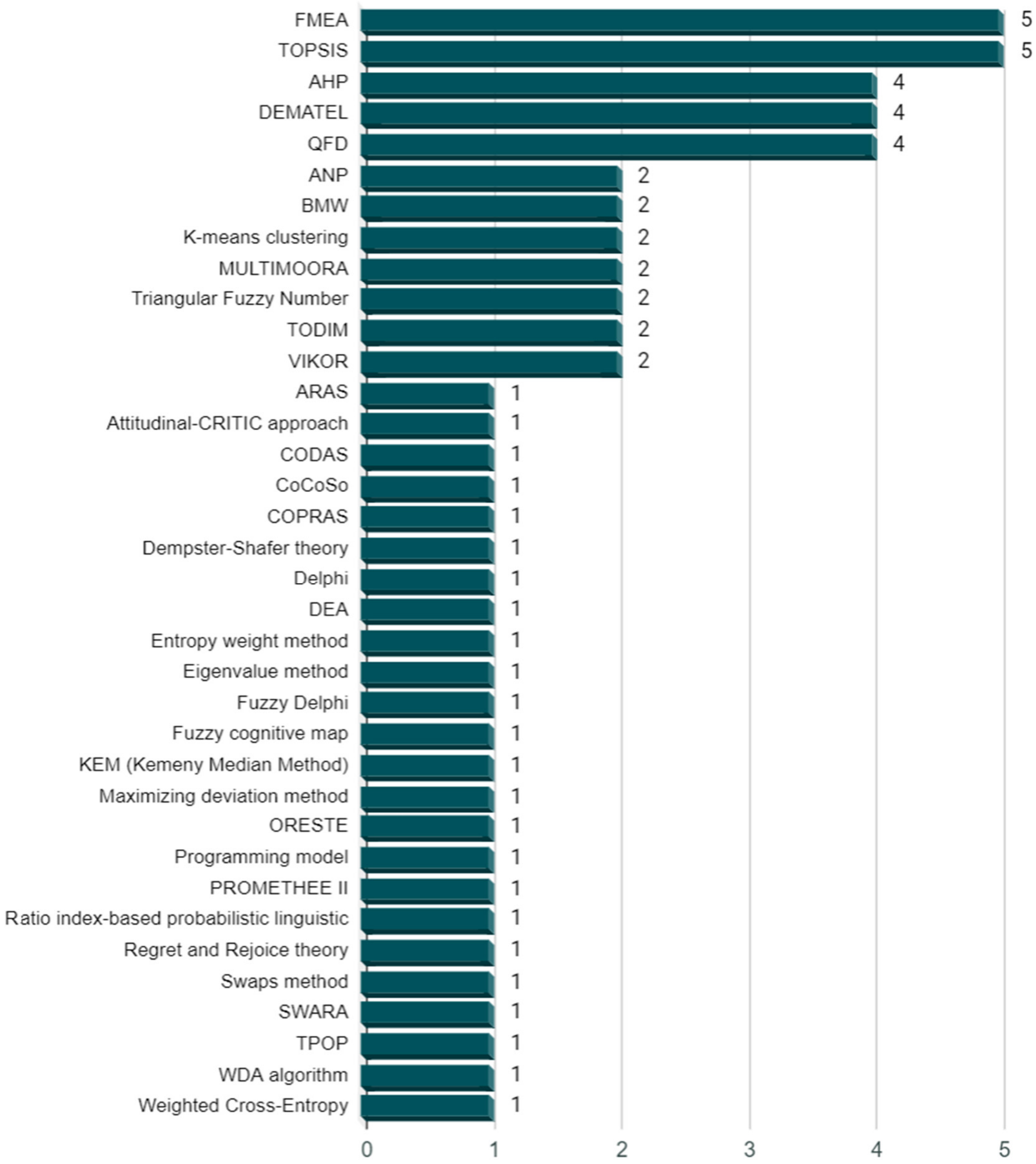

Figure 8. Frequency of Integrating Techniques with HFLTS and HFLTS Extension Techniques.

