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Selection of Supply Chain Sustainability Management System by Fuzzy Additive Preference Programming Method

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Abstract: A selection of suitable sustainability management systems (SMS) is a major part of supply chain strategies to create a competitive advantage, reduce total costs, and manage long-term sustainability. A framework and method for prioritizing supply chain SMSs are presented in this research. Analytic hierarchy process (AHP) is the most common method for alternative selection in multi-criteria decision-making (MCDM). However, complex information is mixed with ambiguity and uncertainty, which makes decision makers unable to use precise or crisp numbers, so fuzzy numbers are presented to remedy this difficulty. Therefore, this research proposes a fuzzy additive preference programming (FAPP) to select the optimum SMS for a supply chain. FAPP method can produce the unique normalized optimal priority vector of fuzzy pairwise comparison matrices for SMS selection effectively with linear constraints. The additive linear constraints can eliminate the weaknesses of existing methods and equalize the upper and lower triangular fuzzy judgments. In addition, the proposed method can identify abnormal pairs of fuzzy judgments that cause inconsistency. The proposed methodology can prioritize the key criteria which lead to the selection of the most appropriate SMS. An example of SMS selection in a rubber factory demonstrates the feasibility and validity of the proposed method.

Keywords: sustainability management systems; multiple criteria analysis; decision analysis; analytic hierarchical process; fuzzy linear programming

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1. Introduction

Supply chain management (SCM) is the management of the flow of goods and services from upstream to downstream to reduce cost and increase the quality of products and services. However, it is no longer enough for today's business because the economy, society, and environment have changed [1]. An organization cannot focus solely on profits because resources are reduced, and impacts on the environment and community are also increasing; these affect human livelihoods, causing the social trend against the industries that release harmful toxins to the world [2]. Therefore, activities in a supply chain must co-operate with a friendly sustainability management system (SMS) for the environment and society. The SCM must be controlled in parallel with a good economy within the supply chain to achieve long-term balance. Socio-economic and environmental factors are the key for a supply chain to achieve sustainability, while traditional supply chain management is no longer adequate [3].

Many different industries [4,5] have started to implement sustainable strategies and sustainable practices in a variety of ways. The selection of an optimal SMS will enable the most efficient use of environmental resources, raw materials, energy, human resources, and budget. Supply chains that want to develop further and expand their networks need a stable foundation for long-term survival. Support is required by the management system to help the supply chain achieve its sustainability goals that make the supply chain applicable in the long term. However, there is not a clear direction for a supply chain and which SMS should be properly implemented. Furthermore, the selection should be based on the critical criteria of the supply chain.

Many research works have intensively studied the critical criteria for green supply chain management (GSCM) and sustainable supply chain management (SSCM) [6–9]. These criteria lead to the way of selecting the appropriate SMS. Various SMSs have been presented, but they have not been organized and classified clearly for practical uses. Prioritization criteria and selection of SMS have been evaluated as a sophisticated multiple attribute decision making (MADM) problem [8], which has been applied to many applications [10–12]. Among the MADM methods, the analytic hierarchy process method (AHP) is the most popular method for prioritizing criteria and alternatives [13]. AHP's advantages are the use of pairwise comparison matrices and the ability to deal with both quantitative and qualitative data. However, only crisp numbers can be used. In some situations, there are uncertainties, in which decision makers (DMs) cannot give exact information, so evaluation by the use of interval numbers and fuzzy numbers has been presented [14,15].

Although AHP has been widely employed in a problem related to sustainability in various industries [16–18], it is difficult to give precise information about criteria and alternatives because of the complexity of real-world problems and qualitative information. The fuzzy analytic hierarchy process (FAHP) multi-criteria decision-making technique is regarded as one of the most potent instruments for dealing with uncertainty [19]. So, several FAHP methods have been proposed [20–22]. These methods can allow DMs to handle the vagueness and provide more realistic results than the original one. They have been applied in many applications [23–25]. However, these methods still have some weaknesses and faults [26–28]. They can be grouped according to the computational constraints into two main groups: additive constraints models and multiplicative constraints models. Each type has a different computational nature.

Existing additive constraints models have a weakness. In calculating the upper and lower triangular fuzzy judgments, it can be proven that the weights obtained from both judgments are unequal, which can confuse DMs. The fuzzy preference programming (FPP) method [29] is an example of this type of model. Moreover, extent analysis and linear goal programming methods [26,30] are also in the additive constraints group that need both upper and lower triangular fuzzy judgments to be solved simultaneously to find the solution. They are more complex than FPP. Various existing multiplicative constraint methods have been introduced. They include logarithmic goal programming, lambda-max, geometric mean method, and logarithmic fuzzy preference programming method (LFPP) [31,32]. LFPP is the most outstanding method available, but nonlinear constraints are used.

This research aims to gather and categorize the critical SSCM criteria and SMSs for practical problems in a way that is easy to understand and apply. The framework for selecting appropriate SMSs which any industry can utilize is proposed to find the critical factors, and also the most appropriate SMS that is a contribution of the research from the application side. Moreover, a fuzzy additive preference programming (FAPP) method is proposed to rank significant criteria and prioritize the most suitable SMS for a company. It can find the most suitable SMS and critical criteria for a supply chain that can be a guideline for sustainable operations in a supply chain. This new method is an additive constraints method that can eliminate the existing disadvantages. Only upper or lower triangular fuzzy judgment is used in computation and both solutions from upper or lower triangular fuzzy judgments are the same. Moreover, abnormal pairs of fuzzy judgments that cause inconsistency in the decision matrix can be easily identified by the proposed method. It can deal with both quantitative and qualitative data in which uncertainty data can be used, so vagueness and more realistic results than the original one can be handled. These are major contributions of the research from the theoretical side.

This research is organized as follows: Section 2 provides the relevant theoretical background information on evaluation criteria and SMSs. Section 3 introduces and explains the existing method and the proposed method. The results of selecting an SMS are shown in Section 3 and conclusions are presented in Section 4.

2. A Framework for the Supply Chain Sustainability Management System Selection

This section explains the SMS selection framework, beginning with a study of the literature specifying the sustainability criteria and then the relevant SMSs for the solution. SMSs are alternatives for the selection.

