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## Article

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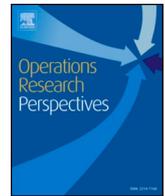
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# Fermatean fuzzy CRITIC-CODAS-SORT for characterizing the challenges of circular public sector supply chains

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## ABSTRACT

The challenges of implementing circular supply chains (CSCs) are well documented, but their characterization in public sector supply chains is unavailable. Thus, this paper closes such a gap by viewing it as a multiple criteria sorting (MCS) problem. Following a systematic literature review of identifying CSC challenges, they are analytically mapped to public sector characteristics through a novel integration of Criteria Importance Through Intercriteria Correlation (CRITIC) and Combinative Distance-based Assessment (CODAS)-SORT (CODAS-SORT) methods under a Fermatean fuzzy environment. Unlike other comparable methods, the proposed Fermatean fuzzy CRITIC-CODAS-SORT is a computationally efficient MCS tool that only requires minimal cognitive workload from expert decision-makers. The Fermatean fuzzy CRITIC generates the weights of domain characteristics, while the Fermatean fuzzy CODAS-SORT assigns the CSC challenges to predefined classes. Findings reveal that inadequate top management support, inadequate government policies, lack of interest in the concept of circularity, lack of incentives to adopt CSC practices, restrictive collection policies, inadequate knowledge on CSC, and size and complexity of supply chains are the most relevant CSC challenges in the public sector. These findings would contribute to the design of effective initiatives and resource allocation decisions in advancing the circularity of supply chains in the public sector. Various policy insights are proposed, along with some future research agenda.

## 1. Introduction

The notion of circular economy (CE) is motivated by the need to transition to cleaner production in response to the climate crisis and other environmental concerns (e.g., eutrophication and loss of the natural habitat, among others), which are primarily driven by anthropogenic activities since the industrial revolution [32]. The CE principle subscribes to the following popular facets of sustainable production and consumption: reduce, reuse, and recycle [39]. However, it provides greater emphasis on circularity or the closing of the production loop [33, 65]. Unlike the conventional linear practice where wastes are produced and conveniently discarded at the end of the product life cycle, the circularity concept promotes the adoption of strategies to bring those wastes back to the upstream production processes for use as inputs [21].

The CE principle aims to redesign the linear chain of production processes into a circular one, extending the life cycle of products.

Consequently, it minimizes waste production and the continual use of resources [23]. Several works have made empirical assessments on the impact of adopting the CE principle (e.g., [16,63]). A comprehensive review of empirical works on CE implementation was recently reported by Bjørnset et al. [10]. Their work elucidates that CE implementation improves the environmental performance of enterprises and regions, although some implementation drawbacks need to be addressed, especially in the economic and social dimensions. The promising effects of the CE principle have motivated domain scholars to explore its application at the scale of supply chains, which gave rise to the concept of the circular supply chain (CSC) [22]. The CSC concept aims to organize consumers and producers in such a way that supports the notion of circularity. However, closing the production loop at the scale of supply chains is associated with additional challenges over existing ones [26].

Implementing CE strategies usually requires hefty investments, technological developments, and drastic changes in the management of

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man, material, machine, and the production environment [26]. At the scale of supply chains, the incorporation of this principle is further complicated. For instance, various studies (e.g., [12,15,35]) highlighted that one of the most prominent barriers to CSC implementation is the difficulty of organizing institutions to cooperate and commit to CE strategies. It is apparent that private institutions are primarily motivated by profit. The hefty costs of implementing CE strategies are among the factors that discourage enterprises from cooperating for fear of being uncompetitive in the market [14]. The cost of CE strategies usually arises from the required production retrofits to make wastes amenable for remanufacturing [54]. The CE principle just recently gained traction in the literature. Technologies required to implement CE strategies are mostly in development and have not yet come to age for industrial-scale applications [14].

The consequences of the insufficiency of existing CE technologies are apparent in the usually low quality of their resulting products [19]. The quality of products coming from recycled wastes affects the preference of consumers [17,71]. In fact, despite the quality being at par with conventional products, most consumers are found to have an inherent prejudice against products coming from recycled materials, which makes CE products difficult to sell at sufficiently profitable prices [40]. The availability of materials that are amenable to recycling is also one of the major challenges in CSC implementation [6,18,20,28,31,64]. Enterprises are often demotivated by the manifold processes involved in reverse logistics, which can require costly and special collection, handling, and storing practices, especially for hazardous, volatile, and perishable wastes [11,27,48,51].

While these CSC implementation barriers are apparent in supply chains in the private sector, the case of supply chains in the public sector offers some unique challenges. Unlike the private sector, public sector supply chains (PSSCs) are rarely concerned with profit since their primary objective is public welfare [2]. In this regard, the public sector may invest in technology development to implement CSC strategies as long as it maximizes public welfare. However, institutions in the public sector usually interpret the benefit of strategies to public welfare based on existing laws and regulations. Investments that depart from the priorities of the government, as indicated in policies, are usually deemed illegal [4]. This rigid bureaucratic structure of institutions in the public sector may hamper CSC implementation.

Although institutions in the public sector have unique characteristics, they are not fully differentiable from those in the private sector. For instance, the general producer-consumer structure in private sector supply chains is also present in PSSCs. Although, unlike the private sector, the utilization of retailing and warehousing services is not as pronounced [4]. Thus, these supply chain stages are seldom observed in PSSCs. Accounting practices in the public and private sectors are also generally the same, although the public sector is generally more transparent due to the nature of its financing activities [3]. Unlike enterprises in the private sector which obtain their finances either through partnerships (e.g., external investments), loans, or selling commercial products or services, institutions in the public sector obtain most of their finances from government revenues which can be generally defined as the function of the country's GDP and average tax rate [8]. Consequently, the financial capacity of the public sector is deemed more significant and stable than the private sector.

Strategies that may work for addressing CSC barriers in the private sector may not be generalizable to the public sector due to the latter's unique characteristics. Ambe [3] comprehensively identified these characteristics as departures of supply chains in the private sector. This makes the investigation of CSC barriers in the public sector particularly interesting. Despite the interesting aspects of PSSC, such a topic is not yet explored in the current literature. Most efforts to understand CSCs are performed in the sole context of private sectors or without appropriate differentiation of the public and the private sectors. Public sector supply chains are particularly interesting because of the volume of their consumption and waste generation. For instance, during the COVID-19

pandemic, most personal protective equipment acquired worldwide was purchased by institutions in the public sector [66]. Thus, the increased generation of COVID-19 medical wastes may be attributable to the prevailing linear strategy employed in most PSSCs. Thus, understanding PSSCs is essential to advancing the circularity agenda, which has become increasingly important due to the spike in the volume of waste generated during the COVID-19 pandemic.

The environmental crises consequent to human activities that the COVID-19 pandemic has worsened have warranted, more than ever, the need to implement the CE principle to transition into cleaner production and consumption. The large and complex scale of supply chains has made this implementation challenging, requiring directed efforts to address them. Barriers (i.e., hereinafter referred to as "challenges") to CSC implementation have been studied in the literature, but in the absence of the needed characterization of PSSCs. Focusing on the analysis of CSC challenges to PSSCs is essential to advancing the CE agenda. However, minimal attention is provided to understanding these challenges in the public sector, which remains a significant knowledge gap in the domain literature. Thus, this study intends to address this gap analytically. Here, comprehensive identification of CSC challenges is performed through a systematic literature review (i.e., the PRISMA statement). Given the characteristics of PSSCs [3], the identified CSC challenges are analytically mapped to these characteristics and processed using an integrated method for obtaining the most relevant challenges. Such a mapping generates a multi-attribute decision-making (MADM) problem, where the CSC challenges must be evaluated under multiple PSSC characteristics. The decision problem then identifies those challenges highly associated with the characteristics of PSSCs.

In this paper, the proposed method involves the integrated application of the CRITERIA Importance Through Intercriteria Correlation (CRITIC) and multiple criteria sorting (MCS) method based on the Combinative Distance-based Assessment (CODAS) approach (i.e., CODAS-SORT) under Fermatean fuzzy set (FFS) environment to account for epistemic uncertainties in expert decision-making. The Fermatean fuzzy (FF) CRITIC assigns priority weights of the characteristics, while the FF CODAS-SORT sorts the CSC challenges by identifying those highly relevant challenges to PSSCs. Although the FF CRITIC has been recently offered in the literature [25,38,55], the integration of FFS within CODAS-SORT is not yet explored, despite recent works offering some formulation on integrating FFS within the CODAS (e.g., [7,9,56,61]). Thus, collectively, the application of an integrated FF CRITIC-CODAS-SORT in a MADM problem is not yet demonstrated in the domain literature. This forms the novel methodological contribution of this paper. In summary, the following research questions (RQs) are addressed in this study:

- (RQ1) How can public sector CSC challenges be obtained from those reported in the literature?,
- (RQ2) What are the most important CSC challenges in the public sector?, and
- (RQ3) Based on the characteristics of the public sector, what measures can be employed to address these CSC challenges?

The PRISMA statement addresses RQ1 and obtains the list of CSC challenges from the domain literature. On the other hand, RQ2 is resolved following a two-stage approach. In the first stage, the FF CRITIC assigns the priority weights of the characteristics of PSSCs. In the second stage, the FF CODAS-SORT identifies the high relevant CSC challenges for PSSCs. The insights gained from the integrated analytic process that resolves the RQ2 provide directions in elucidating the measures in RQ3. Overall, the proposed framework for answering these RQs provides a systematic and analytic approach to advancing the circularity of PSSCs.

The remainder of this paper is arranged as follows. Section 2 presents some background of FFS, the CRITIC, and CODAS methods. Section 3 details the systematic literature review that generates the list of CSC challenges and demonstrates the application of the proposed FF CRITIC-

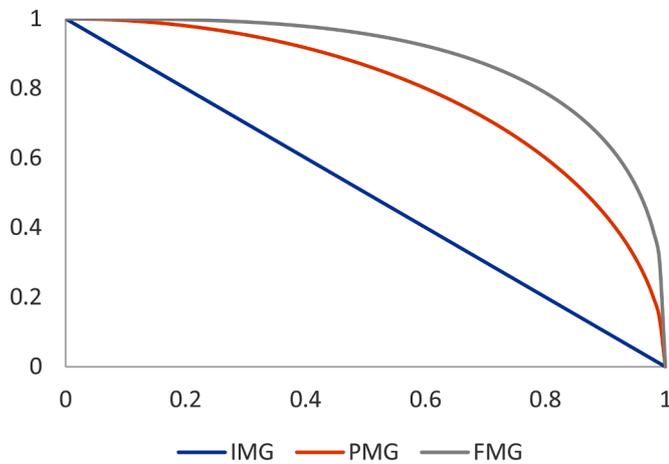


Fig. 1. Comparison of space of FMGs, PMGs, and IMGs.

CODAS-SORT in identifying the most relevant challenges. The findings are discussed in Section 4, along with some key managerial insights. It ends with concluding remarks and a discussion of limitations and future works in Section 5.

## 2. Preliminaries

### 2.1. Fermatean fuzzy set

The fuzzy set theory has been well-regarded for dealing with imprecise information and uncertainties. It was developed primarily by Zadeh [70] as an application for the numerous valued logics to illustrate the behavior of complex electrical systems. An extension of the fuzzy set theory was introduced by Atanassov [5], which is the intuitionistic fuzzy set (IFS). It is characterized by a membership function, a non-membership function, and a hesitancy degree that expresses support, opposition, and neutrality in eliciting information [5], respectively, extending the concept of membership functions of Zadeh’s fuzzy set theory. It is defined as follows:

**Definition 1.** [5]. Let  $\Delta$  be a non-empty universe of discourse. The IFS  $F$  has the general form

$$F = \{(x, \mu_F(x), \nu_F(x)) : x \in \Delta\} \tag{1}$$

where  $\mu_F(x) : \Delta \rightarrow [0, 1]$  and  $\nu_F(x) : \Delta \rightarrow [0, 1]$  such that  $0 \leq \mu_F(x) + \nu_F(x) \leq 1$  for all  $x \in \Delta$ . Furthermore,  $\mu_F(x)$  and  $\nu_F(x)$  refer to the degree of membership and degree of non-membership of the element  $x \in \Delta$  in the set  $F$ , respectively.

However, in practical application, it is possible that decision-makers may elicit their judgment fulfilling a set condition either to an assisting or opposing degree greater than 1. Thus, [68] introduced the notion of Pythagorean fuzzy sets (PFS) to address this possible condition, whose illustration is given as follows:

**Definition 2.** [68]. Let  $\Delta$  be a non-empty universe of discourse. The PFS  $\mathcal{P}$  can be presented as

$$\mathcal{P} = \{(x, \mu_{\mathcal{P}}(x), \nu_{\mathcal{P}}(x)) : x \in \Delta\} \tag{2}$$

where  $\mu_{\mathcal{P}}(x) : \Delta \rightarrow [0, 1]$  and  $\nu_{\mathcal{P}}(x) : \Delta \rightarrow [0, 1]$  such that  $0 \leq (\mu_{\mathcal{P}}(x))^2 + (\nu_{\mathcal{P}}(x))^2 \leq 1$  for all  $x \in \Delta$ . Furthermore,  $\mu_{\mathcal{P}}$  and  $\nu_{\mathcal{P}}(x)$  refer to the degree of membership and degree of non-membership of the element  $x \in \Delta$  in the set  $\mathcal{P}$ , respectively. For any  $\mathcal{P}$  and  $x \in \Delta$ , the degree of indeterminacy,  $\pi_{\mathcal{P}}(x)$  can be calculated by

$$\pi_{\mathcal{P}}(x) = \sqrt{1 - (\mu_{\mathcal{P}}(x))^2 - (\nu_{\mathcal{P}}(x))^2} \tag{3}$$

However, the PFS could not handle certain conditions. For instance,  $\mu_{\mathcal{P}} = 0.9$  and  $\nu_{\mathcal{P}} = 0.6$  suggests that  $0.9^2 + 0.6^2 \leq 1$ . Thus, Senapati and Yager [59] proposed the notion of the FFS to provide a tool for handling uncertain information more easily and is more flexible in capturing uncertain information than IFS and PFS. The features and operators of FFS are defined as follows:

**Definition 3.** [59]. Let  $\Delta$  be a non-empty universe of discourse. The Fermatean fuzzy set  $T$  in  $\Delta$  can be presented as

$$T = \{(x, \mu_T(x), \nu_T(x)) : x \in \Delta\} \tag{4}$$

where  $\mu_T(x) : \Delta \rightarrow [0, 1]$  and  $\nu_T(x) : \Delta \rightarrow [0, 1]$  such that  $0 \leq (\mu_T(x))^3 + (\nu_T(x))^3 \leq 1$  for all  $x \in \Delta$ . Furthermore,  $\mu_T(x)$  and  $\nu_T(x)$  refer to the degree of membership and degree of non-membership of the element  $x$  in the set  $T$ , respectively. Meanwhile, the degree of indeterminacy,  $\pi_T(x)$  is identified through

$$\pi_T(x) = \sqrt[3]{1 - (\mu_T(x))^3 - (\nu_T(x))^3} \tag{5}$$

Fig. 1 shows the difference among the spaces related to intuitionistic membership grades (IMG), Pythagorean membership grades (PMG), and Fermatean membership grades (FMG). In general, these fuzzy sets are part of a class of  $q$ -rung orthopair fuzzy sets in which the sum of the  $q^{\text{th}}$  power of the membership function and the  $q^{\text{th}}$  power of the non-membership function is bounded by one [69]. For instance,  $q = 1$  implies IFS,  $q = 2$  implies PFS.

**Definition 4.** [59]. Suppose that  $T = (\mu_T, \nu_T)$ ,  $T_1 = (\mu_{T_1}, \nu_{T_1})$ , and  $T_2 = (\mu_{T_2}, \nu_{T_2})$  are three distinct FFS and  $\alpha > 0$ , then the following are the operators for the FFS:

$$T_1 \cap T_2 = (\min\{\mu_{T_1}, \mu_{T_2}\}, \max\{\nu_{T_1}, \nu_{T_2}\}) \tag{6}$$

$$T_1 \cup T_2 = (\max\{\mu_{T_1}, \mu_{T_2}\}, \min\{\nu_{T_1}, \nu_{T_2}\}) \tag{7}$$

$$T^c = (\nu_T, \mu_T) \tag{8}$$

$$T_1 \oplus T_2 = \left( \sqrt[3]{(\mu_{T_1})^3 + (\mu_{T_2})^3 - (\mu_{T_1})^3 (\mu_{T_2})^3}, \nu_{T_1} \nu_{T_2} \right) \tag{9}$$

$$T_1 \otimes T_2 = \left( \mu_{T_1} \mu_{T_2}, \sqrt[3]{(\nu_{T_1})^3 + (\nu_{T_2})^3 - (\nu_{T_1})^3 (\nu_{T_2})^3} \right) \tag{10}$$

$$\alpha T = \left( \sqrt[3]{1 - (1 - (\mu_T)^3)^\alpha}, (\nu_T)^\alpha \right) \tag{11}$$

$$T^\alpha = \left( (\mu_T)^\alpha, \sqrt[3]{1 - (1 - (\nu_T)^3)^\alpha} \right) \tag{12}$$

Additional operations on subtraction and division of FFS were introduced by Senapati and Yager [58].