In addition to the approaches used to model DM preferences, another factor which 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 7, in most of the studies (31), the weights were calculated by a decision-making technique, or an aggregation operator based on the DM judgements (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 8 presents the classification of the studies based on factors related to their support of group decision making (RQ3.5). We found that all of the studies applied methods support group decision making, even though the application presented by Finger and Lima-Junior [8] considered only one DM. The average number of participating DMs in the analyzed applications was 6.4 and the mode was 3. In nine studies, the weights of the DMs were taken into account in obtaining the results

(RQ3.6). Among these, seven studies used methods to make this calculation, and two studies attributed numerical values to arrive at their weights.

Table 8. Classification of the Studies in terms of Group Decision Making.

Author(s)	Supports group decision making	Number of DMs	Allows weighting of DM opinions	How are DM weights assigned?	Method used to calculate DM weights	Aggregates DM opinions?	Procedure used to aggregate DM opinions	Applies to iterative consensus method
Tüysüz & Şimşek [52]	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. [57]	Yes	4	No	N/A	N/A	Yes	OWGA	No
Wu et al. [56]	Yes	30	No	N/A	N/A	Yes	Fuzzy arithmetic mean	No
Liao et al. [47]	Yes	4	Yes	Attributes numeric values	N/A	Yes	IWGA	No
Pérez-Domínguez et al. [53]	Yes	6	No	N/A	N/A	Yes	HFLTS-TOPSIS	No
Yalçın et al. [59]	Yes	5	No	N/A	N/A	Yes	Ordered Weighted Average (OWA)	No
Krishankumar et al. [74]	Yes	3	No	N/A	N/A	Yes	GMSM	No
Li et al. [67]	Yes	5	No	N/A	N/A	Yes	GWOWA	No
Qu et al. [72]	Yes	3	No	N/A	N/A	Yes	Degree of group satisfaction and the regret theory	No
Wang et al. [66].	Yes	Not informed	No	N/A	N/A	Yes	DHHFLTS-ORESTE	No

Ren et al. [78]	Yes	4	No	N/A	N/A	Yes	Programming model	No
Zhang et al. [68]	Yes	Not informed	No	N/A	N/A	Yes	Ratio index-based probabilistic linguistic	No
Zhang et al. [69]	Yes	5	No	N/A	N/A	Yes	HFLTS-BWM	No
Krishankumar et al. [75]	Yes	3	Yes	Calculated	Mathematical model	Yes	GMSM	No
Liu et al. [49]	Yes	4	Yes	Attributes numeric values	N/A	Yes	Based on degrees of hesitancy and similarity	Yes
Büyüközkan & Güler [54]	Yes	3	No	N/A	N/A	Yes	AHP and OWA	No
Lima-Junior & Hsiao [50]	Yes	2	No	N/A	N/A	Yes	HFLTS-TOPSIS	No
Zolfaghari & Mousavi [76]	Yes	3	No	N/A	N/A	Yes	Interval-valued Hesitant Fuzzy Linguistic Prioritized Weighted Average	No
Shen & Liu [63]	Yes	Not informed	No	N/A	N/A	Yes	DHHFLTS-COPRAS	No
Wu et al. [73]	Yes	10	No	N/A	N/A	No	N/A	Yes
Finger & Lima-Junior [8]	Yes	1	No	N/A	N/A	Yes	HFLTS-QFD	No
Erol et al. [51]	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. [71]	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. [65]	Yes	5	Yes	Calculated	Nonlinear programming and genetic algorithm	Yes	Double Hierarchy Hesitant Linguistic Weighted Average (DHHLWA)	No
Dai et al. [64]	Yes	3	Yes	Calculated	Entropy weight method	Yes	Entropy weight method	No
Wu et al. [77]	Yes	3	Yes	Calculated	Optimization model	Yes	Optimization model	No
Lima et al. [79]	Yes	4	No	N/A	N/A	Yes	HFLTS-AHP and OWA	No
Krishankumar et al. [62]	Yes	3	Yes	Calculated	WDA algorithm	Yes	Attitudinal-CRITIC approach	No
Dolatabad et al. [48]	Yes	11	Yes	Calculated	Method not defined	Yes	Hesitant Fuzzy Linguistic Weighted Average (HFLWA)	No
Zheng et al. [55]	Yes	22	Yes	Calculated	Maximizing consensus approach	Yes	HFLTS-DEMATEL	No