2.1. Sustainability Criteria

SSCM has been evaluated to establish a guideline for managing limited resources and costs in a supply chain. Most studies on sustainability criteria focus on three dimensions: environment, social, and economic [33–35], which are insufficient to establish the direction of the sustainability management system to be regarded as more connected. The search was limited to SCI journals or conference research papers with a high index published between 2008 and 2020 with the keywords: sustainability, sustainable supply chain management, and sustainability criteria. This newly constructed framework for the supply chain sustainability management system selection comprises eight criteria, which can be described as follows:

- Company (C_1): Company consists of the entire management team and employees of an organization. The company criterion has a profound effect on the supply chain for the optimum SMS selection. It involves top management supporting and motivating, strategy and goals, process/system operations [36], incentives and rewards, reputation loss, business characteristics, organizational culture, and innovation [37].
- Suppliers (C_2): Suppliers' criterion is the key to success for any supply chain. If the company can select the relevant suppliers that are concerned about sustainability, it can greatly affect the organization's efficiency. The selection of suppliers requires many factors, such as reasonable price, high-quality product, on-time delivery, nontoxic or chemical uses, etc. [38,39].
- Competition (C_3): The changing preferences of consumers tend to impact the competition in the market of services and products [40]. In the current situation, companies need to work rapidly to perceive consumer demands and market advantages. In competition, a company must consider market segment, product pricing, and competitive advantage [41].
- Consumption (C_4): As the increasing social trend opposes products that pollute the environment and communities, consumers are more concerned about selecting products and services, and also consider effects such as degradation and recycling. So, manufacturers must evaluate these features to receive a competitive advantage. The relevant factors of consumption are green image, green product, consumer characteristics, reverse logistics, and feedback [39,42].
- Government (C_5): The government is a critical criterion involving enactment and setting standards or requirements that industries must comply with. If a factory fails to comply with the laws, there are penalties and loss of image. The factors of government are laws/regulations/standards, government support, display of green policies, environmental policies of the government, transparency, and enforcement [43,44].
- Social (C_6): It is a sustainability criterion for both inside and outside the organization. Nevertheless, the outside social criterion is the main focus, which includes the surrounding communities and consumers. Social factors within a supply chain consider workers, employees, suppliers, customers, and stakeholders. The social criteria can be divided into two factors: communities and corporate social responsibility [45,46].
- Economic (C_7): Sustainable economic production neither exploits nor harms natural resources and the environment. If nature is destroyed, it will directly impact the economy in the country due to natural disasters, pollution, and waste. The economic criteria can be divided into three relevant evaluation factors: cost and benefit, tax on the green product, and production cost [39,47].

- Environment (C_8): Environmental concern is the main factor that most developed countries criticize and use for imported products. The outputs obtained from production processes are not only products, but may also be unhealthy substances causing pollution and waste, which organizations need to be aware of. The issues about the environment are CO_2 emission, risk management, pollution prevention, energy reduction, and waste reduction. These are included in the environmental regulations of the importing countries' standards [39,46,47].

Various SMSs have been presented and have shown their effectiveness. These management systems are alternatives for a company. The successful applications of SMS from various previous works were gathered and categorized into four types of SMS in this research.

2.2. Sustainability Management Systems (SMSs)

Sustainability is essential to the future and it is a key to success for an organization in the long term. Sustainability implementation in an organization is a business opportunity in investing for process improvement, optimization of energy consumption [48], and reduction in waste [49,50]. It is also a path to innovation and creativity for the organization. On the other hand, the real drivers of sustainability are subjective and tend to vary from sector to sector. Organizations may fail to implement sustainability because they do not pay attention to the main criteria and do not select a suitable SMS. Organizational leaders should select and apply the appropriate SMS to regulate their organization for long-term sustainability. Therefore, in this research, SMSs have been investigated and summarized from industrial applications. Various SMSs have been proposed and presented in different aspects, and four systems are suggested in this research: standards-based systems, business-management-based systems, innovation-based systems, and process-optimization-based systems.

2.2.1. Standards-Based Systems (S_1)

Many organizations are concerned about the implementation of SMS. Nevertheless, solving the problem by enacting legislation, regulations, or rules [51,52] to protect and support what is happening has given them more confidence and initiative. A standards-based system is a management system that deals with existing regulations, standards, or rules as a scheme and has a well-organized guideline for implementing sustainability. ISO 14001 is listed as one of the key elements characterized by the most comprehensive environmental sustainability program [48]. It is a standard that controls the organization to comply with the rules that have been set while continuing to operate efficiently. The ISO standard considers the management of resources and the environment. It will lead to positive outcomes for the communities and environment, such as reducing pollution and toxic substances which are harmful to human health. An important tool for a comprehensive ISO 14001 implementation is the life cycle assessment (LCA) [53], which is a quantitative method for estimating resource usage. In addition, Occupational Health and Safety Assessment Series (OHSAS) 18000 can be compatible with the ISO 14001 management system. It has similar document control, management audits, and corrective and preventive actions. It is designed to allow a company to control risk focus by identifying, eliminating, and continuous improvement of hazards and risks within a working environment. Strategies have been developed to assess sustainability options for social, health, and environmental impacts [44].

2.2.2. Business-Management-Based Systems (S_2)

Conducting a business requires the co-operation of an organization, either directly or indirectly, with all parties involved. It is crucial for carrying out successful operations in a supply chain. Co-operation of sustainability for both inside and outside organizations is a social strategy that is called a collaborative system. However, to comprehensively rely on the co-operation of the people, the organization must cultivate the concept of awareness and training with the right practice [54]. It is a form of long-term sustainability that will be a benefit for the whole supply chain. Sustainability with business-management-based systems not only relies on co-operation, but also needs to be able to analyze the overall management. The organization itself has its strengths, weaknesses, opportunities, and threats (SWOT) to determine how to accurately assess a policy or strategy for sustainability [55]. SWOT analysis for optimal organizational utilization can reduce the likelihood of failure by understanding what is missing [55]. The use of a balanced scorecard (BSC) is also one of the effective tools that can solve organizational participation by creating sustainability in an integrated way with the business organization. Images of the company's contribution to sustainable development are desirable to create better corporate performance in all three dimensions of sustainability—economic, environmental, and social [56]. Journeault (2016) stated that the Sustainability Balanced Scorecard (SBSC) is one of the most promising strategic tools to help organizations meet their challenges and to support sustainability strategies.

2.2.3. Innovation-Based Systems (S_3)

Innovation-based systems focus on the innovation of new products, techniques, technologies, new science, and organizational innovation [57–59]. Sustainable development in a supply chain requires a new way of thinking and performing by integrating a new idea of sustainability into supply chain management [60]. Gracia and Quezada (2016) referred to innovation as one of the key types of strategic programs that can generate a set of sustainability strategies to close the gap in the three dimensions of triple bottom line (TBL). The results not only affect the organization, but also society as a whole. Innovation-based systems aim to increase efficiency, reduce costs, and decrease environmental impacts, such as the use of recycled materials or biodegradable materials to transform or reduce environmentally harmful wastes. Environmental Management System (EMS) simplifies the problem of environmental management. It enables the organization to achieve environmental goals by improving the business environment performance and community relations more easily through information systems [61]. In addition, organizational innovation is defined as inclusive of all operational activities that lead to changes in management, mechanisms, strategies, structures, and systems [62]. It is critical to deploy innovative products, services, or new process technology. Innovation is also one of the pillars of sustainable competitive advantage.

2.2.4. Process-Optimization-Based Systems (S_4)

Sustainability by process-optimization-based systems involves the systems that can incorporate sustainability and optimization processes in a supply chain. They are the methods or tools to reduce resource usage, waste, and the consumption of energy [63]. Various mathematical models for sustainable supply chain management have been proposed to optimize the case studies. Cowan et al. (2010) separated environmental sustainability into three components: resource management, energy management, and product sustainability [48]. Resource management means managing production resources, solid wastes, and water conservation in effective ways. Energy management involves energy conservation, renewable energy, GHG emission reduction [50], energy-efficient construction [64], and reduction in pollution. Product sustainability includes product transportation [65], product mix, supply chain audit, and product stewardship. It should be managed sustainably and optimally to satisfy the firm objectives.