**Definition 5.** [58]. Assume  $T_1 = (\mu_{T_1}, \nu_{T_1})$ , and  $T_2 = (\mu_{T_2}, \nu_{T_2})$  are two distinct FFS, then

$$T_1 \boxminus T_2 = \left( \sqrt[3]{\frac{(\mu_{T_1})^3 - (\mu_{T_2})^3}{1 - (\mu_{T_2})^3}}, \frac{\nu_{T_1}^3}{\nu_{T_2}^3} \right) \text{ if } \mu_{T_1} \geq \mu_{T_2}, \nu_{T_1} \leq \min\left\{ \nu_{T_2}, \frac{\nu_{T_2} \pi_1}{\pi_2} \right\} \tag{13}$$

$$T_1 \boxdiv T_2 = \left( \frac{\mu_{T_1}}{\mu_{T_2}}, \sqrt[3]{\frac{(\nu_{T_1})^3 - (\nu_{T_2})^3}{1 - (\nu_{T_2})^3}} \right) \text{ if } \mu_{T_1} \leq \min\left\{ \mu_{T_2}, \frac{\mu_{T_2} \pi_1}{\pi_2} \right\}, \nu_{T_1} \geq \nu_{T_2} \tag{14}$$

**Definition 6.** [59]. Assume  $T_i = (\mu_{T_i}, \nu_{T_i})$  ( $i = 1, 2, \dots, n$ ) be a set of FFS, and  $w = (w_1, w_2, \dots, w_n)^K$  be the corresponding weight vector such

that  $\sum_i w_i = 1$ . Then, the FF weighted average FFWA aggregation operator is defined by:

$$FFWA(T_1, T_2, \dots, T_n) = \left( \sum_{i=1}^n w_i \mu_{T_i}, \sum_{i=1}^n w_i \nu_{T_i} \right). \tag{15}$$

Senapati and Yager [59] provided the concept of a score function  $score : T \rightarrow \mathbb{R}$ ,  $T$  is an FFS and is the basis for ranking FFS alongside the accuracy function. However, the score function cannot rank the FFS in some special cases precisely. Thus, Mishra and Rani [37] proposed a novel FF score function to overcome the shortcomings of the existing score function. The features of this score function are defined as follows:

**Definition 7.** [37]. Suppose that  $T = (\mu_T, \nu_T)$  is an FFS, the score function for  $T$  is defined as:

$$S(T) = \frac{1}{2} [((\mu_T)^3 - (\nu_T)^3 - \ln(1 + (\pi_T)^3)) + 1] \tag{16}$$

where  $\pi_T$  is the corresponding indeterminacy degree. For all  $\mu_T$  and  $\nu_T$ , provided that  $(\mu_T)^3 + (\nu_T)^3 \leq 1$ ,  $S(T) \in [0, 1]$ .

Mishra and Rani [37] show that  $S$  is increasing monotonically with respect to  $\mu_T$  and decreasing monotonically with respect to  $\nu_T$ . The following provides the basis for ranking FFS according to  $S$ .

**Theorem 1.** [37]. For any two FFS  $T_1 = (\mu_{T_1}, \nu_{T_1})$  and  $T_2 = (\mu_{T_2}, \nu_{T_2})$ , if  $\mu_{T_1} > \mu_{T_2}$  and  $\nu_{T_1} < \nu_{T_2}$ , then  $S(T_1) > S(T_2)$ .

The Euclidean distance is also defined in FFS.

**Definition 8.** [59]. Let  $T_1 = (\mu_{T_1}, \nu_{T_1})$  and  $T_2 = (\mu_{T_2}, \nu_{T_2})$  be two distinct FFS. Then, the Euclidean distance between  $T_1$  and  $T_2$  is

$$d(T_1, T_2) = \sqrt{\frac{1}{2} [((\mu_{T_1})^3 - (\mu_{T_2})^3)^2 + ((\nu_{T_1})^3 - (\nu_{T_2})^3)^2 + ((\pi_{T_1})^3 - (\pi_{T_2})^3)^2]} \tag{17}$$

2.2. The CRITIC method

The CRITIC method was developed by Diakoulaki et al. [13], where the priority weights of the criteria in an MADM problem are obtained from a decision matrix. Then, the priority weights are drawn from the contrast intensity of the criteria and conflict concentration of the decision criteria in a given set [13,49,60]. Among other means (e.g., entropy or variance), the contrast intensity and degree of variability among evaluation scores of the elements within a criterion are represented by a standard deviation. Nevertheless, Diakoulaki et al. [13] allow the entropy or variance scores to substitute for standard deviations. Additionally, the conflicting relationships among criteria to the decision problem are described by pairwise linear correlation coefficients. Thus, in the CRITIC method, the amount of information emanated from a given criterion is measured by considering these two sources of information: contrast intensity and conflict of the decision criteria. Unlike other priority weight allocation methods (e.g., analytic hierarchy process, best-worst method, full consistency method), the CRITIC provides an efficient technique for generating priority weights of criteria (or attributes) from a decision matrix. The cognitive workload required from decision-makers in eliciting judgments is significantly minimized, particularly in the presence of a vast number of attributes (e.g., 50 attributes). Recent applications of the CRITIC method were reported in the MADM literature (e.g., [41,47,67]). Recent comparative analyses suggest that CRITIC provides relatively consistent results with other comparable objective-weighting methods such as the M<sup>E</sup>thod based on the Removal Effects of Criteria (M<sup>E</sup>REC) [29] and Stepwise Weight Assessment Ratio Analysis II (SWARA II) [29]. M<sup>E</sup>REC is shown to be

consistent with CRITIC [29], while SWARA II adds another layer of evaluation among criteria or attributes, which may increase the cognitive workload of decision-makers, especially in large-scale MADM problems. This issue of cognitive workload is further amplified with the use of other methods based on pairwise comparisons among elements of the set of attributes, such as the analytic hierarchy process [52], analytic network process [53], best-worst method [50], and full consistency method [46].

**Definition 9.** [13]. Let  $A$  be a finite set of  $m$  alternatives. Then, given a system of  $n$  evaluation criteria  $c_j$  ( $j = 1, \dots, n$ ), the MADM problem in its general form is presented as follows:

$$\max \{c_1(a), c_2(a), \dots, c_n(a) | a \in A\} \tag{18}$$

In this case, for every criterion  $c_j$ , a membership function  $x_j$  is defined, mapping the values of  $c_j$  to the interval  $[0, 1]$ . This transformation is based on the concept of the ideal point. Thus, a value close to the ideal  $c_j^*$  is the best performance in criterion  $j$  and close to the anti-ideal value  $c_j^-$  is the worst performance in criterion  $j$ . The following outlines the steps of determining the priority weights of the criteria using the CRITIC method. Note that, generally, the criteria set can be a set of any homogeneous decision elements.

**Step 1:** Determine the set of  $n$  criteria and  $m$  alternatives constructed as a hierarchical MADM problem.

**Step 2:** Evaluate the performance score  $a_{ij}$  of the  $i$ th ( $i = 1, \dots, m$ ) alternative with respect to the  $j$ th ( $j = 1, \dots, n$ ) criterion. This process forms the decision matrix.

**Step 3:** Compute the normalized matrix  $X = (x_{ij})_{m \times n}$ , where the normalized score  $x_{ij}$  describes a linear normalization of  $a_{ij}$  scores and represents:

$$x_{ij} = \frac{a_{ij} - a_j^-}{a_j^+ - a_j^-} \tag{19}$$

where  $a_j^+ = \max_i a_{ij}$  and  $a_j^- = \min_i a_{ij}$  for  $j = 1, \dots, n$ .

**Step 4:** Generate a vector  $x_j$  denoting the normalized scores of all  $m$  alternatives. Vector  $x_j$  is calculated using Eq. (20).

$$x_j = (x_{1j}, x_{2j}, \dots, x_{mj}) \tag{20}$$

**Step 5:** Obtain the standard deviation of  $x_j$  using the following:

$$\sigma_j = \sqrt{\frac{\sum_{i=1}^m (x_{ij} - \bar{x}_j)^2}{m}}, \text{ where } \bar{x}_j = \frac{\sum_{i=1}^m x_{ij}}{m}. \tag{21}$$

**Step 6:** Create a symmetric matrix  $R = (r_{jk})_{n \times n}$  where  $r_{jk}$  denotes the linear correlation coefficient of two vectors  $x_j$  and  $x_k$ ,  $j, k \in \{1, \dots, n\}$ , using the formula:

$$r_{jk} = \frac{\sum_{i=1}^m (x_{ij} - \bar{x}_j)(x_{ik} - \bar{x}_k)}{\sqrt{\sum_{i=1}^m (x_{ij} - \bar{x}_j)^2 \sum_{i=1}^m (x_{ik} - \bar{x}_k)^2}} \tag{22}$$

where  $r_{jk} \in [-1, 1]$ . Obviously,  $r_{jk} = 1$  whenever  $j = k$ .

**Step 7:** Compute the amount of information  $z_j$  as follows

$$z_j = \sigma_j \sum_{k=1}^n (1 - r_{jk}) \tag{23}$$

where the higher value of  $z_j$  indicates that the criterion  $j$  contains more information.

**Step 8:** Determine the criteria weights according to the following formula

$$w_j = \frac{z_j}{\sum_{k=1}^n z_k} \tag{24}$$

### 2.3. The CODAS method

Initially proposed by Ghorabae et al. [24], the CODAS method follows that the desirability of the alternatives is drawn from  $l^1$ - norm and  $l^2$ -norm indifference spaces for criteria. It offers an efficient and powerful MADM platform based on the notion of “distance”, similarly conceptualized with the more popular Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). In this method, the assessment score of alternatives is based on a combinative form of the Euclidean distance and the secondary measure, Taxicab distance. The alternative having a greater distance from the negative-ideal solution is considered more desirable. Such applications of the CODAS and its extensions have been increasing in the literature (e.g., [34,46,62]). The following outlines the steps of the CODAS method used to solve MADM problems:

**Step 1.** Construct the decision matrix  $A$ ,

$$A = (a_{ij})_{m \times n} = \begin{pmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ a_{m1} & a_{m2} & \dots & a_{mn} \end{pmatrix}, \tag{25}$$

where  $a_{ij} \geq 0$  denotes the performance value of the  $i$ th ( $i = 1, \dots, m$ ) alternative with respect to the  $j$ th ( $j = 1, \dots, n$ ) criterion (or attribute).

**Step 2.** Establish the normalized decision matrix  $N = (n_{ij})_{m \times n}$  with values depending on the type of each criterion following a linear normalization process, such that

$$n_{ij} = \begin{cases} \frac{a_{ij}}{\max_i a_{ij}} & \text{if } j \in P \\ \frac{\min_i a_{ij}}{a_{ij}} & \text{if } j \in C \end{cases} \tag{26}$$

where  $P$  and  $C$  represent the sets of benefit and cost criteria (or attributes), respectively.

**Step 3.** Calculate the weighted normalized decision matrix  $B = (b_{ij})_{m \times n}$  using the following:

$$b_{ij} = w_j n_{ij} \tag{27}$$

wherein  $\sum_{j=1}^n w_j = 1$ ,  $w_j$  denotes the priority weight of the  $j$ th criterion, and  $0 < w_j < 1$ . Any priority weight generation method (e.g., CRITIC) can be used to determine  $w_j$ .

**Step 4.** Obtain the negative ideal solution as follows:

$$b^* = (b_{j^*})_{1 \times n} \tag{28}$$

$$b_{j^*} = \min_i b_{ij} \tag{29}$$

**Step 5.** Determine the Euclidean  $d_i$  and Taxicab  $t_i$  distances of each alternative  $i$  from the negative ideal solution using the following:

$$d_i = \sqrt{\sum_{j=1}^n (b_{ij} - b_{j^*})^2}, \forall i = 1, \dots, m \tag{30}$$

$$t_i = \sum_{j=1}^n |b_{ij} - b_{j^*}|, \forall i = 1, \dots, m \tag{31}$$

**Step 6.** Construct the relative assessment matrix  $H = (h_{ik})_{m \times m}$  defined as follows:

$$h_{ik} = (d_i - d_k) + (\beta(d_i - d_k) \times (t_i - t_k)) \tag{32}$$

where  $k \in \{1, 2, \dots, m\}$  and  $\beta$  is a threshold function defined by the following:

$$\beta = \begin{cases} 1 & \text{if } d_i - d_k \geq \rho \\ 0 & \text{if } d_i - d_k < \rho \end{cases} \tag{33}$$

Whenever  $d_i - d_k$  is less than  $\rho$ , then the two alternatives  $i$  and  $k$  are also compared by the Taxicab distance.

**Step 7.** Compute the assessment score ( $S_i$ ) of each alternative shown as follows:

$$S_i = \sum_{k=1}^m h_{ik} \tag{34}$$

The alternative having the largest  $S_i$  value is considered the most desirable.

As in most MADM methods (e.g., analytic hierarchy process, TOPSIS), a natural extension is to develop a computational formulation for solving multiple criteria sorting (MCS) problems, with the MADM method as its basis (e.g., AHPsort, TOPSIS-Sort). The CODAS-SORT is part of the family of MCS methods that assigns a set of elements (e.g., alternatives) to predefined classes under an evaluation based on multiple criteria. Ocampo et al. [43] and Ocampo and Yamagishi [42] presented a brief discussion of the background of MCS and some popular methods. An exhaustive review of MCS methods can be found in Alvarez et al. [1]. Some evidence points out that the performance of the CODAS-SORT is found to be comparable with TOPSIS-Sort and VIKORSORT [42,43]. However, the CODAS-SORT has a more efficient computational framework than the two MCS methods. For brevity, the computational procedure of the CODAS-SORT is not repeated here. Despite its computational efficiency, some technical issues arise with the sorting framework proposed by Ouhibi and Frikha [44], which prompted a formulation of a modified CODAS-SORT variant, along with the integration of FFS as shown in Gonzales et al. [25].

Due to the presence of vagueness and uncertainty inherent in both CRITIC and CODAS-SORT, the use of the FFS addresses these conditions by overcoming the limitations of the classical fuzzy set [70], and the IFS [5] or the PFS [68]. The FFS is deemed more capable of handling higher levels of uncertainties than the previously developed fuzzy environments.

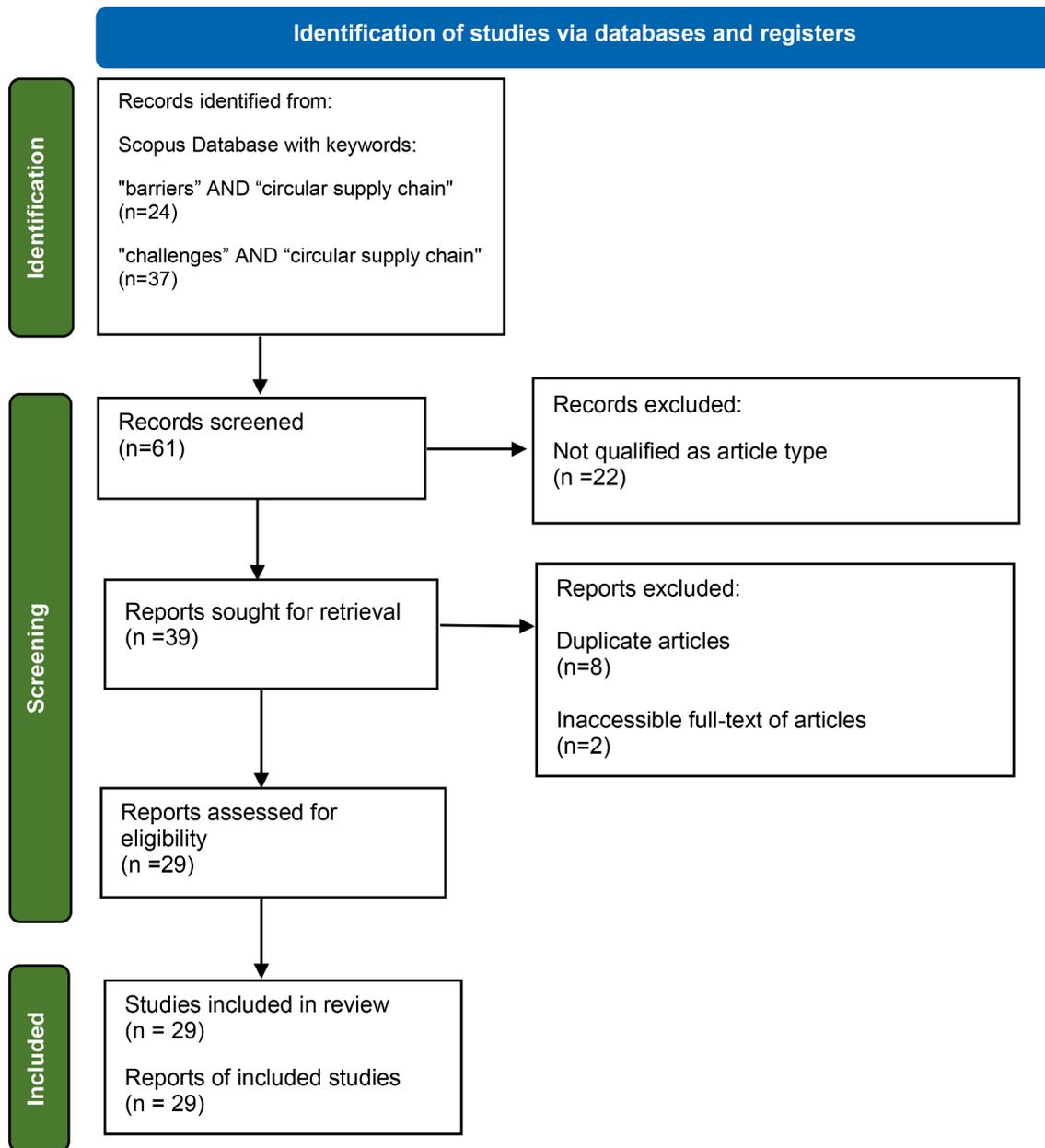


Fig. 2. Reporting items for the systematic review (adapted from the PRISMA statement).

### 3. Methodology

#### 3.1. Systematic literature review of the challenges of circular supply chains

The final list of challenges relevant to CSC is obtained by applying the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement [45], which is a standard approach for performing systematic literature reviews. Following an established process, PRISMA requires selecting a search database, conducting a keyword search, gathering reference articles, performing content analysis by identifying the challenges within the reference articles, and evaluating the relevance and redundancy of the initial list of challenges.