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, such as 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 make it possible to suggest modifications to the DM evaluations by calculating measures of consensus during the evaluation rounds. Examples of iterative methods seeking consensus are presented in Liu et al. [49], Wu et al. [73], Divsalar et al. [71], and Erol et al. [51].

Finally, another important aspect of these applications has to do with how their results were validated. As presented in Figure 9, in 12 studies (35.3%) the results 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 analysis was 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.

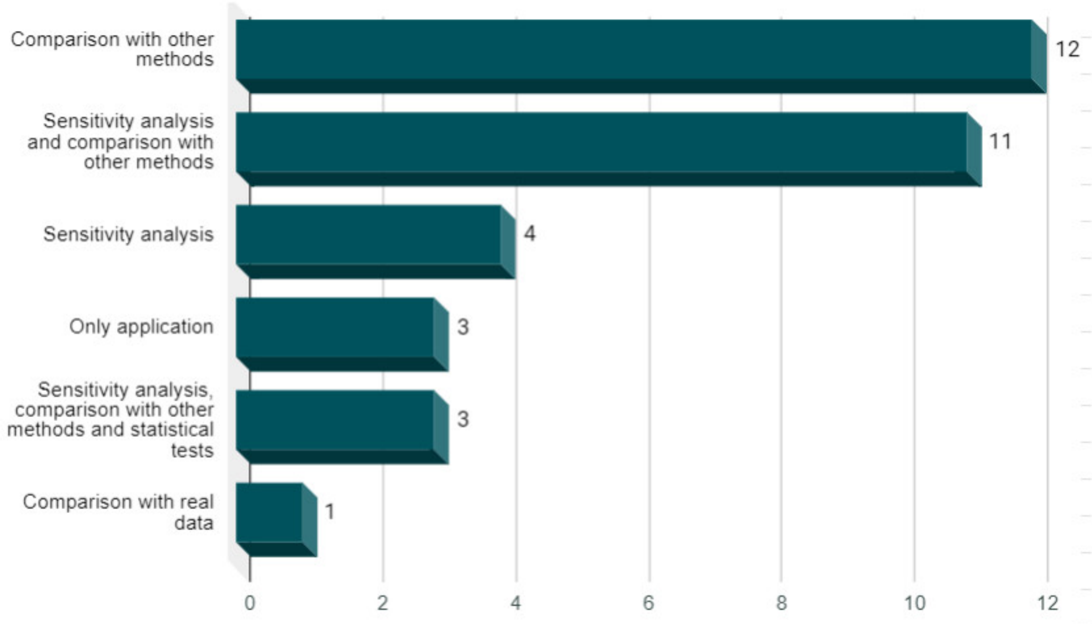

Figure 9. Approaches Utilized to Validate the Analyzed Study Results.

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. [22], which analyzed 1,080 studies based on HFS and HFS extensions, this study finds that the HFLTS approach proposed by Rodríguez et al. [14] has been the most utilized in the analyzed studies. In terms of the type of SCM strategy, our results are similar to the study by Lima-Junior and Carpinetti [6] which investigates decision-making models to evaluate supply chain performance. Both studies indicate 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 has 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 indicate 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 which had the most applications, in analyzing artificial

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intelligence techniques in SCM, Yang et al. [5] found that the return and make processes had fewer applications, while our study has 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 has found that the source and enable processes have had the most applications.

