

A STRUCTURED FRAMEWORK FOR SUSTAINABLE SUPPLIER SELECTION USING A COMBINED BWM-COCOSO MODEL

Sarfaraz HASHEMKHANI ZOLFANI^{1*}, Prasenjit CHATTERJEE², Morteza YAZDANI³

¹*School of Engineering, Catholic University of the North, Larrondo 1281, Coquimbo, Chile*

²*Department of Mechanical Engineering, MCKV Institute of Engineering, Howrah- 711024, West Bengal, India*

³*Department of Management, Universidad Loyola Andaluca, Seville-41014, Spain*

*E-mails: sa.hashemkhani@gmail.com; sarfaraz.hashemkhani@ucn.cl

Abstract. *Purpose* – sustainability in industrial organizations is becoming one of the predominant concepts in the context of modern industrialization due to global warming, economic significance, and social awareness. These have prompted a huge concern toward sustainable supply chain management (SSCM) to be adopted and promoted as an innovative business model. Supplier evaluation and selection play a significant role in SSCM for taking appropriate procurement decisions.

Research methodology – a hybrid MADM model based on Best Worst Method (BWM) and Combined Comprise Solution (CoCoSo) method.

Findings – a case study in the steel industry is presented to demonstrate the effectiveness of the proposed approach. The results show the potentiality of the proposed model in resolving complex sustainability issues in the SCM environment.

Research limitations – other weighting techniques like the analytic network process (ANP) and decision making trial and evaluation laboratory (DEMATEL) approaches can also be combined and performances can be compared.

Practical implications – the proposed model can be used by the organizations to select the most appropriate suppliers who contribute to the movement of the SC towards sustainability.

Originality/Value – a multi-criteria evaluation model has been proposed for solving a sustainable supplier selection problem while considering economic, environmental and social criteria simultaneously by integrating BWM-COCOSO methods.

Keywords: sustainability, Supply Chain Management (SCM), Sustainable Supply Chain Management (SSCM), Multiple Attribute Decision Making (MADM), Best Worst Method (BWM), Combined Compromise Solution (CoCoSo).

JEL Classification: Q01, Z21, C44.

Conference topic: Digitalization of Business Process: Trends, Challenges, Solutions.

Introduction

Sustainability in industrial organizations is becoming one of the predominant concepts and global themes in the 21st century due to changing environmental regulations, economic significance and social awareness. Recently, the conservation of the environment has become indispensable due to climate change, intensification in global warming, scarcity of natural resources and increasing population.

These have prompted public concern over sustainability and environmental issues. Such burning issues with legislation forces industrial organizations to decrease pollution during the whole production process. Hence, the practice of sustainable activities has become mandatory to balance these conflicts. To grow and preserve competitive advantages in the global market, organizations are shifting their focus on sustainable product development to satisfy the end users in terms of environmental requirements. In this context, sustainable supply chain management (SSCM) has become one of the important topics among practitioners and academic researchers (Azadnia, Saman, Wong, Ghadimi, & Zakuan, 2012). Supplier assessment, evaluation and selection play a significant role in SSCM for taking appropriate decisions. There is a vital need for systematic analysis of how specific green and sustainable variables develop in

and effect remained mostly overlooked. By integrating the three pillars of sustainability, namely environmental, economic and social dimensions, SSCM endeavors to minimize the adverse effects of SC operations on the environment. However, despite the increasing awareness, integrating sustainability in SCM strategies remains a challenge for many organizations due to the involvement and evaluation of a wide range of concerns. The suppliers' selection process frequently considers some archetypal factors like cost, product function, quality, performance and aesthetics, and customer satisfaction. Fewer attentions have been paid on the environmental and social impacts of the supplier selection process (Büyüközkan & Çifçi, 2011). Nowadays, the advancement in the supplier selection process has moved towards social and sustainable criteria. Even primarily the selection is the same for both sustainable and regular supplier selections, but the existence of a range of conflicting criteria makes the process reasonably multifaceted and protracted.

1. Literature review

Supply Chain Management (SCM) used to be just a framework which focuses on cost, time and quality, but, nowadays, sustainability approach with three main dimensions (Economic, Social, and Environment) has been developing in different fields included SCM field (Zhu, Sarkis, & Lai, 2008). Applying sustainability concept (Economic, Social, and Environment) in the process of supply chain created a new approach which is named Sustainable Supply Chain Management. This new approach suggested improving outcomes of a supply chain in different aspects of sustainability. Meanwhile, this approach is useful in the highest level of the global supply chain because is related to the policy-making level (Koberg & Longoni, 2019). One of the main challenges between Green SCM and SSCM frameworks is driving forces. Probably, a small size company is not a big player of the industry so there is no need to be a part of the sustainability path so just regulators can motivate or forced all companies to be more sustainable. Indeed, companies can play their role by being a green producer or manufacturer. Eventually, SSCM is a deep concept which needs several prerequisites (Yazdani, Chatterjee, Zavadskas, & Hashemkhani Zolfani, 2017).

Seuring (2013) reviewed modeling approaches for the Sustainable Supply Chain Management and illustrated Life Cycle Assessment (LCA) models, Equilibrium models and Multiple Criteria Decision Making (MCDM) were main modeling techniques. MCDM models and methods have been developing in evaluating and assessing related issues to SSCM.