The framework for SMS selection can be constructed in a hierarchy as shown in Figure 1. The first level or goal is to select the best SMS for a company. The second level shows the main criteria, C_1–C_8, which are company, supplier, competition, consumption, government, social, economic, and environment. Standards-based systems, business-management-based systems, innovation-based systems, and process-optimization-based systems represent alternatives (S_1–S_4) of SMSs in the third level.

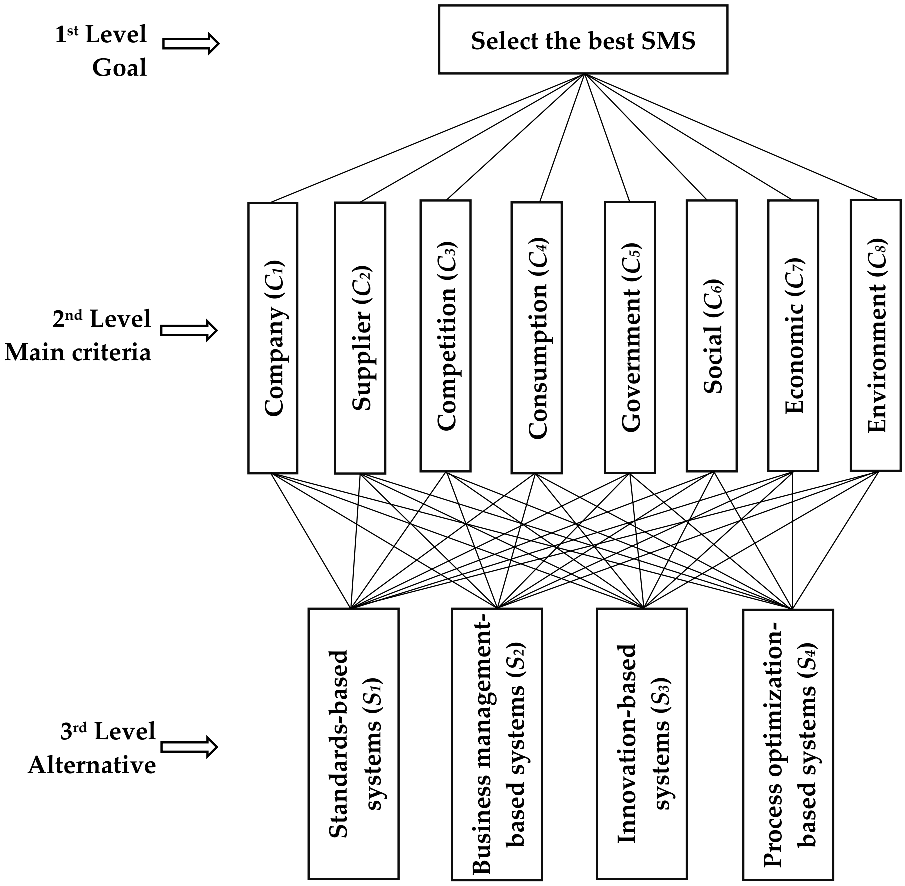

Figure 1. The hierarchical structure of sustainability management system selection.

3. Methodology

The advantage of AHP is the pairwise comparison and the ability to deal with qualitative criteria. However, it cannot deal with imprecise information. A fuzzy set is introduced to cope with uncertainty, then various FAHP methods have been proposed. A triangular fuzzy number is commonly used to represent fuzzy information. FPP method of Mikhailov developed the new FAHP method to sort the priority from fuzzy comparison matrices. FPP method has been recommended to find a solution for both consistent and inconsistent data. FPP and the proposed method are discussed in this section.

3.1. Existing Method: Fuzzy Preference Programming (FPP)

The human decision is not always accurate. A specific form of normal fuzzy sets, which are called a fuzzy number, is more appropriate to use. In a normal fuzzy set, $\widetilde{a}$ is a triangular fuzzy number, which is defined by a membership function as shown in Figure 2 [66].

Let $\widetilde{a}$ be a fuzzy number on the real line $\Re$. Then, its membership function $\mu_{\widetilde{a}}(x)$: $\Re$ $\rightarrow$ [0, 1].

$$\mu_{\widetilde{a}}(x) = \begin{cases} (x-l)/(m-l), x \in [l,\ m] \\ (u-x)/(u-m), x \in [m,\ u] \\ 0,\ \text{otherwise} \end{cases} \quad (1)$$

then $\widetilde{a}$ is called a triangular fuzzy number.

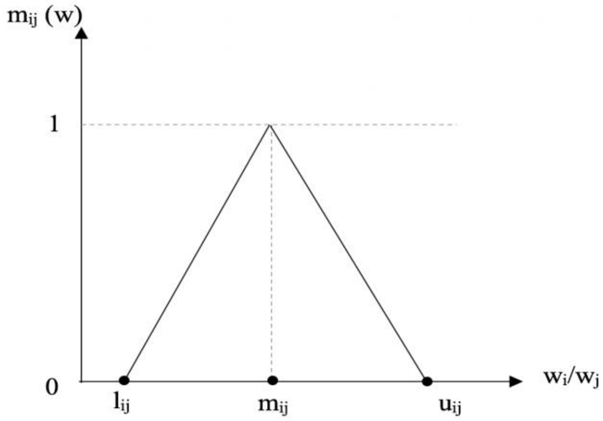

Figure 2. Graphical representation of a triangular membership function.

Now, deliberate a prioritization problem with n unidentified priorities $w = (w_1,\ w_2, \ldots,\ w_n)^T$, where the pairwise comparison judgment is denoted by a fuzzy number as shown in Figure 2, $\widetilde{a}_{ij} = (l_{ij},\ m_{ij},\ u_{ij})$. A positive reciprocal matrix $\widetilde{A} = \{\widetilde{a}_{ij}\}$ is represented by:

$$\widetilde{A} = \begin{bmatrix} 1 & \widetilde{a}_{12} & \cdots & \widetilde{a}_{1n} \\ \widetilde{a}_{21} & 1 & \cdots & \widetilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \widetilde{a}_{n1} & \widetilde{a}_{n2} & \cdots & 1 \end{bmatrix}, \tag{2}$$

$$\widetilde{a}_{ji} = 1/\widetilde{a}_{ij} = (1/u_{ij}\ ,\ 1/m_{ij}\ ,\ 1/l_{ij}\ ). \tag{3}$$

where a_{ij} indicates that the alternative x_i is preferred more than the alternative x_j under a criterion, and $a_{ij} = 1/a_{ji}$, $a_{ii} = 1$, $I, j \in \{1, 2, \ldots, n\}$ [67]. The method of constructing fuzzy matrices used an analogy from crisp numbers to fuzzy numbers. l_{ij}, m_{ij}, and u_{ij} are lower bound, mid-point, and upper bound of fuzzy numbers in the sequence ij.