Finally, in terms of the economic sectors of the participating companies which 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 are 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 have identified various gaps in the research on this subject. Based on the such gaps, as well as in SCC [46], Lima Junior and Carpinetti [6], Wang et al. [11], Kabak [45], and Yang et al. [5], we propose a framework which seeks to help researchers and managers develop future studies on this subject. The framework presented in Figure 10 encompasses pertinent recommendations regarding the following topics: innovative applications of techniques; new combinations of decision-making techniques; comparative studies of decision-making techniques; group decision-making issues, and validation procedures for new decision-making support models.

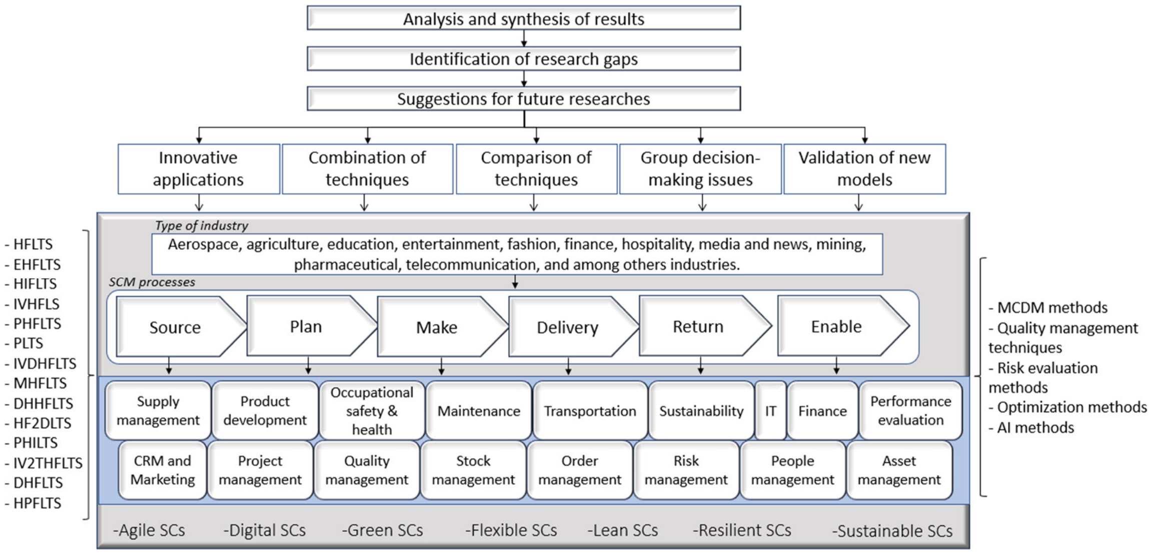

Figure 10. Framework to Guide the Development of Future Studies on this Subject.

5.1. Innovative Applications

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

As Figure 10 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 group decision making under conditions of uncertainty. Based on the research opportunities that we have identified, here is a list of SCM problems which involve selecting, ordering, and categorizing that can be explored in future works. It includes problems associated with various business areas which involve strategic, tactical, and/or operational decision making:

i. Asset management: prioritization of asset management investments, strategic asset allocation, selecting the location of new installations, and layout selection;
ii. CRM (Customer relationship management) and marketing: marketplace selection, marketing strategy selection, market segmentation, customer satisfaction analysis, and customer relationship management software selection;
iii. Finance: credit risk evaluation, corporate financial performance analysis, investment appraisal, budget allocations, and the evaluation of financial plans;
iv. IT (Information Technology): information system selection, computer workstation selection, software quality evaluation, IT service provider selection, and disruptive industry 4.0 technology evaluation;
v. Maintenance: maintenance strategy selection, maintenance service provider selection, maintenance machine selection, and the prioritization of maintenance activities;
vi. Occupational safety & 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;
vii. Order management: prioritization of production orders, order delivery evaluation, and the prioritization of plans to improve order management;
viii. Performance evaluation: performance indicator selection, performance measurement system evaluation, and organizational performance evaluation;
ix. Product development: product development strategy selection, new product material selection, prototype evaluation, and product portfolio evaluation;
x. Project management: project proposal selection, project risk evaluation, project performance indicator selection, project management practice maturity evaluation, and program and/or project success evaluation;
xi. Quality management: six sigma project selection, benchmarking, product or service requirement prioritization, the selection of the certifying body for the implementation of ISO 9001 certification, and the prioritization of continual improvement actions;
xii. Risk management: risk evaluation tool selection, organizational risk evaluation, and supply chain risk evaluation;
xiii. Stock management: stock management strategy selection, ABC classification of stocks, warehouse location selection, and warehouse structure selection;
xiv. Supply management: make or buy, supplier performance monitoring; supplier segmentation, and supplier development program evaluation;
xv. Personnel management: organizational climate evaluation, personnel selection, position evaluation, and skills and qualifications evaluation;
xvi. 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;
xvii. 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 which still have not been addressed with applications, such as those related to asset management, finance, IT, maintenance, marketing, occupational safety & health, order management, and stock management, among other areas. On the other, one can test the use of techniques which 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 up 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