##### 3.1.1. Selection of database

To generate a wide range of peer-reviewed publications from reputable sources, the Scopus database was used. Scopus is the world's largest abstract and citation database of scientific literature [57]. With a

rigorous vetting process for the inclusion of sources in the database, the articles covered by Scopus offer dependable information on the state-of-the-art knowledge in almost all areas of study.

##### 3.1.2. Collection of articles

The CSC is a relatively new topic in the domain field and has not been comprehensively explored in the literature. Fig. 2 describes the process of obtaining the final list of challenges through the PRISMA statement. The search query conducted in the Scopus database using the keywords "barriers AND circular supply chain" yielded 24 document results. Then, a filter applied to this query was based on the document type (i.e., article), which yielded 17 documents. Due to the possible gaps in the semantics of our search keywords, we further conducted another search query using the keywords "challenges AND circular supply chain". It generated 37 documents, and a filter was applied based on the document type (i.e., article) to produce 22 documents. The search queries then generated a total of 39 journal articles. These were evaluated based on the relevance of the challenges of CSC. The evaluation found eight

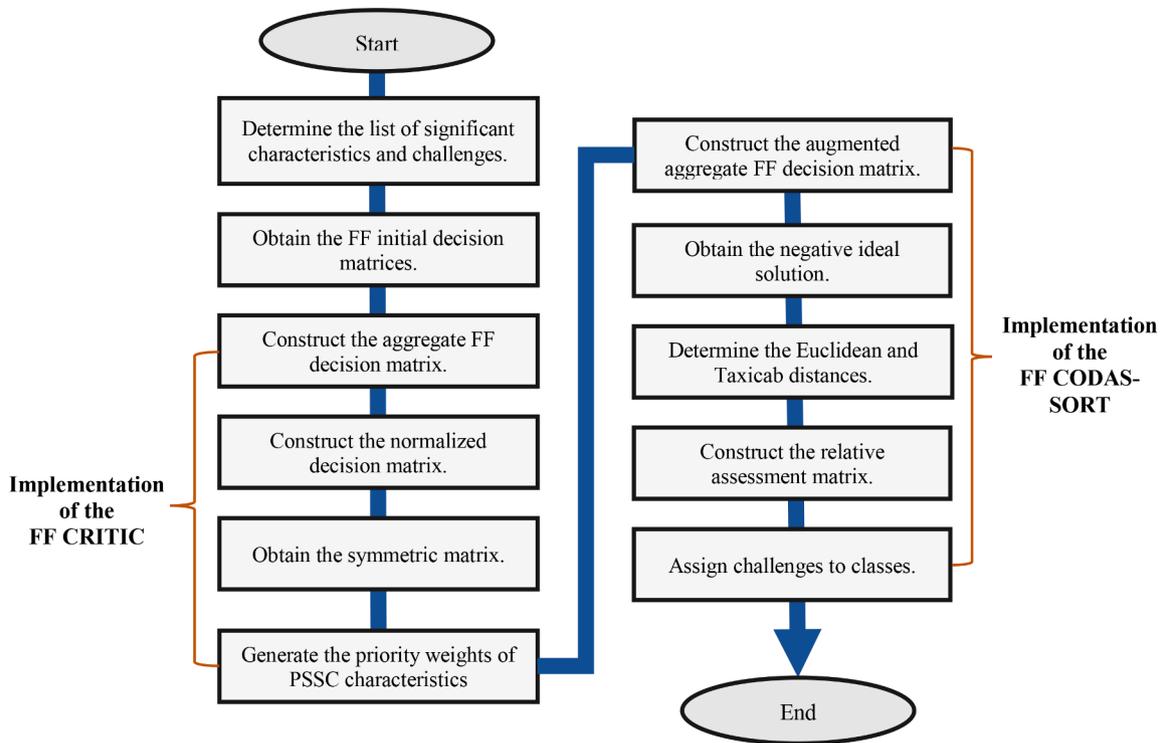


Fig. 3. The proposed methodological framework.

Table 1

[31]. List of characteristics of public sector supply chains.

Code	Characteristics	Brief description
C1	Goal	The quality of service is the delivery to citizens for public welfare.
C2	View of supply chain management	Supply Chain Management (SCM) is viewed as a procurement tool in contrast to viewing procurement as an element of SCM.
C3	Sources of revenue	Revenue is sourced from taxes and fees instead of sales of goods and services.
C4	Governance	It is governed by legislative bodies, laws, and regulations instead of the board of directors and business plans.
C5	Skills	Have less skilled actors.
C6	Receptiveness	The emphasis is on accountability and transparency.
C7	Organizational Structures	Highly complex system of organizations with various tasks.
C8	Low competency	There is low competency present in the SCM of public sectors.
C9	Low confidentiality	Confidentiality in the system is low.
C10	Low degree of collaboration	Collaboration among the multiple actors of SCM is low.
C11	Low degree of integration	There is a lack of integration in the complex system of public SCM in the optimization of logistics support and secondary inventory management.
C12	Low strategic partnership	Strategic partnership among the multiple actors of public SCM is low.
C13	Low degree of implementation	There is a low implementation of SCM practices.
C14	Low application of technological infrastructure	There is insufficient application of available technological infrastructure for SCM.

duplicate journal articles and two inaccessible journal articles (i.e., abstract only). With these, 29 journal articles were finally identified for systematic review. The articles were then accessed to extract the relevant challenges. The list of 29 journal articles with their corresponding year of publication, author(s), and title of the journal article is shown in the Supplementary Material. A list of 50 challenges of CSC, along with

Table 2

Linguistic evaluation scale.

Linguistic term	Non-FFS scores	FFS
Extremely Low	1	(0.1, 0.9)
Low	2	(0.25, 0.6)
Moderately Low	3	(0.4, 0.5)
Medium	4	(0.5, 0.4)
Moderately High	5	(0.6, 0.3)
High	6	(0.7, 0.2)
Extremely High	7	(0.9, 0.1)

their corresponding codes for easy retrieval, was obtained from the conducted literature review and is also presented in the Supplementary Material.

### 3.2. The proposed procedure for the integrated Fermatean fuzzy CRITIC-CODAS-SORT approach

Fig. 3 shows the proposed procedure of the FF CRITIC-CODAS-SORT approach in establishing the significant association of the challenges of CSC to the characteristics of the PSSC. The proposed methodological framework consists of two main procedures: (1) obtaining the priority weights of the characteristics through FF CRITIC and (2) sorting these challenges via FF CODAS-SORT. In this framework, the weights generated from step (1) are integrated into step (2). The application of the proposed approach is discussed as follows:

**Step 1.** Determine the list of significant characteristics of PSSC and challenges of CSC. Ambe [31] offered a comprehensive list of 14 PSSC characteristics (see Table 1). In addition, Section 3.1. identifies 50 challenges through the PRISMA framework (see Supplementary Material). Using these lists, a questionnaire (see Supplementary Material) was constructed wherein initial evaluations were obtained. In this paper, seven decision-makers were asked to elicit judgments on the relevant association of each challenge to the characteristics using a predefined scale as the association scores. The expert

**Table 3**  
The symmetric matrix.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14
C1	1.0000	0.4103	-0.0556	0.5562	0.0171	0.2190	0.3243	0.0717	0.1150	0.1781	0.2236	0.1889	0.1969	-0.0314
C2	0.4103	1.0000	0.0529	0.4680	-0.1854	0.2135	0.4408	-0.0008	0.1381	0.3542	0.4994	0.1035	0.2417	-0.0346
C3	-0.0556	0.0529	1.0000	0.0452	-0.1180	0.1120	-0.0756	0.0724	-0.0515	-0.1349	-0.0856	0.0038	-0.0158	0.1775
C4	0.5562	0.4680	0.0452	1.0000	0.0879	0.2518	0.3005	0.1059	0.1626	0.2849	0.4130	0.4441	0.3771	0.0736
C5	0.0171	-0.1854	-0.1180	0.0879	1.0000	-0.0406	-0.0263	0.6259	0.1745	0.0590	0.0237	0.2040	0.0166	0.0578
C6	0.2190	0.2135	0.1120	0.2518	-0.0406	1.0000	0.4629	0.0235	0.1490	0.3036	0.4196	0.1606	0.1619	-0.0835
C7	0.3243	0.4408	-0.0756	0.3005	-0.0263	0.4629	1.0000	0.0063	0.1577	0.1929	0.3328	0.2381	0.5108	0.0688
C8	0.0717	-0.0008	0.0724	0.1059	0.6259	0.0235	0.0063	1.0000	0.2198	0.0132	0.1239	0.3093	0.1750	0.1917
C9	0.1150	0.1381	-0.0515	0.1626	0.1745	0.1490	0.1577	0.2198	1.0000	0.1113	0.2050	0.0613	0.2340	-0.0159
C10	0.1781	0.3542	-0.1349	0.2849	0.0590	0.3036	0.1929	0.0132	0.1113	1.0000	0.3678	0.2177	0.1587	-0.0678
C11	0.2236	0.4994	-0.0856	0.4130	0.0237	0.4196	0.3328	0.1239	0.2050	0.3678	1.0000	0.3045	0.2425	-0.0247
C12	0.1889	0.1035	0.0038	0.4441	0.2040	0.1606	0.2381	0.3093	0.0613	0.2177	0.3045	1.0000	0.5828	0.0961
C13	0.1969	0.2417	-0.0158	0.3771	0.0166	0.1619	0.5108	0.1750	0.2340	0.1587	0.2425	0.5828	1.0000	0.3145
C14	-0.0314	-0.0346	0.1775	0.0736	0.0578	-0.0835	0.0688	0.1917	-0.0159	-0.0678	-0.0247	0.0961	0.3145	1.0000

**Table 4**  
Priority weights of the public sector supply chain characteristics.

Characteristics	$\sigma_j$	$z_j$	$w_j$
C1	0.2068	2.1887	0.0723
C2	0.2211	2.2767	0.0752
C3	0.2575	3.3665	0.1111
C4	0.2384	2.2478	0.0742
C5	0.1914	2.3164	0.0765
C6	0.1826	1.9441	0.0642
C7	0.2093	2.1066	0.0695
C8	0.1954	2.1612	0.0713
C9	0.1653	1.8741	0.0619
C10	0.1712	1.877	0.062
C11	0.1828	1.82	0.0601
C12	0.2179	2.1975	0.0725
C13	0.1793	1.7579	0.058
C14	0.1756	2.1564	0.0712

**Table 5**  
The negative ideal solution.

Criteria	$b_j^r$
C1	(0.5000, 0.5000)
C2	(0.5000, 0.5000)
C3	(0.5000, 0.4714)
C4	(0.4714, 0.4929)
C5	(0.4929, 0.5000)
C6	(0.5000, 0.5000)
C7	(0.5000, 0.5000)
C8	(0.5000, 0.3286)
C9	(0.3286, 0.5000)
C10	(0.5000, 0.5000)
C11	(0.5000, 0.5000)
C12	(0.5000, 0.5000)
C13	(0.5000, 0.5000)
C14	(0.5000, 0.0000)

decision-makers were chosen in such a way that satisfies the following qualifications: (1) managerial or administrative experience in a public sector, (2) at least ten years of professional experience in a public organization, and (3) sufficient knowledge in the public supply chain.

**Step 2.** Obtain the FF initial decision matrices. Initial decision matrices  $\tilde{A}^k = (\tilde{a}_{ij}^k)_{m \times n}$ , for  $k = 1, \dots, K$ , where  $\tilde{a}_{ij}^k$  represents the degree of association of a CSC challenge  $i$  to a PSSC characteristic  $j$  elicited by the  $k$ th decision-maker in linguistic terms were constructed. These matrices were transformed into FF decision matrices using the linguistic scale shown in Table 2.

**Table 6**  
Euclidean  $d_i$  and Taxicab distances  $t_i$ .

Challenges	$d_i$	$t_i$	Challenges	$d_i$	$t_i$
B1	0.0595	0.1991	B27	0.0506	0.1729
B2	0.0654	0.2175	B28	0.0708	0.2330
B3	0.0585	0.1946	B29	0.0654	0.2100
B4	0.0754	0.2466	B30	0.0596	0.1890
B5	0.0661	0.2171	B31	0.0618	0.1961
B6	0.0540	0.1761	B32	0.0550	0.1852
B7	0.0648	0.2103	B33	0.0541	0.1712
B8	0.0592	0.2036	B34	0.0510	0.1719
B9	0.0555	0.1875	B35	0.0695	0.2235
B10	0.0306	0.0933	B36	0.0639	0.2039
B11	0.0438	0.1455	B37	0.0690	0.2253
B12	0.0418	0.1392	B38	0.0685	0.2265
B13	0.0474	0.1466	B39	0.0542	0.1892
B14	0.0580	0.1841	B40	0.0584	0.1951
B15	0.0726	0.2387	B41	0.0535	0.1938
B16	0.0820	0.2569	B42	0.0532	0.1754
B17	0.0715	0.2301	B43	0.0665	0.2211
B18	0.0690	0.2319	B44	0.0374	0.1198
B19	0.0768	0.2469	B45	0.0537	0.1833
B20	0.0620	0.2121	B46	0.0650	0.2223
B21	0.0670	0.2138	B47	0.0501	0.1762
B22	0.0705	0.2372	B48	0.0508	0.1770
B23	0.0654	0.2183	B49	0.0729	0.2307
B24	0.0795	0.2503	B50	0.0413	0.1376
B25	0.0598	0.2052	L2	0.0713	0.2459
B26	0.0552	0.1885	L1	0.0019	0.0003

3.2.1. Implementation of the FF CRITIC

Step 3 to Step 6 demonstrate the application of FF CRITIC in generating the priority weights of the PSSC characteristics.

**Step 3.** Construct the aggregate FF decision matrix. The aggregate FF decision matrix  $\tilde{A} = (\tilde{a}_{ij})_{m \times n}$  is constructed, where  $\tilde{a}_{ij}$  is obtained using Eq. (15) and  $w_i = \frac{1}{k}$ , i.e., decision-makers are considered to have a comparable level of knowledge and experience concerning the circularity of PSSC, and the resulting matrix is shown in Appendix 1.

**Step 4.** Construct the normalized decision matrix. The score function of  $\tilde{a}_{ij}$  ( $\forall i, j$ ) was obtained using Eq. (16). This process transforms the aggregate evaluation scores in FFS to their corresponding crisp (non-FFS) values. The resulting matrix was then used to construct the normalized decision matrix presented in Appendix 2. The standard deviation  $\sigma_j$  was computed using Eq. (21).

**Step 5.** Obtain the symmetric matrix  $R$ . The symmetric matrix  $R$  was constructed using Eq. (22) and is shown in Table 3.

**Step 6.** Generate the priority weights  $w_j, j = 1, \dots, n$ , of PSSC characteristics. The information value  $z_j$  is calculated using Eq. (23). The

**Table 7**  
The relative assessment matrix.

Challenges	$h_j(L2)$	$h_j(L1)$	Challenges	$h_j(L2)$	$h_j(L1)$
B1	-0.0118	0.0690	B26	-0.0161	0.0633
B2	-0.0059	0.0773	B27	-0.0207	0.0572
B3	-0.0128	0.0676	B28	-0.0005	0.0849
B4	0.0041	0.0916	B29	-0.0059	0.0768
B5	-0.0052	0.0781	B30	-0.0117	0.0686
B6	-0.0173	0.0613	B31	-0.0095	0.0716
B7	-0.0065	0.0761	B32	-0.0163	0.0630
B8	-0.0121	0.0690	B33	-0.0172	0.0611
B9	-0.0158	0.0636	B34	-0.0203	0.0576
B10	-0.0407	0.0313	B35	-0.0018	0.0827
B11	-0.0275	0.0481	B36	-0.0074	0.0746
B12	-0.0295	0.0455	B37	-0.0023	0.0822
B13	-0.0239	0.0522	B38	-0.0028	0.0816
B14	-0.0133	0.0665	B39	-0.0171	0.0622
B15	0.0013	0.0876	B40	-0.0129	0.0675
B16	0.0107	0.1007	B41	-0.0178	0.0616
B17	0.0002	0.0856	B42	-0.0181	0.0603
B18	-0.0023	0.0826	B43	-0.0048	0.0788
B19	0.0055	0.0934	B44	-0.0339	0.0398
B20	-0.0093	0.0729	B45	-0.0176	0.0613
B21	-0.0043	0.0791	B46	-0.0063	0.0772
B22	-0.0008	0.0849	B47	-0.0212	0.0567
B23	-0.0059	0.0774	B48	-0.0205	0.0576
B24	0.0082	0.0970	B49	0.0016	0.0874
B25	-0.0115	0.0697	B50	-0.0300	0.0448
B26	-0.0161	0.0633	B26	-0.0161	0.0633

two values,  $\sigma_j$  and  $z_j$ , are used to obtain the priority weights  $w_j$  using Eq. (24). The  $w_j$  values are presented in Table 4.

3.2.2. Implementation of the FF CODAS-SORT

Step 7 to Step 11 discuss the application of FF CODAS-SORT in sorting the CSC challenges.

**Step 7.** Construct the augmented matrix  $\bar{A}$ . From the aggregate FF decision matrix in Step 3, the limit profiles of classes are introduced. In general,  $L$  ( $e = 1, \dots, L$ ) classes can be predefined for the MCS process. These classes generate  $L - 1$  limit profiles. Each  $e$  class contains lower and upper boundaries, denoted by  $l_e^a$  and  $l_e^b$ , where  $l_e^b = l_{e+1}^a$ . The aggregate FF decision matrix with the  $L - 1$  limit profiles

is used to construct  $\bar{A} = (\bar{a}_{ij})_{m \times n}$  and is presented in Appendix 3. In this paper,  $L = 3$  classes (i.e., low relevance, moderate relevance, and high relevance) and two limit profiles are introduced.