FPP was developed by Mikhailov (2003) for deriving optimal crisp priorities [29]. It transforms the prioritization problem into a linear (interval numbers) or a nonlinear program (fuzzy numbers). It can be applied for both consistent and inconsistent data. Mikhailov applied the max–min approach for finding the maximizing solution that leads to the following nonlinear optimization problem [29]:

Model: FPP

$$\begin{array}{c} \max \lambda \\ \text{s.t.} \quad (m_{ij} - l_{ij})\lambda w_j - w_i + l_{ij} w_j \leq 0, \\ (u_{ij} - m_{ij})\lambda w_j + w_i - u_{ij} w_j \leq 0, \\ \sum_{k=1}^{n} w_k = 1, w_k > 0, k = 1, 2, \ldots, n, \\ i = 1, 2, \ldots, n-1,\ j = 2, 3, \ldots, n,\ j > i. \end{array} \tag{4}$$

where w_i and w_j are the weights of criteria. The optimal value of the consistency index is λ. If it is positive, solution ratios are satisfied with the initial judgments ($l_{ij} \leq w_i/w_j \leq u_{ij}$). If it is negative, the solution ratios are strongly inconsistent ($l_{ij} > w_i/w_j$ or $w_i/w_j > u_{ij}$).

FPP has a drawback because lower and upper triangular judgments of fuzzy pairwise comparison matrices are not the same, since the FPP does not consider the asymmetric properties of pairwise comparison judgments. This research has shown a new FAHP that can find a suitable priority from the fuzzy pairwise comparison matrices.

3.2. The Proposed Method: Fuzzy Additive Preference Programming (FAPP)

FAPP method is based on AHP and fuzzy set. The advantage of AHP is the pairwise comparison. However, it cannot deal with imprecise information. Fuzzy sets are introduced to cope with uncertainty, then various FAHP methods have been proposed. A triangular fuzzy number is commonly used to represent fuzzy information. In a normal fuzzy set,

$\widetilde{a}$ is a triangular fuzzy number, which is defined by a membership function, as shown in Figure 2 [66].

Mikhailov's scale is the general scale that has a symmetrical distribution. The comparison matrices evaluated by Saaty's asymmetric scale need to be adjusted for the membership function to fit the correct proportion. For example, if the interval judgment is [1/3, 5], according to the concept of FPP by Mikhailov, the value of the middle point m_{ij} = 8/3 (calculated by (l_{ij} + u_{ij})/2), where l_{ij} and u_{ij} are the lower and upper bounds, but, when it is compared with the Saaty's scale, the value of m_{ij} is 2, as shown in Figure 3. Therefore, to obtain a reasonable distance, Mikhailov's scale is needed to adjust the distance value.

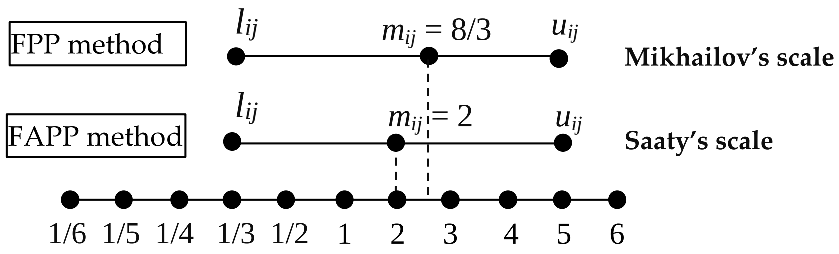

Figure 3. Mikhailov's scale and Saaty's scale.

Chen and Xu (2015) developed the method for interval reciprocal comparison matrices to find the weight of the criteria based on Saaty's scale with three kinds of membership functions [68]. In the same way, the FAPP method for fuzzy comparison matrices can also be developed.

Considering the interval of judgments, the following equation is used to check the consistency of data:

$$l_{ij} \leq w_i/w_j \leq u_{ij}\ ,\ i = 1,\ 2,\ \ldots,\ n-1, \quad j = 2,\ 3,\ \ldots,\ n,\ j > i, \tag{5}$$

Consistency can be checked by the ratio of $w_i/w_{j.}$ If the ratio of w_i/w_j is between the lower and upper bounds, it means that the data are consistent. Otherwise, the data are inconsistent and cannot be used. These data need to be reconsidered until they are consistent before calculating the weights. By the FAPP method, inconsistent pairs of fuzzy judgments in the decision matrix can be easily found. Then, a new assessment can be carried out. It is not necessary to re-evaluate all pairs of fuzzy judgments in the decision matrix, which is the advantage of the proposed method. For inconsistent cases, priority vectors that satisfy Equation (5) do not exist.

From Chen and Xu (2015) [68]:

$$\mu_P(w^*) = \max_{w \in Q^n} \min_{i,j} \{\mu_{ij}(w_i, w_j)\} \tag{6}$$

where $\mu_{ij}^L(w)$ is the membership function of $\widetilde{a}_{ij}$ and p is a total feasible area.

$$Q^n = \{(w_1, w_2, \ldots, w_n) \mid w_i \geq 0, \textstyle\sum_{i=1}^n w_i = 1\} \tag{7}$$

FPP method does not consider the properties of asymmetry of Saaty's scale. Therefore, a new method has been generated in this research to modify the solution based on the total satisfaction degree of all constraints as:

$$\mu_P(w) = \sum_{i=1}^{n} \sum_{j=i+1}^{n} \mu_{ij}(w_i, w_j) \tag{8}$$

where $\mu_{ij}(w_i, w_j)$ represents the membership functions from the solutions Equations (9)–(12), which have four different types of fuzzy pairwise comparison judgments.

Membership functions are classified into 4 cases as follows:

$$\text{Case 1}: \quad 1 \le l_{ij} < m_{ij} < u_{ij}$$
$$\mu_{ij}(w_i, w_j) = \begin{cases} 1 - (w_i - l_{ij}w_j)/(m_{ij} - l_{ij}) \ , & w_i/w_j \le m_{ij} \\ 1 - (-w_i + u_{ij}w_j)/(u_{ij} - m_{ij}), & w_i/w_j \ge m_{ij} \end{cases} \tag{9}$$

$$\text{Case 2}: \quad l_{ij} < 1 \le m_{ij} < u_{ij}$$
$$\mu_{ij}(w_i, w_j) = \begin{cases} 1 - ((1/l_{ij})w_i - w_j) \ /(m_{ij} + 1/l_{ij} - 2), & w_i/w_j \le m_{ij} \\ 1 - (-w_i + u_{ij}w_j)/(u_{ij} - m_{ij}) \ , & w_i/w_j \ge m_{ij} \end{cases} \tag{10}$$

$$\text{Case 3}: \quad l_{ij} < m_{ij} < 1 \le u_{ij}$$
$$\mu_{ij}(w_i, w_j) = \begin{cases} 1 - ((1/l_{ij})w_i - w_j)/(1/l_{ij} - 1/m_{ij}), & w_i/w_j \le m_{ij} \\ 1 - (-w_i + u_{ij}w_j)/(u_{ij} + 1/m_{ij} - 2), & w_i/w_j \ge m_{ij} \end{cases} \tag{11}$$

$$\text{Case 4}: \quad l_{ij} < m_{ij} < u_{ij} < 1$$
$$\mu_{ij}(w_i, w_j) = \begin{cases} 1 - ((1/l_{ij})w_i - w_j) \ /(1/l_{ij} - 1/m_{ij}), & w_i/w_j \le m_{ij} \\ 1 - ((-1/u_{ij})w_i + w_j)/(1/m_{ij} - 1/u_{ij}), & w_i/w_j \ge m_{ij} \end{cases} \tag{12}$$