There are various combinations of HFLTS and HFLTS extension techniques, and other types of methods that still have not been tested in SCM problems. Given the low frequency of applications that employ 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.

More specifically, 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, Qualitative Flexible Multiple Criteria Method (QUALIFLEX), 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) which 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 which 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 demonstrate the need to conduct comparative studies involving MCDM techniques based on HFLTSs and HFLTS extensions. Even though some of the analyzed studies have compared the numeric outputs of distinct techniques when applied to the same problem, the literature offers few comparative studies which discuss 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 group decision making, and agility in the decision-making process [24].

The realization of studies which 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. Group Decision-Making Issues

There are some topics related to group decision making in SCM that have been little studied and deserve more attention. Even though all of the analyzed studies provide support for group decision making, we have verified that there are few methods which 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 which make this possible to deal appropriately with uncertainty in the definition of DM weights.

An important emergent research topic is large group decision-making problems. These problems are a special case in terms of group decision-making processes in which the opinions of a large number of people are collected. There are various large group decision-making problems inherent in SCM which could be investigated in future works, for example, strategic decisions which involve DMs from various departments or organizations, or product or service evaluations made 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 group decision making which 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 which 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 in DM preferences, as well as models based on adaptive consensus strategies which automatically update DM weights with each iteration.

5.5. Validation of New Decision-Making Models

Future studies could use validation procedures which 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 that analyze the obtained results such as hypothesis tests, variance analysis, and error measurements. 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 over the results.

To verify the consistency of the obtained results, it is important to conduct tests considering a larger number of application cases, in order to evaluate the performance of these techniques under distinct scenarios, 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 graphic interfaces based on these techniques to verify their usability in various organization areas.

6. Conclusions

This study has 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 have been characterized in accordance with a group of factors related to their origin, SCM, HFLTSs and decision making. The results demonstrate that this research subject is quite recent and there has been substantial growth in the number of publications about this topic. The applications we have identified provide support for a wide variety of decision-making problems, with their main focuses being on supplier selection, failure evaluation, and performance evaluation.

We have 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 has been confirmed that all of the analyzed models are appropriate for providing support for group decision making, even though few of them permit the attribution of distinct weights to DMs. There are also few models designed to obtain a consensus among DMs.

The results of this study demonstrate 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 which deserve greater attention from researchers and practitioners.

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 presents a wide array of directions for future studies which encompass topics related to innovative applications, combinations of techniques, comparisons of techniques, group decision-making issues, and validation procedures for new decision-making models. To further our knowledge this is the first study to present a systematic review which focuses on real applications of HFLTS and HFLTS extension techniques. It is also the first study to analyze applications of decision techniques that deal with uncertainty and hesitation in SCM. That being said, we believe that this study will contribute to the dissemination of the use of HFLTS and HFLTS extensions to solve real SCM problems to minimize the effects of uncertainty on the results and contribute to the promotion of more structured and rational decision-making processes.

Finally, a limitation of this study is that there may be works which present HFLTS or HFLTS extension applications that were not identified in our searches. Even though we consulted various databases, this list is not exhaustive. In addition, we opted to include just 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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