**Step 8.** Obtain the negative ideal solution  $b^*$ .  $\bar{A}$  was used to obtain the negative ideal solution  $\tilde{b}^* = (\tilde{b}_{j^*})_{1 \times n}$  using Eq. (29). Since the elements in  $\bar{A}$  are FFS, then Theorem 1 discussed in Section 2.1. was used to obtain  $\tilde{b}^*$ . The resulting vector is illustrated in Table 5.

**Step 9.** Determine the Euclidean and Taxicab distances. The Euclidean distance  $D_i(\bar{a}_{ij}, \tilde{b}_{j^*})$  between each challenge  $i$  (including the limit profiles) and the ideal negative solution  $b_{j^*}^*$  obtained in the previous Step 8 (Section 3.2.) is calculated using Eq. (35).

$$D_i(\bar{a}_{ij}, \tilde{b}_{j^*}) = \sum_{j=1}^n w_j d(\bar{a}_{ij}, b_{j^*}^*) \tag{35}$$

where  $w_j$  represents the priority weights of PSSC characteristics obtained from FF CRITIC in Step 6 in Section 3.2. and  $d(\bar{a}_{ij}, b_{j^*}^*)$  is calculated using Eq. (17).

On the other hand, the Taxicab distance  $\tilde{t}_i(\bar{a}_{ij}, \tilde{b}_{j^*})$  between each challenge  $i$  (including the limit profiles) and the ideal negative solution  $b_{j^*}^*$  obtained in Step 8 in Section 3.2. is calculated analogously using Eq. (31). Considering that both elements are FFS, Eq. (13) was used to obtain their difference. Then, Eq. (16) was used to transform the obtained taxicab distance  $\tilde{t}_i(\bar{a}_{ij}, \tilde{b}_{j^*})$  to their corresponding crisp value  $t_i(\bar{a}_{ij}, \tilde{b}_{j^*})$ . Both the Euclidean and Taxicab distances are shown in Table 6.

**Step 10.** Construct the relative assessment matrix. Following Step 6 in Section 2.2., the relative assessment matrix  $H = (h_{ik})_{m \times m}$  is calculated, where  $h_{ik}$  is shown in Eq. (36), and the resulting matrix is featured in Table 7. The threshold parameter was set to be  $\rho = 0.02$ .

$$h_{ik} = (D_i(\bar{a}_{ij}, \tilde{b}_{j^*}) - D_k(\bar{a}_{kj}, \tilde{b}_{j^*})) + (\beta(D_i(\bar{a}_{ij}, \tilde{b}_{j^*}) - D_k(\bar{a}_{kj}, \tilde{b}_{j^*})) \times (t_i(\bar{a}_{ij}, \tilde{b}_{j^*}) - t_k(\bar{a}_{kj}, \tilde{b}_{j^*}))) \tag{36}$$

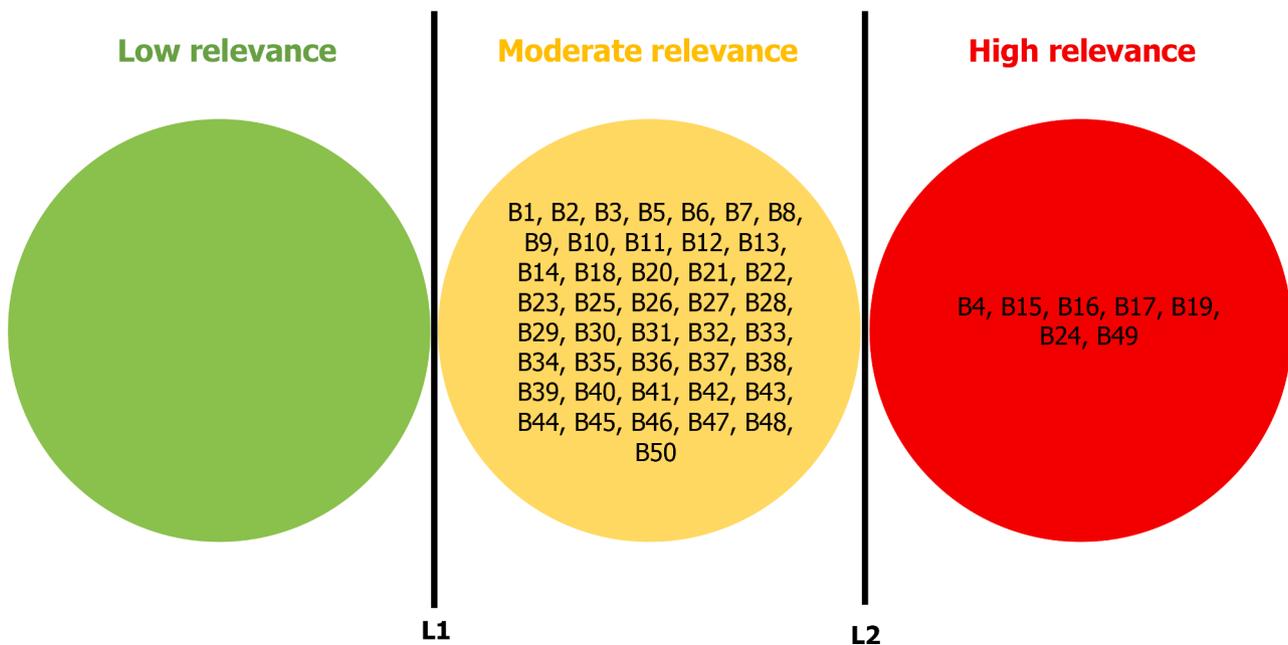


Fig. 4. Sorting of CSC challenges to different classes.

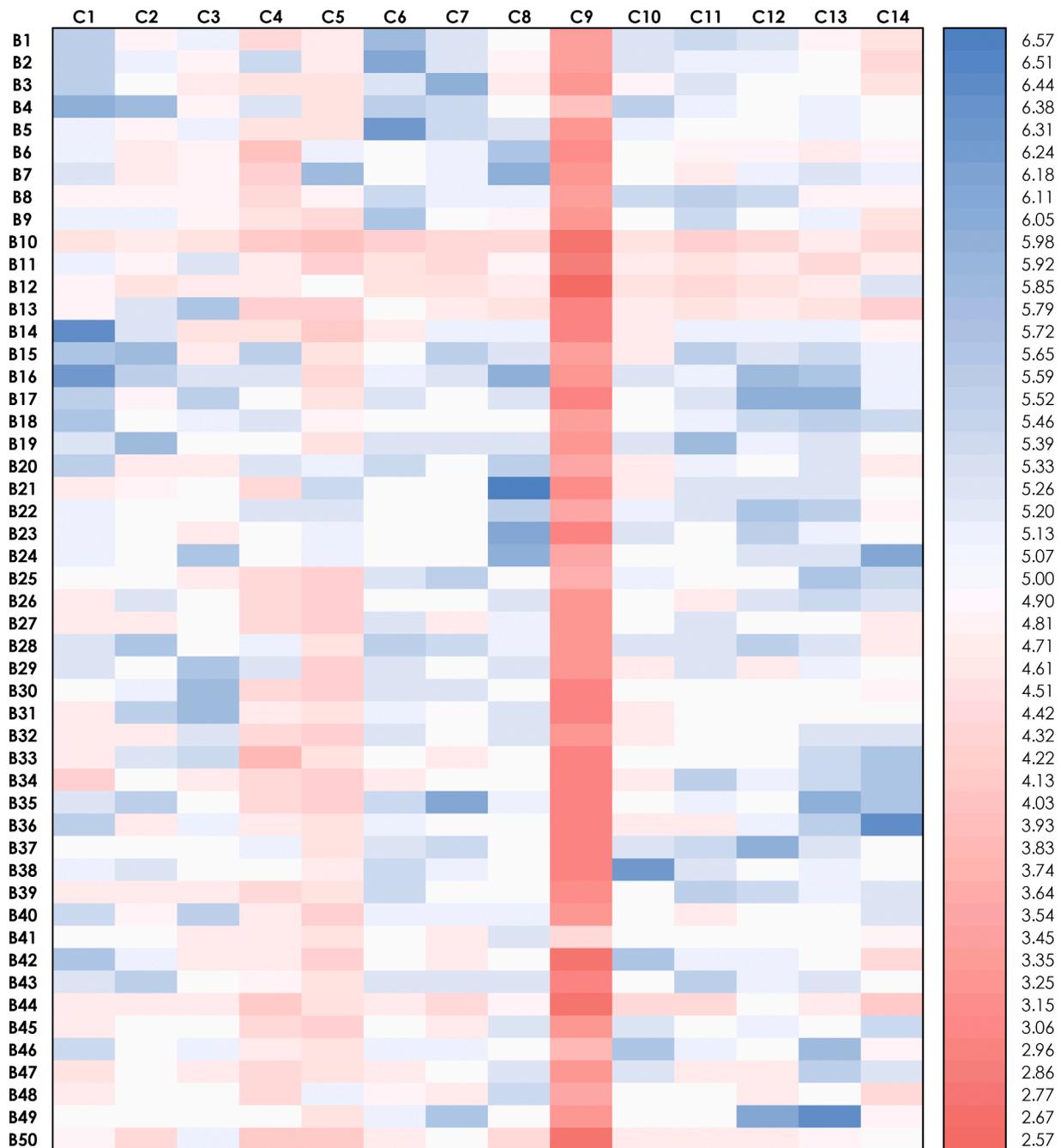


Fig. 5. Average of expert evaluations.

Step 11. Assign the CSC challenges to classes.

The final classification of CSC challenges is illustrated in Fig. 4.

#### 4. Results and discussion

##### 4.1. Characteristics of the decision matrix

The proposed integrated FF CRITIC-CODAS-SORT, as in any MADM method, is dependent on the elicitations of the experts on the relevance of CSC implementation challenges on the characteristics of PSSCs. Thus, it is deemed essential that preliminary analysis is performed to ensure that the gathered data is sufficient for use as inputs into the proposed method. The average of expert evaluations in non-FFS is presented in Fig. 5. It is observed that, on average, most challenges have low

relevance compared to the characteristics pertaining to the organizational structure of PSSCs (C7). The complex organizational structure of institutions in PSSCs arises from the highly bureaucratic practice in the public sector, differentiating it from the private sector, where authority is usually decentralized. Upon further assessment, indeed, none of the challenges relate much to this characteristic. Following the basic assumptions of any MADM problem, it is also important to check whether there are CSC challenges that are dominated by other challenges in the expert evaluations. Similarly, it is important to check if there are challenges that are dominating the expert evaluations. Dominating and dominated challenges are not present in the decision matrix, implying that all CSC challenges are non-trivial.

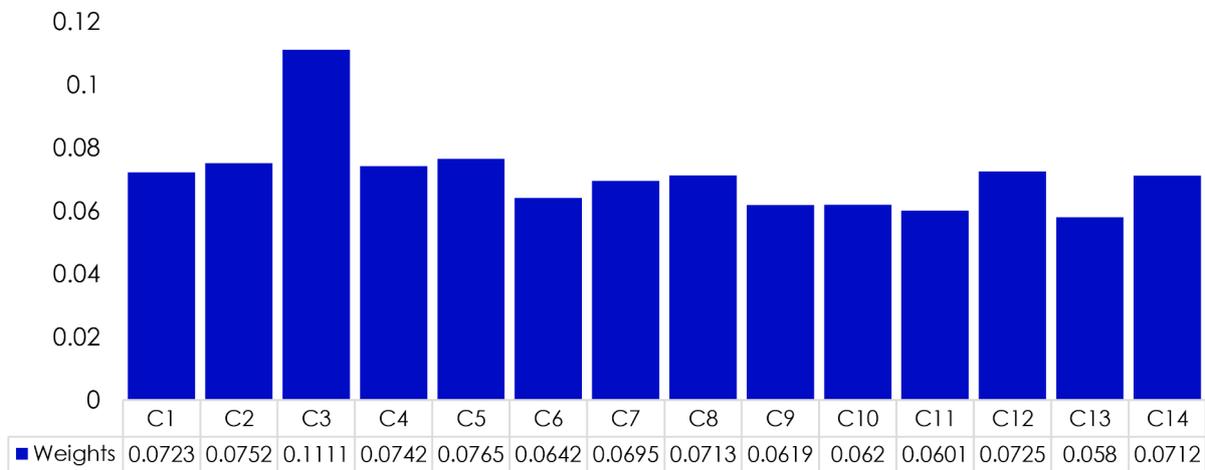


Fig. 6. The priority weights of the characteristics.

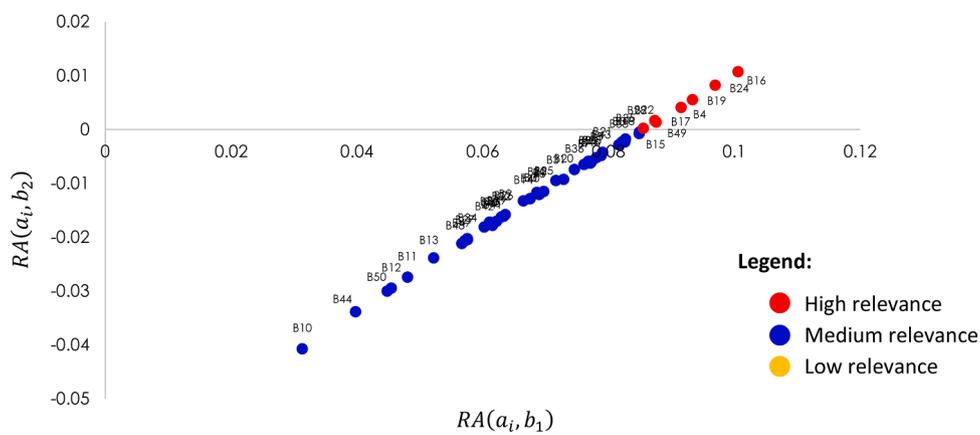


Fig. 7. Plot of  $RA(\alpha_i, b_k)$  values of the CSC challenges.

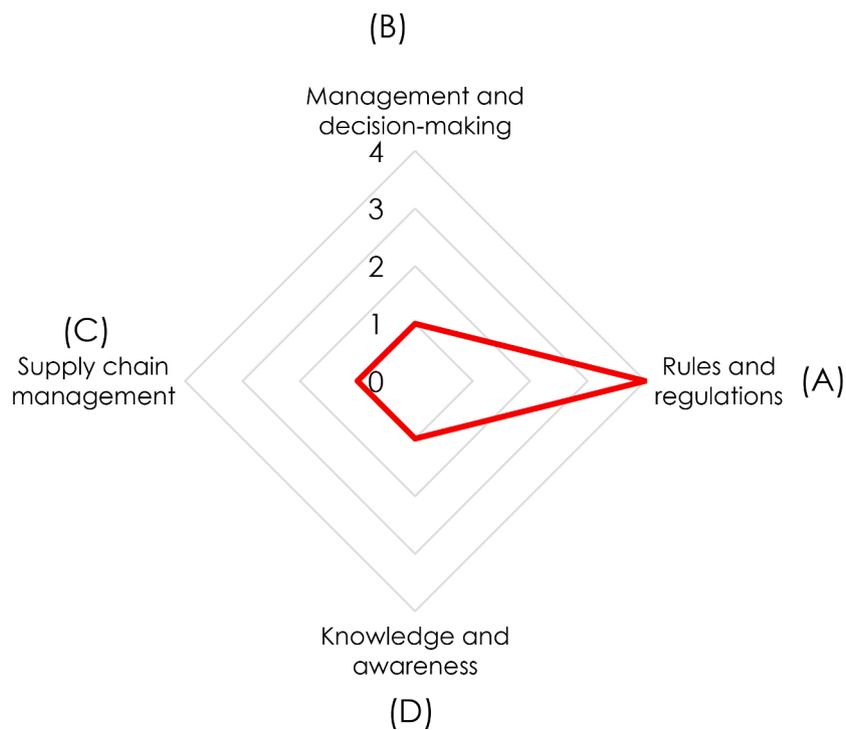
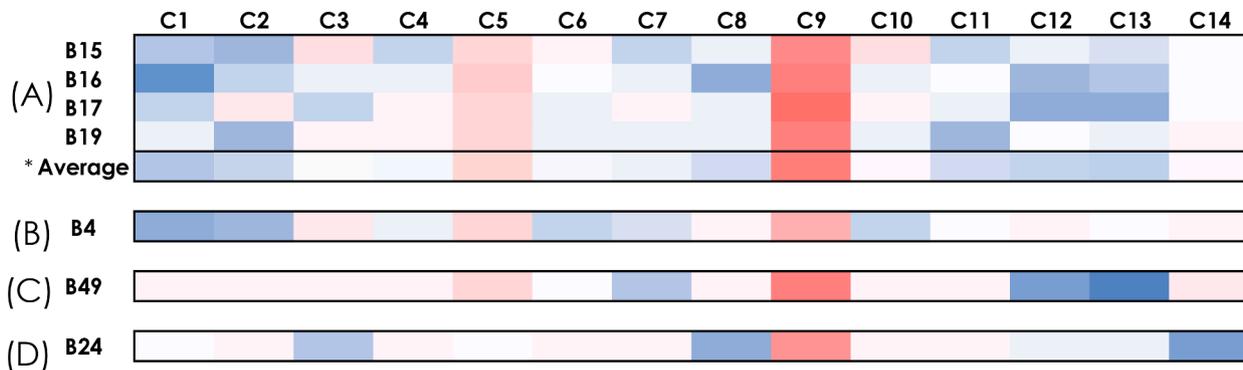


Fig. 8. Frequency of high relevance challenges in key categories.



\*The average evaluation scores of the high relevance barriers in (A)

Fig. 9. Isolated heat map (from Fig. 5) of high relevance challenges.