Proposition 1. *If the membership function $\mu_{ij}(w_i, w_j)$ is a membership function type according to the Equations (9)–(12), then Equation (8) is convex.*

Proof. From Equations (9)–(12) linear membership functions, $\mu_{ij}(w_i, w_j)$ ($i, j = 1, 2, \ldots, n$) are convex, so linear combination functions $\mu_p(w)$ of these membership functions are convex as well. □

From the total satisfaction degree function of Equation (8), the new FAPP problem can be derived as:

$$\mu_p(w^*) = \max_{w \in Q^n} \left\{ \sum_{i=1}^{n} \sum_{j=i+1}^{n} \mu_{ij}(w_i, w_j) \right\} \tag{13}$$

Equation (13) can be changed into an FAPP problem by matching and substituting each pair of a fuzzy pairwise comparison matrix in each case. Then, use the following model to solve the problem:

Model: FAPP

$$\begin{gathered} \max \sum_{i=1}^{n} \sum_{j=i+1}^{n} (p_{ij}^{+} + p_{ij}^{-}) \\ \text{s.t. } p_{ij}^{+} \le \ \mu_{ij}(w_i, w_j), \\ p_{ij}^{-} \le \ \mu_{ij}(w_i, w_j), i = 1, 2, \ldots n-1, \ j = 2, 3, \ldots, n, \ j > i, \\ \textstyle\sum_{i=1}^{n} w_i = 1, \ w_i > \ 0, \quad 1, 2, \ldots, \ n \end{gathered} \tag{14}$$

where p_{ij}^{+} is a positive deviation from m_{ij} to u_{ij} and p_{ij}^{-} is a negative deviation from m_{ij} to l_{ij}.

The membership function of $\mu_{ij}(w_i, w_j)$ is represented by Figure 4.

Proposition 2. *The problem in Equation (14) has a single solution.*

Proof. Membership functions, $\mu_{ij}(w_i, w_j)$ ($i, j = 1, 2, \ldots, n$) derived from Equations (9)–(12) are the unimodal piecewise continuous functions. They are rigorously increasing or decreasing around the most likely ratio. Moreover, based on Proposition 1, the sum of the values of $\mu_p(w)$ is strictly convex too. Therefore, there is only one point of w^* over the Q^n that maximizes the value of the total membership functions in Equation (13). □

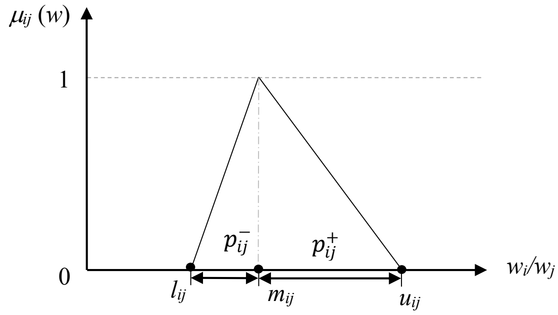

Figure 4. Graphical representation of a membership function, $\mu_{ij}(w_i,w_j)$.

Theorem 1. *The priorities derived by the FAPP method from the upper triangular elements of the lower triangle fuzzy comparison matrix can be proved as follows:*

Proof. Consider a pair of fuzzy judgments $\tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij})$ in case 1, represented by Equation (9), and $\tilde{a}_{ji} = (1/u_{ij}, 1/m_{ij}, 1/l_{ij})$ in case 4, illustrated in Equation (12). The constraints of the model in Equation (14) derived from $\tilde{a}_{ji}$ of case 1 can be written as:

$1 - ((-1/u_{ij})w_i + w_j)/(1/m_{ij} - 1/u_{ij})$
$1 - ((1/l_{ij})w_i - w_j)/(1/l_{ij} - 1/m_{ij})$
which can be equivalently expressed as:
$1 - (w_i - l_{ij}w_j)/(m_{ij} - l_{ij})$
$1 - (-w_i + u_{ij}w_j)/(u_{ij} - m_{ij})$
Consider $\tilde{a}_{ij}$ in case 2, represented by Equation (10), and $\tilde{a}_{ji}$ in case 3, illustrated by Equation (11). The constraints of the model in Equation (14) derived from $\tilde{a}_{ji}$ can be exhibited as:
$1 - ((1/l_{ij})w_i - w_j)/(1/l_{ij} - 1/m_{ij})$
$1 - (-w_i + u_{ij}w_j)/(u_{ij} + 1/m_{ij} - 2)$
which can be equivalently expressed as:
$1 - ((1/l_{ij})w_i - w_j)/(m_{ij} + 1/l_{ij} - 2)$
$1 - (-w_i + u_{ij}w_j)/(u_{ij} - m_{ij})$. □

According to the above proof, choosing the right membership function along with the principle of the FAPP method, the constraints for $\tilde{a}_{ij}$ and $\tilde{a}_{ji}$ are always the same. Then, the result of weights from both the lower or upper triangular elements of a fuzzy comparison matrix will always be the same.

4. A Real Case Study for Sustainability Management Systems Selection

The real case study of a rubber factory that intends to select the suitable SMS for its factory is presented. The factory has already implemented GSCM and has committed to improve its SCM by SSCM, so it needs to select the appropriate SMS for its factory. The procedure for applying the FAPP method of the case study is divided into the following steps:

Step 1: Set the goal to select the most suitable SMS for the factory. Then, define the criteria and alternatives of SMSs, as shown in Figure 1,

Step 2: Assign appropriate specialists to conduct pairwise comparison matrices. In this case, assessments were undertaken by the head of purchasing, planning supervisor, head of quality, production engineer, and R&D engineer, each with more than 10 years of working experience. They needed to identify and determine the relationships among sustainability criteria and SMSs or alternatives for each criterion. Information is imprecise, so uncertain assessments can be translated by triangular fuzzy judgments [69]. In this research, the geometric mean was used to combine DMs' opinions [70]. Table 1 shows a jointed decision-making matrix of sustainability criteria and Table 2 shows jointed decision matrices of SMSs based on criteria.

Table 1. The fuzzy pairwise comparison matrix of sustainability criteria and weights results.