#### 4.2. Priority weights of the public sector supply chain characteristics

The priority weights indicate the relative importance of the characteristics in evaluating the CSC challenges in the context of PSSCs. The visual summary of these weights obtained using FF CRITIC is presented in Fig. 6. The priority weights of the characteristics are relatively compact within the range of 0.058-0.0765 apart from the characteristic of the revenue source (C3), which stands out with a priority weight of 0.1111. One of the clear distinguishing characteristics of PSSCs is the nature of their financing. Unlike the private sector, which sources its finances from partnerships, external investments, loans, and the selling of commercial products and services, the public sector relies primarily on tax collection. Generally, the public sector’s capacity to afford needed investments to implement CE strategies is much larger than that of the private sector due to the magnitude of their collections. Based on these results, the discrimination of CSC implementation challenges through these challenges is largely influenced by the evaluation of C3.

#### 4.3. Classification of circular supply chain challenges

The plot of the sorting results obtained from FF CODAS-SORT is presented in Fig. 7. The majority of CSC challenges are classified to have “medium relevance” to PSSC apart from those pertaining to the lack of policies for promoting CSC (B15); difficulty in coordinating supply chain due to size and complexity (B49); lack of incentives to enterprises that commit to CSC strategies (B17); inadequate leadership, management, and support from top management of enterprises (B4); restrictive collection regulation that makes waste collection difficult (B19); inadequate knowledge in enterprises for implementing CSC strategies (B24); and lack of vision geared towards circularizing the supply chain (B16). These challenges are classified as “high relevance” to PSSCs. In the succeeding paragraphs, the “high relevance” challenges are better emphasized.

The existing literature supports those highly relevant CSC challenges. Similar to the findings of Khandelwal and Barua [30], the support of the legislative body (e.g., Congress, Board of Directors, Board of Regents) is highly relevant in implementing CSC practices (B15). Furthermore, Sandvik and Stubbs [54] agree that a lack of a systematic industry-wide collection system remains a problem in implementing CSC (B19). As Mangla et al. [36] emphasized, the absence of a comprehensive policy framework also affects the initiative of an organization to enforce circularity practices in their operations. Especially in the public sector, wherein every aspect of the supply chain is required strictly to adhere to a standardized procedure defined by a legislative body authorized by the government, there needs to be an initiative in the legislative body to promote and enforce circular models. The top management needs a collective vision (B16) to create an industry-wide policy for CSC. The policy framework may gear towards developing

industry incentives to promote CSC practices (B17) [36]. Although financial resources may not be an issue for the public sectors in any project implementation, the enormous cost required for implementing circularity operations may be a problem in some areas, especially most localities in developing economies. Thus, financial and economic incentives for such an initiative from a small public organization can help advance their implementation process.

Aside from the difficulty in financial resources in acquiring technological advancements to support circularity initiatives, the expertise, information, and technology are inadequate and inaccessible (B19), especially in developing countries. Similar to the findings of Kazancoglu et al. [28], the lack of technical knowledge is a highly relevant challenge that needs to be addressed. Especially in a public sector wherein the organization members are less skilled and the application of technology in the supply chain is insufficient [3], acquiring human resources with highly technical and competent skills in the supply chain is essential. Furthermore, Sandvik and Stubbs [54] support the importance of aligning the principles of circularity of the supply chain despite its size and complexity (B49). With its size and complexity, the PSSC has an intricate system of organizations [3] that makes it difficult for the management to lead, support, and commit (B4). Khandelwal and Barua [30] support the importance of leadership and commitment from the management, wherein communication between departments may interrupt the monitoring of circular activities within the organization.

#### 4.4. Managerial insights

Four management aspects need to be focused on in addressing the challenges to CSC implementation in the public sector, namely: rules and regulations (A), management and decision-making (B), supply chain management (C), and knowledge and awareness (D). The frequency of high relevance challenges classified under the key aspects (categories) (see Fig. 8) provides insights on what aspects of PSSCs need priority intervention. Clearly, for CSC to be implemented in the public sector, there is a need to prioritize interventions that address inadequacies in current rules and regulations.

In the subsequent discussions, some proposals are provided per key aspect based on the public sector characteristics related to the “high relevance” challenges. Fig. 9 isolates the high relevance challenges from the evaluation summary presented in Fig. 5. It also tags the management aspects on the “high relevance” challenges. A way to interpret the degree of “relatedness” of a challenge to a characteristic is to view the characteristic as causal to or a facilitator of the challenges. This view is adopted here.

Based on the average evaluation score of the “high relevance” challenges in (A) (see Fig. 8), the “high relevance” challenges associated with the rules and regulations aspect are, on average, primarily related to the following public sector characteristics: C1, C2, and C11-C13.

There are two ways to address these challenges based on their relatedness to a public sector characteristic. First, strategies targeted at configuring the characteristics may be adopted, although such strategies may be too ideal. A more conservative approach tends to synergize with the public sector's characteristics while addressing the challenges. A mix of the former and the latter strategy is adopted here, but more emphasis on the latter. For the rules and regulations aspect, a way to simultaneously address B15, B16, B17, and B19 is through a policy that incentivizes institutions that adopt circularity practices. For instance, including circularity metrics (i.e., percent volume of recycled waste) in the assessment criteria for attaining performance incentives is a step that supports this end.

Providing incentives for CE practices can drive workers in the public sector to adopt CSC strategies. Such a policy is essential in urging PSSC actors to have a shared vision toward circularity. Although primarily driven by monetary benefit, such a vision may be a vital initial step in fostering partnerships and collaboration between actors in the supply chain. The proposed policy could be a tool to configure C11-C13 characteristics for addressing the determined challenges. A feature that may be added to the policy deals with education through skills training, seminar, and the imposition of the mandatory adoption of a sustainable development goal (SDG) as an overarching principle in each public institution. This feature is essential to increase the appreciation of the public sector on the concept of sustainability by emphasizing its importance in advancing public welfare. While supply chain management (SCM) is merely viewed by most institutions in the public sector as a procurement tool, with sufficient background on sustainability practices for SCM, CE practices can be more easily incorporated into the procurement process. It synergizes with C1 and C2 characteristics while advancing the CSC agenda. It is also essential to implement policies that facilitate CSC activities. For instance, CSC activities usually involve the collection of wastes that may be located in various geographical regions. Policies that ease collection restrictions, especially transport restrictions from one place to another, can reduce collection costs, making it easier to manage, thus, more efficient. The transfer of waste is highly restrictive, particularly in the Philippine public sector. Wastes, in particular, are documented as part of the inventories and are accountabilities of the public institution supervising them. In the Philippines, transferring inventory, in this case, the waste, from one public sector to another involves a painstaking bureaucratic process. Moreover, the penalty associated with the mismanagement of inventory is costly in that, oftentimes, the benefit of transferring waste is overwhelmed by the risk of inventory losses and mismanagement. In this regard, to advance CSC in the public sector, the bureaucratic process should be streamlined, and the policies associated with the transfer of waste, in particular, should be eased. However, these policy improvements should be designed in such a way that does not compromise accountability. For instance, a separate institution or function should be authorized for this initiative of transferring waste. In this way, public welfare, which is the primary objective of the public sector, is supported by maximizing resource efficiency through making waste materials as inputs for reprocessing in a CSC.

The driver of top management support in the public sector is different from the private sector. Top management support in the private sector is primarily driven by profit, whereas public welfare and accountability are the main drivers in the public sector. The nature of the public sector's function makes it less concerned about profit but more concerned about providing public services and, in effect, accountability. This is apparent in the manifold of extension programs required annually in most institutions in the public sector. Extension programs are activities or projects implemented to alleviate the social, environmental, or economic status. A way to guide extension programs towards CE is to include programs for recycling materials in public institutions as a standard requirement. However, recycling can have some accountability implications in the public sector. Usually, materials (e.g., laptops, chairs, tables) used in institutions in the public sector are strictly accounted for and are often required to be present in inventory

even at the end of their useful life.

This particular public sector characteristic inhibits recycling but can be addressed by institutionalizing it through legislative measures. For instance, a policy that allows donating still-useful materials to accredited recipients may be employed. Such a policy loosens the accounting of materials in the public sector while preserving accountability in management. Furthermore, legislation supporting public-private partnerships to remanufacture recyclable materials, e.g., glass, mirrors, and ceramic materials, can advance the CE agenda effectively. The remanufactured materials can be purchased by public institutions. Such a strategy can facilitate the employment of several workers in the remanufacturing plant, which supports the public sector's public welfare agenda. It also eventually closes the production loop in the PSSC. Furthermore, the complexity of managing waste in the public sector is reduced with the assistance of the private sector. The remanufacturing plant, which belongs to the private sector, is also assisted in both investment requirements and demand by the public sector. The policies and strategies proposed here are targeted at increasing top management support via the institutionalization of policies that facilitate the CSC agenda, which addresses B4 in aspect (B) while synergizing with the public sector characteristics that are most related to, namely: C1, C2, C6, C7, and C10.

The strategies proposed in this section for addressing challenges in aspects (A) and (B) are also tangential to (C) and (D). For instance, the public sector characteristics most related to the challenge B49 in aspect (C) are C7, C12, and C13. Aspect (C) is on SCM, which is the focal point of the proposed policies on training and SDG incorporation in the public sector and the public-private partnership for remanufacturing recyclable products geared towards closing the production loop in the public sector. Similarly, the policy on skills training is vital in addressing the challenge B24 in aspect (D), which is on CSC knowledge and awareness. The said challenge is most related to the C3, C8, and C14 public sector characteristics. The policy intends to increase both the CE awareness and competency of supply chain managers in the public sector so that they can appreciate and employ both technologies and strategies that facilitate the CSC agenda in their institution.

## 5. Conclusion and future work

Despite the growing interest in exploring the challenges (or barriers) of engaging in the circularity of supply chains, current reports often highlight those supply chains in the private sector, leaving the public sector behind. Adopting the insights from those reports regardless of the differentiating characteristics of PSSCs may be counterintuitive. Thus, this study is motivated by the need to identify, explore, and provide possible pathways to address the CSC challenges in the public sector as a way to advance the CE agenda. A systematic and analytic approach was implemented to holistically seek insights to understand CSC in the public sector better. The following processes were carried out: (1) comprehensively identifying the CSC challenges through a systematic literature review using the PRISMA statement, (2) evaluating the priorities of known PSSC characteristics, and (3) sorting of CSC challenges into classes of varying degrees of relevance (or importance).

A novel integrated MCS approach is offered, which involves the CRITIC method for assigning priority weights on the various characteristics of PSSCs, which are used to assess the relevance of the CSC challenges. The CODAS-SORT sorts the CSC challenges into classes, which determines the most important challenges to consider for engaging in efforts to promote CSC in the public sector. The deployment of the CRITIC and CODAS-SORT methods is performed in FFS, which accounts for the epistemic uncertainties inherent in expert decision-making within the context of an integrated CRITIC-CODAS-SORT. The use of the FFS promotes a greater capability of handling uncertainties, especially in performing analyses based on imprecise data. In effect, this paper presents a novel MCS method under uncertainty via the FF CRITIC-CODAS-SORT, which is applied to an emerging problem of

characterizing the challenges to CSC when adopted within supply chains of the public sector. The following findings are obtained from the analysis:

- the most relevant (or critical) CSC challenges in the public sector pertain to inadequate top management support (B4), inadequate government policies (B15), lack of interest in the concept of circularity (B16), lack of incentives to adopt CSC practices (B17), restrictive collection policies (B19), inadequate knowledge on CE (C24), and size and complexity of supply chains (B49).
- based on the CSC challenges, the key management aspects are determined as follows: rules and regulations, management and decision-making, supply chain management, and knowledge and awareness.
- based on the average evaluation of the CSC challenges, the following policy insights are offered: incentive program for institutions that adopt CSC practices, CE skills training program, mandatory SDG adoption in institutions, easing of restrictive waste collection and transport policies, a requirement of recycling projects as part of annual extension programs, policies that facilitate the donation of still-useful materials to accredited recipients, policy on public-private partnerships for the remanufacture recyclable materials.

These insights must be treated with certain limitations. First, following a systematic literature review, the 50 CSC challenges were only obtained from 29 journal articles from 2015 to 2021 in the Scopus database. Second, the comprehensive list of 14 PSSC characteristics was merely derived from Ambe [3], and the CSC challenges were then mapped to these characteristics. This mapping highlights the specific synergistic points between the PSSC characteristics and CSC challenges, which are essential in providing pathways for addressing the identified “high relevance” challenges. Third, seven expert decision-makers were asked to elicit judgments on the relevant association of each challenge to the characteristics using the predefined scale representing the association scores. A nationally or internationally representative sample of experts may be desired to compensate for some knowledge gaps relevant while the seven experts were performing the evaluations.

While this paper is not conclusive on the effectiveness of the proposed policies, the insights obtained from the analysis performed here are useful to guide policy-makers and may be used as starting points for scholarly discussion in the domain agenda. They must be used to complement relevant findings in the field, particularly those exploring CE efforts in supply chains. Future works may endeavor to empirically assess their effectiveness through an actual case study to evaluate the efficacy of these proposed measures. Also, the proposed FF CRITIC-CODAS-SORT involves a process-oriented nature, and the discussion resulting from its application to the analysis of CSC challenges in PSSCs adds much to the learning such an approach creates. For future work,

other MADM methods (e.g., entropy weight method, SWARA, PIPRECIA, among others) may be used to generate priority weights of PSSC characteristics. In addition, extensions of some emerging MADM methods for the sorting process, including EDAS, MARCOS, and RAFSI, may be adopted instead of CODAS. Finally, other fuzzy environments may be integrated to support the decision-making of the domain problem under uncertainty, e.g., Picture fuzzy sets, Spherical fuzzy sets, and neutrosophic sets, among others.

**Data availability statement**

The authors confirm that the data supporting the findings of this study are available within the article.

**CRedit authorship contribution statement**

**Joerabell Lourdes Aro:** Conceptualization, Data curation, Formal analysis, Methodology, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. **Egberto Selerio:** Conceptualization, Data curation, Formal analysis, Methodology, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. **Samantha Shane Evangelista:** Conceptualization, Data curation, Formal analysis, Methodology, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. **Fatima Maturan:** Conceptualization, Data curation, Formal analysis, Methodology, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. **Nadine May Atibing:** Conceptualization, Data curation, Formal analysis, Writing – original draft, Writing – review & editing. **Lanndon Ocampo:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Supervision, Writing – original draft, Writing – review & editing.

**Declaration of Competing Interest**

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

**Supplementary materials**

Supplementary material associated with this article can be found, in the online version, at [doi:10.1016/j.orp.2022.100246](https://doi.org/10.1016/j.orp.2022.100246).

**Appendix**

**Appendix 1**

The aggregate FF decision matrix.

	C1	C2	C3	C4	C5	C6	C7
<b>B1</b>	(0.6857, 0.2429)	(0.6143, 0.3143)	(0.6429, 0.2857)	(0.5214, 0.3857)	(0.5786, 0.3286)	(0.7286, 0.2143)	(0.6571, 0.2714)
<b>B2</b>	(0.7143, 0.2429)	(0.6571, 0.2857)	(0.6143, 0.3429)	(0.6429, 0.2571)	(0.5857, 0.3286)	(0.7714, 0.1857)	(0.6714, 0.2714)
<b>B3</b>	(0.7000, 0.2429)	(0.6286, 0.3000)	(0.6000, 0.3286)	(0.5857, 0.3429)	(0.5571, 0.3429)	(0.6571, 0.2714)	(0.7571, 0.2000)
<b>B4</b>	(0.7714, 0.2000)	(0.7429, 0.2143)	(0.6143, 0.3143)	(0.6714, 0.2714)	(0.5571, 0.3429)	(0.7000, 0.2429)	(0.6857, 0.2571)
<b>B5</b>	(0.6571, 0.2857)	(0.6143, 0.3143)	(0.6571, 0.2857)	(0.5643, 0.3429)	(0.5571, 0.3429)	(0.8000, 0.1714)	(0.6857, 0.2571)
<b>B6</b>	(0.6429, 0.2857)	(0.6000, 0.3286)	(0.6143, 0.3143)	(0.4786, 0.4286)	(0.6357, 0.2857)	(0.6429, 0.3000)	(0.6571, 0.2857)
<b>B7</b>	(0.6714, 0.2714)	(0.6000, 0.3286)	(0.6143, 0.3143)	(0.5143, 0.4000)	(0.7214, 0.2143)	(0.6286, 0.3000)	(0.6571, 0.2857)
<b>B8</b>	(0.6143, 0.3143)	(0.6143, 0.3143)	(0.6143, 0.3143)	(0.5357, 0.3571)	(0.6000, 0.3143)	(0.6857, 0.2571)	(0.6571, 0.2857)
<b>B9</b>	(0.6571, 0.2857)	(0.6429, 0.3143)	(0.6143, 0.3143)	(0.5571, 0.3429)	(0.5357, 0.3571)	(0.7143, 0.2286)	(0.6429, 0.3000)
<b>B10</b>	(0.5786, 0.3429)	(0.6000, 0.3286)	(0.5857, 0.3429)	(0.5071, 0.3857)	(0.4929, 0.4000)	(0.5571, 0.3714)	(0.5714, 0.3571)
<b>B11</b>	(0.6500, 0.2857)	(0.6143, 0.3143)	(0.6571, 0.2714)	(0.5929, 0.3286)	(0.5214, 0.3714)	(0.5857, 0.3429)	(0.5714, 0.3571)
<b>B12</b>	(0.6143, 0.3143)	(0.5857, 0.3429)	(0.6000, 0.3286)	(0.5929, 0.3286)	(0.6071, 0.3000)	(0.5857, 0.3429)	(0.5857, 0.3429)
<b>B13</b>	(0.6071, 0.3143)	(0.6571, 0.2714)	(0.7143, 0.2286)	(0.5286, 0.3714)	(0.5214, 0.3714)	(0.6286, 0.3000)	(0.6000, 0.3286)
<b>B14</b>	(0.8143, 0.1571)	(0.6571, 0.2714)	(0.5857, 0.3429)	(0.5643, 0.3429)	(0.5071, 0.3857)	(0.6000, 0.3286)	(0.6429, 0.2857)