Criteria	C_1	C_2	C_3	C_4	Weight of Criteria (FAPP)$_{upper}$	Weight of Criteria (FPP)$_{upper}$
C_1	(1.00, 1.00, 1.00)	(0.26, 0.35, 0.65)	(0.24, 0.34, 0.46)	(0.80, 1.52, 2.41)	0.0584	0.0533
C_2	(1.54, 2.83, 3.87)	(1.00, 1.00, 1.00)	(0.29, 0.37, 0.52)	(1.25, 2.00, 3.06)	0.0803	0.0864
C_3	(2.19, 2.93, 4.11)	(1.92, 2.69, 3.47)	(1.00, 1.00, 1.00)	(1.32, 2.05, 3.10)	0.1719	0.1812
C_4	(0.42, 0.66, 1.25)	(0.33, 0.50, 0.80)	(0.32, 0.49, 0.76)	(1.00, 1.00, 1.00)	0.0763	0.0607
C_5	(1.55, 2.64, 4.55)	(2.50, 3.82, 4.85)	(0.49, 0.80, 1.35)	(2.30, 3.32, 4.34)	0.2545	0.2245
C_6	(1.64, 2.09, 3.13)	(1.07, 1.52, 2.22)	(0.40, 0.64, 0.94)	(1.00, 1.52, 2.46)	0.1217	0.1387
C_7	(1.43, 2.00, 5.00)	(1.05, 1.28, 2.78)	(0.45, 0.81, 1.00)	(1.01, 1.56, 2.56)	0.1230	0.1415
C_8	(1.59, 2.94, 3.33)	(1.27, 1.61, 2.50)	(0.45, 0.66, 0.99)	(1.28, 1.79, 4.35)	0.1138	0.1137
Criteria	C_5	C_6	C_7	C_8	**Weight of criteria (FAPP)$_{lower}$**	**Weight of criteria (FPP)$_{lower}$**
C_1	(0.22, 0.38, 0.64)	(0.32, 0.48, 0.61)	(0.20, 0.50, 0.70)	(0.30, 0.34, 0.63)	0.0584	0.0505
C_2	(0.21, 0.26, 0.40)	(0.45, 0.66, 0.93)	(0.36, 0.78, 0.95)	(0.40, 0.62, 0.79)	0.0803	0.0840
C_3	(0.74, 1.25, 2.05)	(1.06, 1.55, 2.49)	(1.00, 1.23, 2.21)	(1.01, 1.51, 2.22)	0.1719	0.1792
C_4	(0.23, 0.30, 0.44)	(0.41, 0.66, 1.00)	(0.39, 0.64, 0.99)	(0.23, 0.56, 0.78)	0.0763	0.0603
C_5	(1.00, 1.00, 1.00)	(1.52, 2.27, 3.37)	(1.49, 2.07, 3.07)	(1.09, 1.98, 2.98)	0.2545	0.2205
C_6	(0.30, 0.44, 0.66)	(1.00, 1.00, 1.00)	(0.98, 0.99, 1.00)	(1.01, 1.12, 1.32)	0.1217	0.1409
C_7	(0.33, 0.48, 0.67)	(1.00, 1.01, 1.02)	(1.00, 1.00, 1.00)	(1.14, 2.09, 3.19)	0.1230	0.1436
C_8	(0.34, 0.51, 0.92)	(0.76, 0.89, 0.99)	(0.31, 0.48, 0.88)	(1.00, 1.00, 1.00)	0.1138	0.1209

Step 3: Calculate weights by the model in Equation (13) according to the memberships in Equations (9)–(12). For the case study, the formulation of the model can be illustrated in Equation (15). For example, a_{12} and a_{13} match the membership function in Equation (12), or a_{78} matches the membership function in Equation (9). By using the upper triangular elements of Table 1, the model in Equation (14) can be written as:

$$\max \sum_{i=1}^{8}\sum_{j=i+1}^{8}(p_{ij}^{+}+p_{ij}^{-})\text{Subject to}\begin{cases} p_{12}^{-}\leq 1-(((1/0.26)*w\_1-w\_2)/((1/0.26)-(1/0.35))),\\ p_{12}^{+}\leq 1-(((-1/0.65)*w\_1+w\_2)/((1/0.35)-(1/0.65))),\\ p_{13}^{-}\leq 1-(((1/0.24)*w\_1-w\_3)/((1/0.24)-(1/0.34))),\\ p_{13}^{+}\leq 1-(((-1/0.46)*w\_1+w\_3)/((1/0.34)-(1/0.46))),\\ \vdots\\ p_{78}^{-}\leq 1-((w\_7-1.14*w\_8)/(2.09-1.14)),\\ p_{78}^{+}\leq 1((w\_7+3.19*w\_8)/(3.19-2.09)),\end{cases}$$
$$\sum_{i=1}^{n}w_i=1, w_i>0,\ i=1,\ 2,\ldots,n \quad (15)$$

Step 4: Check the consistency of weights obtained from the previous step by Equation (5) whether they are reliable or not. If some of them cannot pass the condition, then they must be re-evaluated until they can pass the condition. The results of criteria weights are shown in Table 1.

Step 5: After passing the consistency check, the criteria can be prioritized from obtained weight values. A high value of weight means a high level of importance.

Step 6: Repeat steps 3–5 for the fuzzy pairwise comparison matrix of SMSs. Then, alternative weights can be acquired as shown in Table 2.

Step 7: Calculate the global weight of each alternative by multiplying the criterion weight by the local weight of alternatives, as shown in Table 3. Then, summarize the global weights of each alternative and rank the alternatives.

Table 2. The fuzzy pairwise comparison matrix of SMSs and weights results.

Alternatives		S_1	S_2	S_3	S_4	$w^*_{\text{FAPP(Upper/Lower)}}$	$w^*_{\text{FPP(Upper)}}$	$w^*_{\text{FPP(Lower)}}$
Based on C_1	S_1	(1, 1, 1)	(0.26, 0.35, 0.51)	(0.61, 1.02, 1.67)	(0.11, 0.13, 0.16)	0.0863	0.0793	0.0763
	S_2	(1.96, 2.86, 3.85)	(1, 1, 1)	(2.01, 2.98, 4.21)	(0.21, 0.35, 0.53)	0.2533	0.2366	0.2317
	S_3	(0.60, 0.98, 1.64)	(0.24, 0.34, 0.50)	(1, 1, 1)	(0.13, 0.15, 0.16)	0.085	0.0866	0.0873
	S_4	(6.25, 7.69, 9.09)	(1.89, 2.86, 4.76)	(6.25, 6.67, 7.69)	(1, 1, 1)	0.5754	0.5976	0.6048
Based on C_2	S_1	(1, 1, 1)	(1.11, 1.29, 1.50)	(0.65, 1.03, 1.24)	(0.32, 0.50, 2.20)	0.2732	0.2758	0.2687
	S_2	(0.67, 0.78, 0.90)	(1, 1, 1)	(0.45, 0.63, 0.84)	(0.85, 1.03, 1.72)	0.2118	0.1876	0.1854
	S_3	(0.81, 0.97, 1.54)	(1.19, 1.59, 2.22)	(1, 1, 1)	(2.93, 3.11, 3.32)	0.3897	0.4007	0.4073
	S_4	(0.45, 2.01, 3.16)	(0.58, 0.97, 1.17)	(0.30, 0.32, 0.34)	(1, 1, 1)	0.1253	0.1359	0.1387
Based on C_3	S_1	(1, 1, 1)	(2.50, 3.19, 3.40)	(4.17, 4.35, 4.56)	(6.36, 6.54, 6.75)	0.5614	0.5679	0.5683
	S_2	(0.29, 0.31, 0.40)	(1, 1, 1)	(1.68, 3.15, 3.36)	(2.50, 3.93, 4.14)	0.2237	0.2228	0.2219
	S_3	(0.22, 0.23, 0.24)	(0.30, 0.32, 0.60)	(1, 1, 1)	(0.92, 1.96, 2.17)	0.1291	0.1249	0.1253
	S_4	(0.14, 0.15, 0.16)	(0.24, 0.25, 0.40)	(0.46, 0.51, 1.09)	(1, 1, 1)	0.0858	0.0843	0.0845
Based on C_4	S_1	(1, 1, 1)	(2.90, 3.79, 4.00)	(3.94, 4.12, 5.81)	(3.76, 6.12, 6.93)	0.6057	Solution is locally infeasible	
	S_2	(0.25, 0.26, 0.34)	(1, 1, 1)	(1.05, 2.95, 3.56)	(1.81, 2.87, 3.68)	0.1598		
	S_3	(0.17, 0.24, 0.25)	(0.28, 0.34, 0.95)	(1, 1, 1)	(1.50, 1.68, 1.89)	0.147		
	S_4	(0.14, 0.16, 0.27)	(0.27, 0.35, 0.55)	(0.53, 0.59, 0.66)	(1, 1, 1)	0.0875		
Based on C_5	S_1	(1, 1, 1)	(2.89, 3.59, 4.10)	(3.91, 4.46, 5.11)	(3.66, 6.81, 7.12)	0.6084	0.591	0.5897
	S_2	(0.24, 0.28, 0.35)	(1, 1, 1)	(1.15, 2.94, 3.59)	(1.83, 2.89, 3.58)	0.1695	0.1949	0.1908
	S_3	(0.20, 0.22, 0.26)	(0.28, 0.34, 0.87)	(1, 1, 1)	(1.49, 1.59, 1.84)	0.1364	0.1288	0.1324
	S_4	(0.14, 0.16, 0.27)	(0.28, 0.35, 0.55)	(0.54, 0.63, 0.67)	(1, 1, 1)	0.0858	0.0853	0.087
Based on C_6	S_1	(1, 1, 1)	(3.25, 3.43, 3.64)	(3.44, 3.62, 3.83)	(0.70, 0.88, 1.09)	0.3707	0.3968	0.3929
	S_2	(0.27, 0.29, 0.31)	(1, 1, 1)	(1.01, 1.78, 1.99)	(0.18, 0.36, 0.57)	0.1081	0.1208	0.1192
	S_3	(0.26, 0.28, 0.29)	(0.50, 0.56, 0.99)	(1, 1, 1)	(0.24, 0.42, 0.63)	0.1024	0.1047	0.1042
	S_4	(0.92, 1.14, 1.43)	(1.75, 2.76, 5.47)	(1.59, 2.38, 4.17)	(1, 1, 1)	0.4188	0.3777	0.3837
Based on C_7	S_1	(1, 1, 1)	(0.91, 1.09, 1.30)	(0.96, 1.14, 1.35)	(0.47, 0.65, 1.80)	0.2914	0.2820	0.2782
	S_2	(0.77, 0.92, 1.10)	(1, 1, 1)	(0.85, 1.03, 1.24)	(0.74, 0.92, 1.73)	0.2684	0.2511	0.2469
	S_3	(0.74, 0.88, 1.04)	(0.80, 0.97, 1.17)	(1, 1, 1)	(1.46, 1.64, 1.85)	0.2734	0.2805	0.2836
	S_4	(0.56, 1.54, 2.14)	(0.58, 1.08, 1.34)	(0.54, 0.61, 0.68)	(1, 1, 1)	0.1667	0.1864	0.1914
Based on C_8	S_1	(1, 1, 1)	(1.95, 3.64, 4.41)	(8.12, 8.30, 8.51)	(1.25, 1.43, 1.64)	0.4884	0.4581	0.4695
	S_2	(0.23, 0.27, 0.51)	(1, 1, 1)	(1.71, 1.89, 4.23)	(0.17, 0.35, 0.77)	0.1112	0.2005	0.1763
	S_3	(0.11, 0.12, 0.13)	(0.24, 0.53, 0.58)	(1, 1, 1)	(0.13, 0.79, 1.00)	0.0588	0.0562	0.0575
	S_4	(0.61, 0.7 0, 0.80)	(1.30, 2.86, 5.88)	(1.00, 1.27, 7.69)	(1, 1, 1)	0.3415	0.2852	0.2967

Table 3. Overall weights of sustainability criteria and SMSs.

Main Criteria	Criteria Weights	Local Weight of Alternatives				Global Weight of Alternatives			
		S_1	S_2	S_3	S_4	S_1	S_2	S_3	S_4
C_1	0.0584	0.0863	0.2533	0.0850	0.5754	0.0050	0.0148	0.0050	0.0336
C_2	0.0803	0.2732	0.2118	0.3897	0.1253	0.0219	0.0170	0.0313	0.0101
C_3	0.1719	0.5614	0.2237	0.1291	0.0858	0.0965	0.0385	0.0222	0.0147
C_4	0.0763	0.6057	0.1598	0.1470	0.0875	0.0462	0.0122	0.0112	0.0067
C_5	0.2545	0.6084	0.1695	0.1364	0.0858	0.1548	0.0431	0.0347	0.0218
C_6	0.1217	0.3707	0.1081	0.1024	0.4188	0.0451	0.0132	0.0125	0.0510
C_7	0.1230	0.2914	0.2684	0.2734	0.1667	0.0358	0.0330	0.0336	0.0205
C_8	0.1138	0.4884	0.1112	0.0588	0.3415	0.0556	0.0127	0.0067	0.0389
Total	1.0000								
Priority level						0.4611	0.1844	0.1572	0.1973
Alternative ranking						1	3	4	2

Intel (R) Core (TM) i5-3570 CPU @ 3.40 GHz RAM 8.00 GB 64-bit and Lingo 17.0 software were used to analyze the FAPP model problem in this research. The computational time for weights criteria and alternatives ranking based on eight criteria were 0.26 and 0.07 s, respectively.

4.1. Sustainability Criteria Weights

From Table 1, the results of criteria weights by FAPP were w^*_{FAPP} = (0.0584, 0.0803, 0.1719, 0.0763, 0.2545, 0.1217, 0.1230, 0.1138), in which both the upper and lower triangular decision matrix can obtain the same results. The data consistency checks were found to pass the acceptance criteria for all pairs of fuzzy judgments in the decision matrix. The advantage of this method is that it can identify abnormal pairs in the decision matrix. If the resulting value exceeds the lower and upper bounds of that pair, the inconsistency of the pair under consideration shall be reassessed until it meets the condition. However, with the FPP method, prioritizing results of the upper and lower triangular decision matrix were $w^*_{\text{FPP-upper}}$ = (0.0533, 0.0864, 0.1812, 0.0607, 0.2245, 0.1387, 0.1415, 0.1137) and $w^*_{\text{FPP-lower}}$ = (0.0505, 0.0840, 0.1792, 0.0603, 0.2205, 0.1409, 0.1436, 0.1209). The results from the FPP method have the weakness that the weights obtained from the upper triangular fuzzy judgments are not equal to the lower fuzzy judgments. In addition, some weight values cannot be obtained because the solution is locally infeasible, as shown in Table 2. Then, the final ranking cannot be found by the FPP method. It can be concluded that the proposed method ensures the uniqueness of the priorities, while the FPP method may lead to conflicting priority results or may not be able to obtain the weight values.