(continued on next page)

Appendix 1 (continued)

	C1	C2	C3	C4	C5	C6	C7
B15	(0.7286, 0.2286)	(0.7286, 0.2143)	(0.6000, 0.3286)	(0.6857, 0.2429)	(0.5643, 0.3429)	(0.6429, 0.3000)	(0.7143, 0.2429)
B16	(0.8000, 0.1714)	(0.7000, 0.2429)	(0.6571, 0.2714)	(0.6429, 0.2714)	(0.5357, 0.3571)	(0.6571, 0.2857)	(0.6714, 0.2714)
B17	(0.7000, 0.2429)	(0.6071, 0.3143)	(0.7000, 0.2429)	(0.6286, 0.3000)	(0.5500, 0.3429)	(0.6857, 0.2714)	(0.6286, 0.3000)
B18	(0.7286, 0.2286)	(0.6357, 0.3000)	(0.6571, 0.2857)	(0.6429, 0.2714)	(0.6071, 0.3143)	(0.6286, 0.3000)	(0.6286, 0.3000)
B19	(0.6857, 0.2714)	(0.7571, 0.2143)	(0.6286, 0.3000)	(0.6286, 0.3000)	(0.5500, 0.3429)	(0.6857, 0.2714)	(0.6857, 0.2714)
B20	(0.7000, 0.2429)	(0.6000, 0.3286)	(0.6000, 0.3286)	(0.6429, 0.2714)	(0.6214, 0.2857)	(0.6714, 0.2571)	(0.6286, 0.3000)
B21	(0.6000, 0.3286)	(0.6071, 0.3143)	(0.6286, 0.3000)	(0.5429, 0.3571)	(0.6643, 0.2571)	(0.6429, 0.3286)	(0.6286, 0.3000)
B22	(0.6571, 0.2857)	(0.6286, 0.3000)	(0.6286, 0.3000)	(0.6429, 0.2714)	(0.6500, 0.2714)	(0.6286, 0.3000)	(0.6286, 0.3000)
B23	(0.6571, 0.2857)	(0.6286, 0.3000)	(0.5857, 0.3571)	(0.6286, 0.3000)	(0.6214, 0.2857)	(0.6429, 0.3000)	(0.6429, 0.3000)
B24	(0.6571, 0.2857)	(0.6286, 0.3000)	(0.7286, 0.2286)	(0.6286, 0.3000)	(0.6357, 0.2857)	(0.6286, 0.3000)	(0.6286, 0.3000)
B25	(0.6286, 0.3000)	(0.6429, 0.3000)	(0.5857, 0.3571)	(0.5714, 0.3571)	(0.5214, 0.3714)	(0.6857, 0.2714)	(0.7143, 0.2429)
B26	(0.6000, 0.3286)	(0.6571, 0.2714)	(0.6286, 0.3000)	(0.5429, 0.3571)	(0.5214, 0.3714)	(0.6286, 0.3000)	(0.6286, 0.3000)
B27	(0.6000, 0.3286)	(0.6000, 0.3286)	(0.6286, 0.3000)	(0.5429, 0.3571)	(0.5214, 0.3714)	(0.6857, 0.2714)	(0.6000, 0.3286)
B28	(0.6857, 0.2714)	(0.7143, 0.2286)	(0.6286, 0.3000)	(0.6143, 0.2857)	(0.5500, 0.3429)	(0.7143, 0.2429)	(0.6714, 0.2571)
B29	(0.6714, 0.2714)	(0.6286, 0.3000)	(0.7143, 0.2286)	(0.6429, 0.2714)	(0.5214, 0.3714)	(0.6857, 0.2714)	(0.6286, 0.3000)
B30	(0.6286, 0.3000)	(0.6429, 0.2857)	(0.7429, 0.2143)	(0.5571, 0.3857)	(0.5214, 0.3714)	(0.6857, 0.2714)	(0.6857, 0.2714)
B31	(0.6000, 0.3286)	(0.7000, 0.2429)	(0.7429, 0.2143)	(0.5714, 0.3286)	(0.5500, 0.3429)	(0.6429, 0.2857)	(0.6286, 0.3000)
B32	(0.6000, 0.3286)	(0.6000, 0.3286)	(0.6714, 0.2714)	(0.5429, 0.3571)	(0.5214, 0.3714)	(0.6857, 0.2714)	(0.6286, 0.3000)
B33	(0.6000, 0.3286)	(0.6714, 0.2714)	(0.6714, 0.2571)	(0.4714, 0.4429)	(0.5500, 0.3429)	(0.6286, 0.3000)	(0.6000, 0.3286)
B34	(0.5500, 0.3714)	(0.6286, 0.3000)	(0.6000, 0.3286)	(0.5286, 0.3857)	(0.5214, 0.3714)	(0.6000, 0.3286)	(0.6286, 0.3000)
B35	(0.6571, 0.2714)	(0.7000, 0.2429)	(0.6286, 0.3000)	(0.5429, 0.3571)	(0.5214, 0.3714)	(0.6857, 0.2571)	(0.7714, 0.1857)
B36	(0.7000, 0.2429)	(0.5857, 0.3571)	(0.6429, 0.2857)	(0.5714, 0.3286)	(0.5500, 0.3429)	(0.6571, 0.2857)	(0.6286, 0.3000)
B37	(0.6286, 0.3000)	(0.6429, 0.3000)	(0.6286, 0.3000)	(0.6571, 0.2857)	(0.5500, 0.3429)	(0.6857, 0.2714)	(0.6714, 0.2571)
B38	(0.6571, 0.2857)	(0.6857, 0.2714)	(0.6286, 0.3000)	(0.6286, 0.3000)	(0.5786, 0.3286)	(0.6714, 0.2571)	(0.6571, 0.2857)
B39	(0.6000, 0.3286)	(0.6000, 0.3286)	(0.5857, 0.3571)	(0.5429, 0.3571)	(0.5500, 0.3429)	(0.6857, 0.2571)	(0.6286, 0.3000)
B40	(0.6714, 0.2571)	(0.6143, 0.3143)	(0.7000, 0.2429)	(0.5714, 0.3286)	(0.5214, 0.3714)	(0.6571, 0.2857)	(0.6571, 0.2857)
B41	(0.6286, 0.3000)	(0.6286, 0.3000)	(0.6000, 0.3286)	(0.5714, 0.3286)	(0.5500, 0.3429)	(0.6286, 0.3000)	(0.6000, 0.3286)
B42	(0.7143, 0.2286)	(0.6429, 0.2857)	(0.6000, 0.3286)	(0.5714, 0.3286)	(0.5214, 0.3714)	(0.6286, 0.3000)	(0.6000, 0.3286)
B43	(0.6857, 0.2714)	(0.7000, 0.2429)	(0.6286, 0.3000)	(0.6143, 0.3429)	(0.5500, 0.3429)	(0.6857, 0.2714)	(0.6571, 0.2714)
B44	(0.6000, 0.3286)	(0.6000, 0.3286)	(0.6000, 0.3286)	(0.5000, 0.4143)	(0.5500, 0.3429)	(0.6000, 0.3286)	(0.5714, 0.3571)
B45	(0.5857, 0.3571)	(0.6286, 0.3000)	(0.6286, 0.3000)	(0.5429, 0.3571)	(0.5214, 0.3714)	(0.6286, 0.3000)	(0.6000, 0.3286)
B46	(0.6857, 0.2571)	(0.6286, 0.3000)	(0.6571, 0.2857)	(0.5714, 0.3286)	(0.5500, 0.3429)	(0.6571, 0.2857)	(0.6571, 0.2857)
B47	(0.5786, 0.3429)	(0.6286, 0.3000)	(0.5857, 0.3571)	(0.5429, 0.3571)	(0.5500, 0.3429)	(0.6000, 0.3286)	(0.6286, 0.3000)
B48	(0.6000, 0.3286)	(0.6286, 0.3000)	(0.6286, 0.3000)	(0.5429, 0.3571)	(0.6214, 0.2857)	(0.6143, 0.3143)	(0.6000, 0.3286)
B49	(0.6286, 0.3000)	(0.6429, 0.3000)	(0.6286, 0.3000)	(0.6286, 0.3000)	(0.5500, 0.3429)	(0.6571, 0.2857)	(0.7286, 0.2286)
B50	(0.6143, 0.3143)	(0.5714, 0.3571)	(0.6429, 0.2857)	(0.5143, 0.3857)	(0.5071, 0.3857)	(0.6000, 0.3286)	(0.6286, 0.3000)
	<b>C8</b>	<b>C9</b>	<b>C10</b>	<b>C11</b>	<b>C12</b>	<b>C13</b>	<b>C14</b>
B1	(0.6429, 0.3000)	(0.4214, 0.4857)	(0.6571, 0.2714)	(0.6714, 0.2571)	(0.6571, 0.2714)	(0.6143, 0.3143)	(0.5429, 0.3714)
B2	(0.6143, 0.3143)	(0.4143, 0.5143)	(0.6571, 0.2714)	(0.6429, 0.2857)	(0.6429, 0.2857)	(0.6429, 0.3000)	(0.5571, 0.3571)
B3	(0.6000, 0.3286)	(0.4143, 0.4714)	(0.6143, 0.3143)	(0.6571, 0.2714)	(0.6286, 0.3000)	(0.6286, 0.3000)	(0.5571, 0.3429)
B4	(0.6286, 0.3000)	(0.4714, 0.4571)	(0.7000, 0.2429)	(0.6571, 0.2857)	(0.6286, 0.3000)	(0.6571, 0.2857)	(0.6286, 0.3000)
B5	(0.6857, 0.2714)	(0.4071, 0.5000)	(0.6571, 0.2857)	(0.6286, 0.3000)	(0.6286, 0.3000)	(0.6571, 0.2857)	(0.6286, 0.3000)
B6	(0.7286, 0.2286)	(0.4000, 0.4857)	(0.6286, 0.3000)	(0.6143, 0.3143)	(0.6143, 0.3143)	(0.6000, 0.3571)	(0.6000, 0.3143)
B7	(0.7571, 0.2000)	(0.4143, 0.4714)	(0.6286, 0.3000)	(0.6000, 0.3286)	(0.6571, 0.2857)	(0.6571, 0.2714)	(0.6286, 0.2857)
B8	(0.6571, 0.2857)	(0.4286, 0.4571)	(0.6857, 0.2571)	(0.6857, 0.2429)	(0.6857, 0.2571)	(0.6143, 0.3143)	(0.5857, 0.3429)
B9	(0.6143, 0.3143)	(0.4143, 0.4714)	(0.6286, 0.3000)	(0.6714, 0.2571)	(0.6429, 0.3000)	(0.6571, 0.2857)	(0.5429, 0.3714)
B10	(0.5714, 0.3571)	(0.3429, 0.5857)	(0.5857, 0.3429)	(0.5429, 0.4000)	(0.5714, 0.3571)	(0.6000, 0.3286)	(0.5571, 0.3571)
B11	(0.6143, 0.3143)	(0.3643, 0.5429)	(0.6000, 0.3286)	(0.5857, 0.3429)	(0.6000, 0.3286)	(0.5714, 0.3571)	(0.5857, 0.3286)
B12	(0.6000, 0.3286)	(0.3286, 0.6000)	(0.5857, 0.3429)	(0.5714, 0.3571)	(0.5857, 0.3429)	(0.6000, 0.3286)	(0.6571, 0.2714)
B13	(0.5857, 0.3429)	(0.3857, 0.5000)	(0.6000, 0.3286)	(0.5857, 0.3429)	(0.6000, 0.3286)	(0.5857, 0.3429)	(0.5286, 0.3714)
B14	(0.6429, 0.2857)	(0.3857, 0.5000)	(0.6000, 0.3286)	(0.6429, 0.2857)	(0.6429, 0.2857)	(0.6429, 0.2857)	(0.5857, 0.3143)
B15	(0.6571, 0.2714)	(0.4286, 0.4571)	(0.6000, 0.3286)	(0.6857, 0.2429)	(0.6571, 0.2714)	(0.6857, 0.2571)	(0.6286, 0.2857)
B16	(0.7429, 0.2000)	(0.4143, 0.4714)	(0.6571, 0.2714)	(0.6429, 0.2857)	(0.7286, 0.2143)	(0.7286, 0.2286)	(0.6143, 0.2857)
B17	(0.6857, 0.2714)	(0.3714, 0.5571)	(0.6286, 0.3000)	(0.6571, 0.2714)	(0.7429, 0.2000)	(0.7429, 0.2000)	(0.6143, 0.2857)
B18	(0.6286, 0.3000)	(0.4286, 0.4571)	(0.6286, 0.3000)	(0.6571, 0.2857)	(0.6857, 0.2571)	(0.7000, 0.2429)	(0.6714, 0.2571)
B19	(0.6857, 0.2714)	(0.4143, 0.4714)	(0.6857, 0.2714)	(0.7571, 0.2143)	(0.6429, 0.2857)	(0.6857, 0.2714)	(0.6286, 0.3000)
B20	(0.7000, 0.2429)	(0.4429, 0.4429)	(0.6000, 0.3286)	(0.6429, 0.2857)	(0.6286, 0.3000)	(0.6857, 0.2714)	(0.5714, 0.3286)
B21	(0.8143, 0.1429)	(0.4000, 0.4857)	(0.6000, 0.3286)	(0.6571, 0.2714)	(0.6857, 0.2714)	(0.6857, 0.2714)	(0.6286, 0.3000)
B22	(0.7000, 0.2429)	(0.4429, 0.4429)	(0.6571, 0.2857)	(0.6857, 0.2714)	(0.7286, 0.2286)	(0.7000, 0.2429)	(0.6000, 0.3143)
B23	(0.7714, 0.1857)	(0.3714, 0.5571)	(0.6857, 0.2714)	(0.6286, 0.3000)	(0.7000, 0.2429)	(0.6571, 0.2857)	(0.6143, 0.3000)
B24	(0.7429, 0.2000)	(0.4429, 0.4429)	(0.6286, 0.3000)	(0.6286, 0.3000)	(0.6857, 0.2714)	(0.6857, 0.2714)	(0.7714, 0.1857)
B25	(0.6429, 0.3000)	(0.4571, 0.4857)	(0.6429, 0.2857)	(0.6286, 0.3000)	(0.6286, 0.3000)	(0.7286, 0.2286)	(0.6714, 0.2571)
B26	(0.6857, 0.2714)	(0.4143, 0.4714)	(0.6286, 0.3000)	(0.6000, 0.3286)	(0.6857, 0.2714)	(0.6714, 0.2571)	(0.6429, 0.2714)
B27	(0.6571, 0.2857)	(0.4143, 0.4714)	(0.6286, 0.3000)	(0.6714, 0.2714)	(0.6286, 0.3000)	(0.6286, 0.3000)	(0.5714, 0.3286)
B28	(0.6429, 0.2857)	(0.4143, 0.4714)	(0.6857, 0.2714)	(0.6857, 0.2714)	(0.7000, 0.2429)	(0.6857, 0.2714)	(0.5714, 0.3286)
B29	(0.6857, 0.2714)	(0.4143, 0.4714)	(0.6000, 0.3286)	(0.6857, 0.2714)	(0.6000, 0.3286)	(0.6571, 0.2857)	(0.6286, 0.3000)
B30	(0.6286, 0.3000)	(0.3714, 0.5571)	(0.6286, 0.3000)	(0.6286, 0.3000)	(0.6286, 0.3000)	(0.6286, 0.3000)	(0.6000, 0.3143)
B31	(0.6857, 0.2714)	(0.3857, 0.5000)	(0.6000, 0.3286)	(0.6286, 0.3000)	(0.6286, 0.3000)	(0.6286, 0.3000)	(0.6000, 0.3000)
B32	(0.6714, 0.2714)	(0.4143, 0.4714)	(0.6000, 0.3286)	(0.6286, 0.3000)	(0.6286, 0.3000)	(0.6571, 0.2714)	(0.6571, 0.2714)
B33	(0.6286, 0.3000)	(0.3857, 0.5000)	(0.6286, 0.3000)	(0.6286, 0.3000)	(0.6286, 0.3000)	(0.6714, 0.2571)	(0.6857, 0.2286)
B34	(0.6286, 0.3000)	(0.3857, 0.5000)	(0.6000, 0.3286)	(0.7000, 0.2429)	(0.6429, 0.2857)	(0.6714, 0.2571)	(0.6857, 0.2286)
B35	(0.6571, 0.2857)	(0.3857, 0.5000)	(0.6286, 0.3000)	(0.6429, 0.2857)	(0.6286, 0.3000)	(0.7571, 0.2000)	(0.6857, 0.2286)
B36	(0.6429, 0.3000)	(0.3714, 0.5571)	(0.6000, 0.3286)	(0.6000, 0.3286)	(0.6571, 0.2857)	(0.7000, 0.2429)	(0.8143, 0.1571)
B37	(0.6286, 0.3000)	(0.3714, 0.5286)	(0.6857, 0.2714)	(0.6714, 0.2571)	(0.7714, 0.2000)	(0.6857, 0.2714)	(0.6286, 0.3000)
B38	(0.6286, 0.3000)	(0.3714, 0.5571)	(0.8000, 0.1714)	(0.6857, 0.2714)	(0.6429, 0.3000)	(0.6571, 0.2857)	(0.6286, 0.3000)
B39	(0.6286, 0.3000)	(0.4000, 0.4857)	(0.6286, 0.3000)	(0.7000, 0.2429)	(0.6714, 0.2571)	(0.6571, 0.2857)	(0.6429, 0.2714)

(continued on next page)

Appendix 1 (continued)