The results of weights show that government and competition criteria are the most significant drivers for the rubber company, which are external factors that force the factory to implement SMS. Rasti-Barzoki and Moon (2020) and Veldman and Gaalman (2020) also stated that government and competition are significant criteria for sustainability goals and sustainability investments. The Thai government encourages organizations to embark on a more sustainable supply chain to build more robust and sustainable networks with long-term balance, by adopting the development principle according to Bio-Circular-Green (BCG) economy model. The factory has planned to deploy the model; it intends to compete in the annual contest for the Thailand sustainable investment award to improve the organization's reputation. Although this case study company has the country's largest market share in the OEM market, it has not stopped growing itself to maintain existing standards and continues to receive ISO 14001 certification this year. The company has introduced new technologies for research and developed new products, so it will be able to accommodate market needs that vary with technology and societal developments, such as the design to lower the weight of the structure and environmentally friendly design. It enters new market sectors for both local and international markets to increase its competitive advantage over competitors.

The next criteria are TBL, which have the same level of importance. These criteria are significant for SCM, GSCM, and SSCM, as recommended by the works of Mai-Moulin et al. (2021), Ashrafi et al. (2022), and Lazar (2022) [33–35]. The company has channeled to a new market and developed new products simultaneously from a social perspective. The case study company intends to produce shared value to help as many individuals as possible in society and to create various corporate social responsibility (CSR) programs in specific localities. The company is green industry level 4, aiming for promoting the green culture to be in all enterprise-wide operating processes by complying with the 'Zero waste management' policy via '3RS' or 'Reduce, Reuse, and Recycle" process, including water and energy management, environmental care in the workplace area, installation of solar panels for promoting renewable energy, carbon footprint management, and reduction in the greenhouse gas emission into the Earth's atmosphere. Finally, supplier, consumption, and company are the less significant criteria for the factory.

4.2. Sustainability Management Systems Weights

From Figure 5, the results of prioritizing SMS show that the factory should choose standards-based systems to be implemented for sustainability with the highest score. Process-optimization-based systems, business-management-based systems, and innovation-based systems are ordered, respectively. The weight evaluation of sustainability criteria corresponds to the selection of standards-based systems with the weights of 0.2545 and 0.1719 for government and competition criteria, respectively. This factory has already implemented GSCM, so it is relatively easy to follow a similar procedure to achieve sustainability. For this case study, the manufacturer must complete a project to obtain an ISO 14001 license and participate in a Thai government-sponsored initiative on issues concerning the sustainability of Thai industry. ISO 14001 is the best practice for GSCM that can increase business performance. It is recommended to be initiated by top management [71]. ISO 50001 is another choice that can reduce production costs due to energy efficiency, increase emissions responsibility, reduce degradation of the Earth's atmosphere, and further enhance an excellent corporate image.

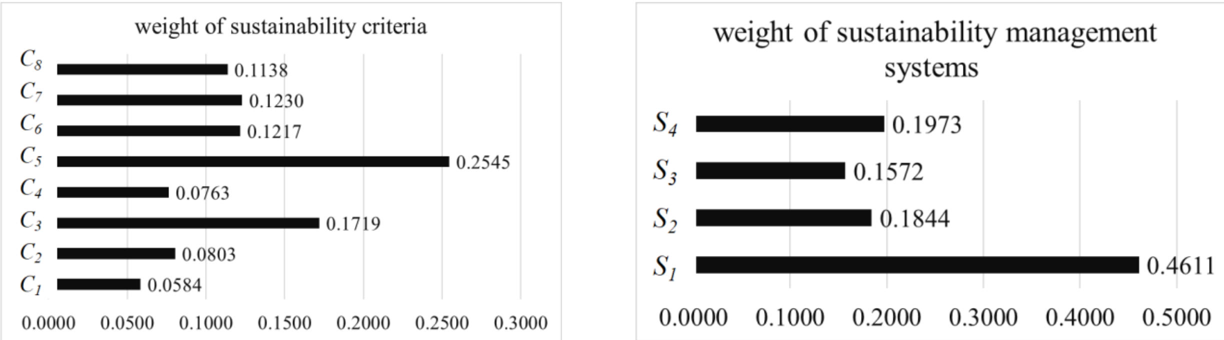

Figure 5. The weights obtained from the overall ratings of sustainability criteria for selecting an SMS.

This factory's competitors all have production control standards to keep the maximum plant quality. The company tries to maintain standards that are similar to or greater than its competitors regularly. Different factories have different backgrounds, so they may select different SMSs to implement in their factories.

In the case that the solution of SMS is different from this research, the possible contributions of each SMS are as follows:

(1) Standards-based systems: the company should establish standards to enforce as guidelines for sustainability within the organization, such as ISO 14001 and OHSAS 18000.
(2) Business-management-based systems: the organization requires both internal and external co-operation. Tools that can be used to help achieve sustainability include BSC and SWOT.
(3) Innovation-based systems: the company should focus on the pursuit of organizational innovation, technology, and innovative equipment applied to the organization, in the production, or even waste disposal. Tools that were applied to the successful organization are EMS, accessible solar power, carbon capture and storage, hydrogen in the energy transition, etc.
(4) Process-optimization-based systems: organizations should focus on using tools to improve processes to be more efficient, reduce energy consumption, and reduce emissions.

5. Conclusions

In this research, the FAPP method was proposed to solve the problem of choosing a suitable SMS. The method is an additive constraints model that uses only linear functions. It can utilize both qualitative and quantitative data and can reduce the weakness of the existing method by ensuring the same priority ranking for upper and lower triangular judgments with the same fuzzy pairwise comparison matrix. In addition, the FAPP can identify abnormal pairs of fuzzy judgments that cause inconsistency in the decision matrix. The hierarchical framework for prioritizing SMSs was also presented. There are eight main criteria, which consist of company, supplier, competition, consumption, government, social, economic, and environment; and four SMSs, which are standards-based systems, business-management-based systems, innovation-based systems, and process-optimization-based systems. This framework can be used by any industry that wants to implement sustainability. An example is provided to show the methodology and the effectiveness of the proposed method over an existing method. The comparison results between FAPP and the FPP method reveal the validity and feasibility of the proposed method. They clearly show that the proposed method works better than existing additive constraints methods. The result from the model can give the direction for the factory to manage its system. Moreover, critical factors involving the implementation of SMS can be made known. Then, the operations for the sustainability of the factory can be deployed. Suggestions for each SMS are also provided in the research.

The FAPP method can be applied to a wide range of MCDM problems because it can be used with both qualitative and quantitative data. The limitation of the methods is that each pair of data in the decision matrix has to match the related membership function, which may take some time to consider. Future research will be focused on developing a faster solution generation. Furthermore, the framework of SMS selection can be extended to the detailed operations of each SMS. The FAPP model can be further improved by reducing the time of determining membership functions.

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Abbreviations

SCM	Supply Chain Management
SMS	Sustainability Management System
GSCM	Green Supply Chain Management
SSCM	Sustainable Supply Chain Management
MADM	Multiple Attribute Decision Making
AHP	Analytic Hierarchy Process
DMs	Decision Makers
FAHP	Fuzzy Analytic Hierarchy Process
FPP	Fuzzy Preference Programming
LFPP	Logarithmic Fuzzy Preference Programming method
FAPP	Fuzzy Additive Preference Programming
LCA	Life cycle assessment
OHSAS	Occupational Health and Safety Assessment Series
SWOT	Strengths, weaknesses, opportunities, or threats
BSC	Balanced Scorecard
SBSC	Sustainability Balanced Scorecard
TBL	Triple Bottom Line
EMS	Environmental Management System
BCG	Bio-Circular-Green
CSR	Corporate social responsibility

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