	C1	C2	C3	C4	C5	C6	C7
B40	(0.6571, 0.2857)	(0.4143, 0.4714)	(0.6286, 0.3000)	(0.6000, 0.3286)	(0.6286, 0.3000)	(0.6286, 0.3000)	(0.6429, 0.2714)
B41	(0.6857, 0.2714)	(0.5571, 0.3571)	(0.6286, 0.3000)	(0.6286, 0.3000)	(0.6429, 0.3000)	(0.6429, 0.3000)	(0.6000, 0.3143)
B42	(0.6286, 0.3000)	(0.3429, 0.5571)	(0.7143, 0.2286)	(0.6429, 0.2857)	(0.6429, 0.2857)	(0.6286, 0.3000)	(0.5429, 0.3571)
B43	(0.6857, 0.2714)	(0.3714, 0.5571)	(0.6286, 0.3000)	(0.7143, 0.2429)	(0.6429, 0.2857)	(0.6857, 0.2714)	(0.6286, 0.3000)
B44	(0.6143, 0.3143)	(0.3429, 0.5571)	(0.5714, 0.3571)	(0.5714, 0.3571)	(0.6429, 0.3000)	(0.6000, 0.3286)	(0.5143, 0.3857)
B45	(0.6857, 0.2714)	(0.4143, 0.4714)	(0.6714, 0.2714)	(0.6286, 0.3000)	(0.6571, 0.2857)	(0.6286, 0.3000)	(0.6714, 0.2571)
B46	(0.6286, 0.3000)	(0.4857, 0.4143)	(0.7143, 0.2286)	(0.6429, 0.2857)	(0.6286, 0.3000)	(0.7571, 0.2143)	(0.6000, 0.3143)
B47	(0.6571, 0.2714)	(0.4143, 0.4714)	(0.6714, 0.2714)	(0.6000, 0.3286)	(0.6000, 0.3286)	(0.7000, 0.2429)	(0.6429, 0.2714)
B48	(0.6714, 0.2571)	(0.4571, 0.4429)	(0.6286, 0.3000)	(0.6286, 0.3000)	(0.6286, 0.3286)	(0.6286, 0.3000)	(0.5429, 0.3571)
B49	(0.6286, 0.3000)	(0.4143, 0.4714)	(0.6286, 0.3000)	(0.6286, 0.3000)	(0.7714, 0.1857)	(0.8286, 0.1571)	(0.6000, 0.3143)
B50	(0.5714, 0.3571)	(0.3571, 0.5286)	(0.6000, 0.3286)	(0.6000, 0.3286)	(0.6000, 0.3286)	(0.6143, 0.3143)	(0.6143, 0.3000)

Appendix 2

The normalized decision matrix.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14
B1	0.4208	0.1880	0.3197	0.1890	0.2989	0.6319	0.3621	0.2248	0.3662	0.3030	0.5324	0.3621	0.1211	0.0594
B2	0.5292	0.3962	0.1457	0.7554	0.3255	0.8436	0.4286	0.1311	0.3131	0.3030	0.3989	0.2957	0.2077	0.0932
B3	0.4738	0.2558	0.0803	0.4562	0.2182	0.3323	0.9078	0.0857	0.3614	0.1426	0.4643	0.2318	0.1647	0.0966
B4	0.7812	0.9039	0.1570	0.9095	0.2182	0.5038	0.5009	0.1783	0.5564	0.4820	0.4614	0.2318	0.2551	0.2810
B5	0.3159	0.1880	0.4021	0.3672	0.2182	1.0000	0.5009	0.3832	0.3106	0.3005	0.3361	0.2318	0.2551	0.2810
B6	0.2698	0.1229	0.1570	0.0298	0.5437	0.2764	0.3591	0.5646	0.3081	0.1940	0.2756	0.1704	0.0724	0.2028
B7	0.3665	0.1229	0.1570	0.1572	1.0000	0.2279	0.3591	0.6982	0.3614	0.1940	0.2175	0.3591	0.2573	0.2833
B8	0.1787	0.1880	0.1570	0.2528	0.3853	0.4436	0.3591	0.2762	0.4166	0.4191	0.6032	0.5009	0.1211	0.1617
B9	0.3159	0.3184	0.1570	0.3390	0.1429	0.5666	0.2923	0.1311	0.3614	0.1940	0.5324	0.2923	0.2551	0.0594
B10	0.0762	0.1229	0.0065	0.1418	0.0000	0.0000	0.0000	0.0000	0.0486	0.0457	0.0000	0.0000	0.0791	0.0932
B11	0.2926	0.1880	0.4060	0.4930	0.0934	0.0859	0.0000	0.1311	0.1539	0.0932	0.1616	0.1114	0.0000	0.1648
B12	0.1787	0.0603	0.0803	0.4930	0.4180	0.0859	0.0546	0.0857	0.0000	0.0457	0.1079	0.0546	0.0791	0.3688
B13	0.1585	0.3995	0.7858	0.2208	0.0934	0.2279	0.1114	0.0420	0.2564	0.0932	0.1616	0.1114	0.0388	0.0310
B14	1.0000	0.3995	0.0065	0.3672	0.0458	0.1314	0.2957	0.2274	0.2564	0.0932	0.3989	0.2957	0.2101	0.1677
B15	0.5887	0.8119	0.0803	1.0000	0.2428	0.2764	0.6524	0.2785	0.4166	0.0932	0.6032	0.3621	0.3558	0.2833
B16	0.9241	0.6356	0.4060	0.7521	0.1429	0.3299	0.4286	0.6312	0.3614	0.3030	0.3989	0.7359	0.5215	0.2446
B17	0.4738	0.1574	0.6841	0.6710	0.1943	0.4415	0.2318	0.3832	0.1499	0.1940	0.4643	0.8207	0.5830	0.2446
B18	0.5887	0.2887	0.4021	0.7521	0.4140	0.2279	0.2318	0.1783	0.4166	0.1940	0.4614	0.5009	0.4093	0.4153
B19	0.4171	1.0000	0.2367	0.6710	0.1943	0.4415	0.4983	0.3832	0.3614	0.4169	1.0000	0.2957	0.3540	0.2810
B20	0.4738	0.1229	0.0803	0.7521	0.4812	0.3878	0.2318	0.4431	0.4737	0.0932	0.3989	0.2318	0.3540	0.1314
B21	0.1357	0.1574	0.2367	0.2788	0.6842	0.2702	0.2318	1.0000	0.3081	0.0932	0.4643	0.4983	0.3540	0.2810
B22	0.3159	0.2558	0.2367	0.7521	0.6126	0.2279	0.2318	0.4431	0.4737	0.3005	0.5983	0.7341	0.4093	0.2028
B23	0.3159	0.2558	0.0000	0.6710	0.4812	0.2764	0.2923	0.7691	0.1499	0.4169	0.3361	0.5761	0.2551	0.2422
B24	0.3159	0.2558	0.8894	0.6710	0.5437	0.2279	0.2318	0.6312	0.4737	0.1940	0.3361	0.4983	0.3540	0.7983
B25	0.2233	0.3225	0.0000	0.3899	0.0934	0.4415	0.6524	0.2248	0.4775	0.2474	0.3361	0.2318	0.5215	0.4153
B26	0.1357	0.3995	0.2367	0.2788	0.0934	0.2279	0.2318	0.3832	0.3614	0.1940	0.2175	0.4983	0.3064	0.3261
B27	0.1357	0.1229	0.2367	0.2788	0.0934	0.4415	0.1114	0.2762	0.3614	0.1940	0.5297	0.2318	0.1647	0.1314
B28	0.4171	0.7220	0.2367	0.6053	0.1943	0.5650	0.4313	0.2274	0.3614	0.4169	0.5983	0.5761	0.3540	0.1314
B29	0.3665	0.2558	0.7858	0.7521	0.0934	0.4415	0.2318	0.3832	0.3614	0.0932	0.5983	0.1114	0.2551	0.2810
B30	0.2233	0.3262	1.0000	0.3190	0.0934	0.4415	0.4983	0.1783	0.1499	0.1940	0.3361	0.2318	0.1647	0.2028
B31	0.1357	0.6356	1.0000	0.4017	0.1943	0.2791	0.2318	0.3832	0.2564	0.0932	0.3361	0.2318	0.1647	0.2053
B32	0.1357	0.1229	0.4924	0.2788	0.0934	0.4415	0.2318	0.3296	0.3614	0.0932	0.3361	0.2318	0.2573	0.3688
B33	0.1357	0.4729	0.4959	0.0000	0.1943	0.2279	0.1114	0.1783	0.2564	0.1940	0.3361	0.2318	0.3064	0.4652
B34	0.0000	0.2558	0.0803	0.2135	0.0934	0.1314	0.2318	0.1783	0.2564	0.0932	0.6749	0.2957	0.3064	0.4652
B35	0.3181	0.6356	0.2367	0.2788	0.0934	0.4436	1.0000	0.2762	0.2564	0.1940	0.3989	0.2318	0.6449	0.4652
B36	0.4738	0.0548	0.3197	0.4017	0.1943	0.3299	0.2318	0.2248	0.1499	0.0932	0.2175	0.3591	0.4093	1.0000
B37	0.2233	0.3225	0.2367	0.8253	0.1943	0.4415	0.4313	0.1783	0.1884	0.4169	0.5324	0.9988	0.3540	0.2810
B38	0.3159	0.5497	0.2367	0.6710	0.2989	0.3878	0.3591	0.1783	0.1499	1.0000	0.5983	0.2923	0.2551	0.2810
B39	0.1357	0.1229	0.0000	0.2788	0.1943	0.4436	0.2318	0.1783	0.3081	0.1940	0.6749	0.4313	0.2551	0.3261
B40	0.3684	0.1880	0.6841	0.4017	0.0934	0.3299	0.3591	0.2762	0.3614	0.1940	0.2175	0.2318	0.1647	0.3261
B41	0.2233	0.2558	0.0803	0.4017	0.1943	0.2279	0.1114	0.3832	1.0000	0.1940	0.3361	0.2923	0.2077	0.2028
B42	0.5307	0.3262	0.0803	0.4017	0.0934	0.2279	0.1114	0.1783	0.0908	0.5475	0.3989	0.2957	0.1647	0.0632
B43	0.4171	0.6356	0.2367	0.5861	0.1943	0.4415	0.3621	0.3832	0.1499	0.1940	0.7500	0.2957	0.3540	0.2810
B44	0.1357	0.1229	0.0803	0.1029	0.1943	0.1314	0.0000	0.1311	0.0908	0.0000	0.1079	0.2923	0.0791	0.0000
B45	0.0908	0.2558	0.2367	0.2788	0.0934	0.2279	0.1114	0.3832	0.3614	0.3586	0.3361	0.3591	0.1647	0.4153
B46	0.4190	0.2558	0.4021	0.4017	0.1943	0.3299	0.3591	0.1783	0.6468	0.5475	0.3989	0.2318	0.6439	0.2028
B47	0.0762	0.2558	0.0000	0.2788	0.1943	0.1314	0.2318	0.2785	0.3614	0.3586	0.2175	0.1114	0.4093	0.3261
B48	0.1357	0.2558	0.2367	0.2788	0.4812	0.1787	0.1114	0.3317	0.5202	0.1940	0.3361	0.1114	0.1647	0.0632
B49	0.2233	0.3225	0.2367	0.6710	0.1943	0.3299	0.7341	0.1783	0.3614	0.1940	0.3361	1.0000	1.0000	0.2028
B50	0.1787	0.0000	0.3197	0.1651	0.0458	0.1314	0.2318	0.0000	0.1578	0.0932	0.2175	0.1114	0.1211	0.2422

Appendix 3

The augmented aggregate FF decision matrix.

	C1	C2	C3	C4	C5	C6	C7
B1	(0.6857, 0.2429)	(0.6143, 0.3143)	(0.6429, 0.2857)	(0.5214, 0.3857)	(0.5786, 0.3286)	(0.7286, 0.2143)	(0.6571, 0.2714)
B2	(0.7143, 0.2429)	(0.6571, 0.2857)	(0.6143, 0.3429)	(0.6429, 0.2571)	(0.5857, 0.3286)	(0.7714, 0.1857)	(0.6714, 0.2714)
B3	(0.7000, 0.2429)	(0.6286, 0.3000)	(0.6000, 0.3286)	(0.5857, 0.3429)	(0.5571, 0.3429)	(0.6571, 0.2714)	(0.7571, 0.2000)
B4	(0.7714, 0.2000)	(0.7429, 0.2143)	(0.6143, 0.3143)	(0.6714, 0.2714)	(0.5571, 0.3429)	(0.7000, 0.2429)	(0.6857, 0.2571)
B5	(0.6571, 0.2857)	(0.6143, 0.3143)	(0.6571, 0.2857)	(0.5643, 0.3429)	(0.5571, 0.3429)	(0.8000, 0.1714)	(0.6857, 0.2571)
B6	(0.6429, 0.2857)	(0.6000, 0.3286)	(0.6143, 0.3143)	(0.4786, 0.4286)	(0.6357, 0.2857)	(0.6429, 0.3000)	(0.6571, 0.2857)
B7	(0.6714, 0.2714)	(0.6000, 0.3286)	(0.6143, 0.3143)	(0.5143, 0.4000)	(0.7214, 0.2143)	(0.6286, 0.3000)	(0.6571, 0.2857)
B8	(0.6143, 0.3143)	(0.6143, 0.3143)	(0.6143, 0.3143)	(0.5357, 0.3571)	(0.6000, 0.3143)	(0.6857, 0.2571)	(0.6571, 0.2857)
B9	(0.6571, 0.2857)	(0.6429, 0.3143)	(0.6143, 0.3143)	(0.5571, 0.3429)	(0.5357, 0.3571)	(0.7143, 0.2286)	(0.6429, 0.3000)
B10	(0.5786, 0.3429)	(0.6000, 0.3286)	(0.5857, 0.3429)	(0.5071, 0.3857)	(0.4929, 0.4000)	(0.5571, 0.3714)	(0.5714, 0.3571)
B11	(0.6500, 0.2857)	(0.6143, 0.3143)	(0.6571, 0.2714)	(0.5929, 0.3286)	(0.5214, 0.3714)	(0.5857, 0.3429)	(0.5714, 0.3571)
B12	(0.6143, 0.3143)	(0.5857, 0.3429)	(0.6000, 0.3286)	(0.5929, 0.3286)	(0.6071, 0.3000)	(0.5857, 0.3429)	(0.5857, 0.3429)
B13	(0.6071, 0.3143)	(0.6571, 0.2714)	(0.7143, 0.2286)	(0.5286, 0.3714)	(0.5214, 0.3714)	(0.6286, 0.3000)	(0.6000, 0.3286)
B14	(0.8143, 0.1571)	(0.6571, 0.2714)	(0.5857, 0.3429)	(0.5643, 0.3429)	(0.5071, 0.3857)	(0.6000, 0.3286)	(0.6429, 0.2857)
B15	(0.7286, 0.2286)	(0.7286, 0.2143)	(0.6000, 0.3286)	(0.6857, 0.2429)	(0.5643, 0.3429)	(0.6429, 0.3000)	(0.7143, 0.2429)
B16	(0.8000, 0.1714)	(0.7000, 0.2429)	(0.6571, 0.2714)	(0.6429, 0.2714)	(0.5357, 0.3571)	(0.6571, 0.2857)	(0.6714, 0.2714)
B17	(0.7000, 0.2429)	(0.6071, 0.3143)	(0.7000, 0.2429)	(0.6286, 0.3000)	(0.5500, 0.3429)	(0.6857, 0.2714)	(0.6286, 0.3000)
B18	(0.7286, 0.2286)	(0.6357, 0.3000)	(0.6571, 0.2857)	(0.6429, 0.2714)	(0.6071, 0.3143)	(0.6286, 0.3000)	(0.6286, 0.3000)
B19	(0.6857, 0.2714)	(0.7571, 0.2143)	(0.6286, 0.3000)	(0.6286, 0.3000)	(0.5500, 0.3429)	(0.6857, 0.2714)	(0.6857, 0.2714)
B20	(0.7000, 0.2429)	(0.6000, 0.3286)	(0.6000, 0.3286)	(0.6429, 0.2714)	(0.6214, 0.2857)	(0.6714, 0.2571)	(0.6286, 0.3000)
B21	(0.6000, 0.3286)	(0.6071, 0.3143)	(0.6286, 0.3000)	(0.5429, 0.3571)	(0.6643, 0.2571)	(0.6429, 0.3286)	(0.6286, 0.3000)
B22	(0.6571, 0.2857)	(0.6286, 0.3000)	(0.6286, 0.3000)	(0.6429, 0.2714)	(0.6500, 0.2714)	(0.6286, 0.3000)	(0.6286, 0.3000)
B23	(0.6571, 0.2857)	(0.6286, 0.3000)	(0.5857, 0.3571)	(0.6286, 0.3000)	(0.6214, 0.2857)	(0.6429, 0.3000)	(0.6429, 0.3000)
B24	(0.6571, 0.2857)	(0.6286, 0.3000)	(0.7286, 0.2286)	(0.6286, 0.3000)	(0.6357, 0.2857)	(0.6286, 0.3000)	(0.6286, 0.3000)
B25	(0.6286, 0.3000)	(0.6429, 0.3000)	(0.5857, 0.3571)	(0.5714, 0.3571)	(0.5214, 0.3714)	(0.6857, 0.2714)	(0.7143, 0.2429)
B26	(0.6000, 0.3286)	(0.6571, 0.2714)	(0.6286, 0.3000)	(0.5429, 0.3571)	(0.5214, 0.3714)	(0.6286, 0.3000)	(0.6286, 0.3000)
B27	(0.6000, 0.3286)	(0.6000, 0.3286)	(0.6286, 0.3000)	(0.5429, 0.3571)	(0.5214, 0.3714)	(0.6857, 0.2714)	(0.6000, 0.3286)
B28	(0.6857, 0.2714)	(0.7143, 0.2286)	(0.6286, 0.3000)	(0.6143, 0.2857)	(0.5500, 0.3429)	(0.7143, 0.2429)	(0.6714, 0.2571)
B29	(0.6714, 0.2714)	(0.6286, 0.3000)	(0.7143, 0.2286)	(0.6429, 0.2714)	(0.5214, 0.3714)	(0.6857, 0.2714)	(0.6286, 0.3000)
B30	(0.6286, 0.3000)	(0.6429, 0.2857)	(0.7429, 0.2143)	(0.5571, 0.3857)	(0.5214, 0.3714)	(0.6857, 0.2714)	(0.6857, 0.2714)
B31	(0.6000, 0.3286)	(0.7000, 0.2429)	(0.7429, 0.2143)	(0.5714, 0.3286)	(0.5500, 0.3429)	(0.6429, 0.2857)	(0.6286, 0.3000)
B32	(0.6000, 0.3286)	(0.6000, 0.3286)	(0.6714, 0.2714)	(0.5429, 0.3571)	(0.5214, 0.3714)	(0.6857, 0.2714)	(0.6286, 0.3000)
B33	(0.6000, 0.3286)	(0.6714, 0.2714)	(0.6714, 0.2571)	(0.4714, 0.4429)	(0.5500, 0.3429)	(0.6286, 0.3000)	(0.6000, 0.3286)
B34	(0.5500, 0.3714)	(0.6286, 0.3000)	(0.6000, 0.3286)	(0.5286, 0.3857)	(0.5214, 0.3714)	(0.6000, 0.3286)	(0.6286, 0.3000)
B35	(0.6571, 0.2714)	(0.7000, 0.2429)	(0.6286, 0.3000)	(0.5429, 0.3571)	(0.5214, 0.3714)	(0.6857, 0.2571)	(0.7714, 0.1857)
B36	(0.7000, 0.2429)	(0.5857, 0.3571)	(0.6429, 0.2857)	(0.5714, 0.3286)	(0.5500, 0.3429)	(0.6571, 0.2857)	(0.6286, 0.3000)
B37	(0.6286, 0.3000)	(0.6429, 0.3000)	(0.6286, 0.3000)	(0.6571, 0.2857)	(0.5500, 0.3429)	(0.6857, 0.2714)	(0.6714, 0.2571)
B38	(0.6571, 0.2857)	(0.6857, 0.2714)	(0.6286, 0.3000)	(0.6286, 0.3000)	(0.5786, 0.3286)	(0.6714, 0.2571)	(0.6571, 0.2857)
B39	(0.6000, 0.3286)	(0.6000, 0.3286)	(0.5857, 0.3571)	(0.5429, 0.3571)	(0.5500, 0.3429)	(0.6857, 0.2571)	(0.6286, 0.3000)
B40	(0.6714, 0.2571)	(0.6143, 0.3143)	(0.7000, 0.2429)	(0.5714, 0.3286)	(0.5214, 0.3714)	(0.6571, 0.2857)	(0.6571, 0.2857)
B41	(0.6286, 0.3000)	(0.6286, 0.3000)	(0.6000, 0.3286)	(0.5714, 0.3286)	(0.5500, 0.3429)	(0.6286, 0.3000)	(0.6000, 0.3286)
B42	(0.7143, 0.2286)	(0.6429, 0.2857)	(0.6000, 0.3286)	(0.5714, 0.3286)	(0.5214, 0.3714)	(0.6286, 0.3000)	(0.6000, 0.3286)
B43	(0.6857, 0.2714)	(0.7000, 0.2429)	(0.6286, 0.3000)	(0.6143, 0.3429)	(0.5500, 0.3429)	(0.6857, 0.2714)	(0.6571, 0.2714)
B44	(0.6000, 0.3286)	(0.6000, 0.3286)	(0.6000, 0.3286)	(0.5000, 0.4143)	(0.5500, 0.3429)	(0.6000, 0.3286)	(0.5714, 0.3571)
B45	(0.5857, 0.3571)	(0.6286, 0.3000)	(0.6286, 0.3000)	(0.5429, 0.3571)	(0.5214, 0.3714)	(0.6286, 0.3000)	(0.6000, 0.3286)
B46	(0.6857, 0.2571)	(0.6286, 0.3000)	(0.6571, 0.2857)	(0.5714, 0.3286)	(0.5500, 0.3429)	(0.6571, 0.2857)	(0.6571, 0.2857)
B47	(0.5786, 0.3429)	(0.6286, 0.3000)	(0.5857, 0.3571)	(0.5429, 0.3571)	(0.5500, 0.3429)	(0.6000, 0.3286)	(0.6286, 0.3000)
B48	(0.6000, 0.3286)	(0.6286, 0.3000)	(0.6286, 0.3000)	(0.5429, 0.3571)	(0.6214, 0.2857)	(0.6143, 0.3143)	(0.6000, 0.3286)
B49	(0.6286, 0.3000)	(0.6429, 0.3000)	(0.6286, 0.3000)	(0.6286, 0.3000)	(0.5500, 0.3429)	(0.6571, 0.2857)	(0.7286, 0.2286)
B50	(0.6143, 0.3143)	(0.5714, 0.3571)	(0.6429, 0.2857)	(0.5143, 0.3857)	(0.5071, 0.3857)	(0.6000, 0.3286)	(0.6286, 0.3000)
L2	(0.7000, 0.3000)	(0.6000, 0.3000)	(0.6000, 0.3000)	(0.6000, 0.2000)	(0.6000, 0.2000)	(0.7000, 0.3000)	(0.6000, 0.3000)
L1	(0.5000, 0.5000)	(0.5000, 0.5000)	(0.5000, 0.5000)	(0.5000, 0.4000)	(0.5000, 0.4000)	(0.5000, 0.5000)	(0.5000, 0.5000)
	<b>C8</b>	<b>C9</b>	<b>C10</b>	<b>C11</b>	<b>C12</b>	<b>C13</b>	<b>C14</b>
B1	(0.6429, 0.3000)	(0.4214, 0.4857)	(0.6571, 0.2714)	(0.6714, 0.2571)	(0.6571, 0.2714)	(0.6143, 0.3143)	(0.5429, 0.3714)
B2	(0.6143, 0.3143)	(0.4143, 0.5143)	(0.6571, 0.2714)	(0.6429, 0.2857)	(0.6429, 0.2857)	(0.6429, 0.3000)	(0.5571, 0.3571)
B3	(0.6000, 0.3286)	(0.4143, 0.4714)	(0.6143, 0.3143)	(0.6571, 0.2714)	(0.6286, 0.3000)	(0.6286, 0.3000)	(0.5571, 0.3429)
B4	(0.6286, 0.3000)	(0.4714, 0.4571)	(0.7000, 0.2429)	(0.6571, 0.2857)	(0.6286, 0.3000)	(0.6571, 0.2857)	(0.6286, 0.3000)
B5	(0.6857, 0.2714)	(0.4071, 0.5000)	(0.6571, 0.2857)	(0.6286, 0.3000)	(0.6286, 0.3000)	(0.6571, 0.2857)	(0.6286, 0.3000)
B6	(0.7286, 0.2286)	(0.4000, 0.4857)	(0.6286, 0.3000)	(0.6143, 0.3143)	(0.6143, 0.3143)	(0.6000, 0.3571)	(0.6000, 0.3143)
B7	(0.7571, 0.2000)	(0.4143, 0.4714)	(0.6286, 0.3000)	(0.6000, 0.3286)	(0.6571, 0.2857)	(0.6571, 0.2714)	(0.6286, 0.2857)
B8	(0.6571, 0.2857)	(0.4286, 0.4571)	(0.6857, 0.2571)	(0.6857, 0.2429)	(0.6857, 0.2571)	(0.6143, 0.3143)	(0.5857, 0.3429)
B9	(0.6143, 0.3143)	(0.4143, 0.4714)	(0.6286, 0.3000)	(0.6714, 0.2571)	(0.6429, 0.3000)	(0.6571, 0.2857)	(0.5429, 0.3714)
B10	(0.5714, 0.3571)	(0.3429, 0.5857)	(0.5857, 0.3429)	(0.5429, 0.4000)	(0.5714, 0.3571)	(0.6000, 0.3286)	(0.5571, 0.3571)
B11	(0.6143, 0.3143)	(0.3643, 0.5429)	(0.6000, 0.3286)	(0.5857, 0.3429)	(0.6000, 0.3286)	(0.5714, 0.3571)	(0.5857, 0.3286)
B12	(0.6000, 0.3286)	(0.3286, 0.6000)	(0.5857, 0.3429)	(0.5714, 0.3571)	(0.5857, 0.3429)	(0.6000, 0.3286)	(0.6571, 0.2714)
B13	(0.5857, 0.3429)	(0.3857, 0.5000)	(0.6000, 0.3286)	(0.5857, 0.3429)	(0.6000, 0.3286)	(0.5857, 0.3429)	(0.5286, 0.3714)
B14	(0.6429, 0.2857)	(0.3857, 0.5000)	(0.6000, 0.3286)	(0.6429, 0.2857)	(0.6429, 0.2857)	(0.6429, 0.2857)	(0.5857, 0.3143)
B15	(0.6571, 0.2714)	(0.4286, 0.4571)	(0.6000, 0.3286)	(0.6857, 0.2429)	(0.6571, 0.2714)	(0.6857, 0.2571)	(0.6286, 0.2857)
B16	(0.7429, 0.2000)	(0.4143, 0.4714)	(0.6571, 0.2714)	(0.6429, 0.2857)	(0.7286, 0.2143)	(0.7286, 0.2286)	(0.6143, 0.2857)
B17	(0.6857, 0.2714)	(0.3714, 0.5571)	(0.6286, 0.3000)	(0.6571, 0.2714)	(0.7429, 0.2000)	(0.7429, 0.2000)	(0.6143, 0.2857)
B18	(0.6286, 0.3000)	(0.4286, 0.4571)	(0.6286, 0.3000)	(0.6571, 0.2857)	(0.6857, 0.2571)	(0.7000, 0.2429)	(0.6714, 0.2571)
B19	(0.6857, 0.2714)	(0.4143, 0.4714)	(0.6857, 0.2714)	(0.7571, 0.2143)	(0.6429, 0.2857)	(0.6857, 0.2714)	(0.6286, 0.3000)
B20	(0.7000, 0.2429)	(0.4429, 0.4429)	(0.6000, 0.3286)	(0.6429, 0.2857)	(0.6286, 0.3000)	(0.6857, 0.2714)	(0.5714, 0.3286)
B21	(0.8143, 0.1429)	(0.4000, 0.4857)	(0.6000, 0.3286)	(0.6571, 0.2714)	(0.6857, 0.2714)	(0.6857, 0.2714)	(0.6286, 0.3000)

(continued on next page)

Appendix 3 (continued)

	C1	C2	C3	C4	C5	C6	C7
B22	(0.7000, 0.2429)	(0.4429, 0.4429)	(0.6571, 0.2857)	(0.6857, 0.2714)	(0.7286, 0.2286)	(0.7000, 0.2429)	(0.6000, 0.3143)
B23	(0.7714, 0.1857)	(0.3714, 0.5571)	(0.6857, 0.2714)	(0.6286, 0.3000)	(0.7000, 0.2429)	(0.6571, 0.2857)	(0.6143, 0.3000)
B24	(0.7429, 0.2000)	(0.4429, 0.4429)	(0.6286, 0.3000)	(0.6286, 0.3000)	(0.6857, 0.2714)	(0.6857, 0.2714)	(0.7714, 0.1857)
B25	(0.6429, 0.3000)	(0.4571, 0.4857)	(0.6429, 0.2857)	(0.6286, 0.3000)	(0.6286, 0.3000)	(0.7286, 0.2286)	(0.6714, 0.2571)
B26	(0.6857, 0.2714)	(0.4143, 0.4714)	(0.6286, 0.3000)	(0.6000, 0.3286)	(0.6857, 0.2714)	(0.6714, 0.2571)	(0.6429, 0.2714)
B27	(0.6571, 0.2857)	(0.4143, 0.4714)	(0.6286, 0.3000)	(0.6714, 0.2714)	(0.6286, 0.3000)	(0.6286, 0.3000)	(0.5714, 0.3286)
B28	(0.6429, 0.2857)	(0.4143, 0.4714)	(0.6857, 0.2714)	(0.6857, 0.2714)	(0.7000, 0.2429)	(0.6857, 0.2714)	(0.5714, 0.3286)
B29	(0.6857, 0.2714)	(0.4143, 0.4714)	(0.6000, 0.3286)	(0.6857, 0.2714)	(0.6000, 0.3286)	(0.6571, 0.2857)	(0.6286, 0.3000)
B30	(0.6286, 0.3000)	(0.3714, 0.5571)	(0.6286, 0.3000)	(0.6286, 0.3000)	(0.6286, 0.3000)	(0.6286, 0.3000)	(0.6000, 0.3143)
B31	(0.6857, 0.2714)	(0.3857, 0.5000)	(0.6000, 0.3286)	(0.6286, 0.3000)	(0.6286, 0.3000)	(0.6286, 0.3000)	(0.6000, 0.3000)
B32	(0.6714, 0.2714)	(0.4143, 0.4714)	(0.6000, 0.3286)	(0.6286, 0.3000)	(0.6286, 0.3000)	(0.6571, 0.2714)	(0.6571, 0.2714)
B33	(0.6286, 0.3000)	(0.3857, 0.5000)	(0.6286, 0.3000)	(0.6286, 0.3000)	(0.6286, 0.3000)	(0.6714, 0.2571)	(0.6857, 0.2286)
B34	(0.6286, 0.3000)	(0.3857, 0.5000)	(0.6000, 0.3286)	(0.7000, 0.2429)	(0.6429, 0.2857)	(0.6714, 0.2571)	(0.6857, 0.2286)
B35	(0.6571, 0.2857)	(0.3857, 0.5000)	(0.6286, 0.3000)	(0.6429, 0.2857)	(0.6286, 0.3000)	(0.7571, 0.2000)	(0.6857, 0.2286)
B36	(0.6429, 0.3000)	(0.3714, 0.5571)	(0.6000, 0.3286)	(0.6000, 0.3286)	(0.6571, 0.2857)	(0.7000, 0.2429)	(0.8143, 0.1571)
B37	(0.6286, 0.3000)	(0.3714, 0.5286)	(0.6857, 0.2714)	(0.6714, 0.2571)	(0.7714, 0.2000)	(0.6857, 0.2714)	(0.6286, 0.3000)
B38	(0.6286, 0.3000)	(0.3714, 0.5571)	(0.8000, 0.1714)	(0.6857, 0.2714)	(0.6429, 0.3000)	(0.6571, 0.2857)	(0.6286, 0.3000)
B39	(0.6286, 0.3000)	(0.4000, 0.4857)	(0.6286, 0.3000)	(0.7000, 0.2429)	(0.6714, 0.2571)	(0.6571, 0.2857)	(0.6429, 0.2714)
B40	(0.6571, 0.2857)	(0.4143, 0.4714)	(0.6286, 0.3000)	(0.6000, 0.3286)	(0.6286, 0.3000)	(0.6286, 0.3000)	(0.6429, 0.2714)
B41	(0.6857, 0.2714)	(0.5571, 0.3571)	(0.6286, 0.3000)	(0.6286, 0.3000)	(0.6429, 0.3000)	(0.6429, 0.3000)	(0.6000, 0.3143)
B42	(0.6286, 0.3000)	(0.3429, 0.5571)	(0.7143, 0.2286)	(0.6429, 0.2857)	(0.6429, 0.2857)	(0.6286, 0.3000)	(0.5429, 0.3571)
B43	(0.6857, 0.2714)	(0.3714, 0.5571)	(0.6286, 0.3000)	(0.7143, 0.2429)	(0.6429, 0.2857)	(0.6857, 0.2714)	(0.6286, 0.3000)
B44	(0.6143, 0.3143)	(0.3429, 0.5571)	(0.5714, 0.3571)	(0.5714, 0.3571)	(0.6429, 0.3000)	(0.6000, 0.3286)	(0.5143, 0.3857)
B45	(0.6857, 0.2714)	(0.4143, 0.4714)	(0.6714, 0.2714)	(0.6286, 0.3000)	(0.6571, 0.2857)	(0.6286, 0.3000)	(0.6714, 0.2571)
B46	(0.6286, 0.3000)	(0.4857, 0.4143)	(0.7143, 0.2286)	(0.6429, 0.2857)	(0.6286, 0.3000)	(0.7571, 0.2143)	(0.6000, 0.3143)
B47	(0.6571, 0.2714)	(0.4143, 0.4714)	(0.6714, 0.2714)	(0.6000, 0.3286)	(0.6000, 0.3286)	(0.7000, 0.2429)	(0.6429, 0.2714)
B48	(0.6714, 0.2571)	(0.4571, 0.4429)	(0.6286, 0.3000)	(0.6286, 0.3000)	(0.6000, 0.3286)	(0.6286, 0.3000)	(0.5429, 0.3571)
B49	(0.6286, 0.3000)	(0.4143, 0.4714)	(0.6286, 0.3000)	(0.6286, 0.3000)	(0.7714, 0.1857)	(0.8286, 0.1571)	(0.6000, 0.3143)
B50	(0.5714, 0.3571)	(0.3571, 0.5286)	(0.6000, 0.3286)	(0.6000, 0.3286)	(0.6000, 0.3286)	(0.6143, 0.3143)	(0.6143, 0.3000)
L2	(0.6000, 0.3000)	(0.6000, 0.4000)	(0.6000, 0.3000)	(0.7000, 0.2000)	(0.7000, 0.3000)	(0.7000, 0.3000)	(0.7000, 0.3000)
L1	(0.5000, 0.5000)	(0.4000, 0.6000)	(0.5000, 0.5000)	(0.5000, 0.4000)	(0.5000, 0.5000)	(0.5000, 0.5000)	(0.5000, 0.5000)

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