Poh and Liang (2017) applied MCDM as a decision support system in the SSCM field and for the fashion industry. As MCDM methods, AHP and ANP both applied in that study. Kafa, Hani, and El Mhamedi (2018) selected and evaluated partners in terms of sustainable supply chain network. In this study, different MCDM methods such as AHP, Preference Ranking Organization Method for Enrichment of Evaluations (PROMETHEE) and TOPSIS as a hybrid model applied by the authors.

R. Grover, R. Grover, Balaji Rao, and Kejriwal (2016) applied AHP and TOPSIS methods in supplier selection based on sustainable criteria (Economic, Social, and Environment). Torkabadi, Pourjavad, and Mayorga (2018) worked on improvements related to the sustainable consumption and production trends in the field of SSCM based on the Fuzzy ANP method. Mohammad, Harris, and Govindan (2019) investigated on a new hybrid model for supplier selection problem and order allocation. In this study Fuzzy AHP, Fuzzy ANP and Fuzzy Multi-Objective Optimization (FMOO) combined as a new hybrid model. Rostamzadeh, Keshavarz Ghorabae, Govindan, Esmaeili, and Bodaghi Khajeh Nobar (2018) applied fuzzy TOPSIS-CRITIC approach in evaluating SSC risk management. Badri Ahmadi, Kusi-Sarpong, and Rezaei (2017) worked on a new topic about the social sustainability of SC based on using a new MCDM method which is called BWM.

Some other related studies which are deeper in the field can be reviewed. Osiro, Lima-Junior, and Ribeiro Carpinetti (2018) focused on selecting supply chain sustainability metrics based on MCDM, Quality Function Deployment (QFD) and Hesitant fuzzy linguistic terms. Su et al. (2016) proposed a new novel model based on hierarchical grey- DEcision Making Trial and Evaluation Laboratory (DEMATEL) approach for improving the process of SSCM. Wan Ahmad, Rezaei, Sadaghiani, and Tavasszy (2017) evaluated external forces that have influences on the SSCM system of oil and gas industry based on the BWM method and its evaluation.

Table 1 indicates that the criteria for selecting sustainable suppliers can be grouped into three major criteria levels. The economic sustainability level signifies premeditated designs that can avoid the requirements of major future refurbishments and thus helps the organizations to reduce costs for energy, water, and maintenance. Environmental sustainability is intended to reduce greenhouse emissions, proper utilization of water and energy along, Environmental management system, use of green technologies, reduced waste. Social sustainability basically human rights, labor relations, employee education, workplace safety and health, rights of stakeholders, etc.

2. Methodologies

2.1. Best Worst method

Best-Worst Method (BWM) has recently been introduced by Rezaei (2015) to reduce the inconsistencies involved in elicitation of criteria weights by trimming down the requirements of huge pairwise comparisons among criteria, as

frequently encountered in Analytic Hierarchy Process (AHP) and Analytic Network Process (ANP) methods-based computations. This method includes solving a linear model (LM) to estimate the weights from the comparisons. The

Table 1. Sustainable supplier selection criteria (source: composed by authors)

Major criteria	Sub-criteria	Definitions	References
Economic	Cost/price	The final cost to purchase a unit of raw or semi-finished products	Azadnia et al. (2012); Büyüközkan and Çifçi (2011); Amindoust, Ahmed, Saghafinia, and Bahreininejad (2012); Kuo, Wang, and Tien (2010); Sarkis and Dhavale (2015)
	Quality	The performance of materials purchased to meet or exceed the requirements and expectations in service or product that were committed to	Amindoust et al. (2012); Azadnia et al. (2012); Büyüközkan and Çifçi (2011); Keskin, İlhan, and Özkan (2010); Sarkis and Dhavale (2015)
	Production capacity	The ability of human, financial, and material resources that is related to product manufacturing	Büyüközkan and Çifçi (2011); Lee, Kang, Hsu, and Hung (2009)
	Financial capability	The capital needed to maintain normal business activities for an enterprise during a certain period of time	Büyüközkan and Çifçi (2011); Amindoust et al. (2012)
	Delivery commitment	The capability of transporting goods from a source location to a predefined destination	Amindoust et al. (2012); Azadnia et al. (2012); Büyüközkan and Çifçi (2011); Keskin et al. (2010); Kuo et al. (2010); Sarkis and Dhavale, 2015)
Social	Health and Safety	Concerned with the safety, health, and welfare of people at work	Amindoust et al. (2012); Azadnia et al. (2012); Luthra, Govindan, Kannan, Mangla, and Garg (2016)
	Human rights issues	A group of legal rights and claimed human rights having to do with labor relations between workers and their employers	Amindoust et al. (2012); Kuo et al. (2010)
	Corporate social responsibility	Charity and welfare services to local communities	Büyüközkan and Çifçi (2011); Sarkis and Dhavale (2015); Amindoust et al. (2012); Kuo et al. (2010)
Environment	Environmental management system	A system that comprehensively evaluates the internal and external environmental performance of an organization	Büyüközkan and Çifçi (2011); Amindoust et al. (2012); Azadnia et al. (2012)
	Pollution and waste control management	The control of pollutants that are released into air, water, or soil	Amindoust et al. (2012); Sarkis and Dhavale (2015)
	Reverse Logistic system		Amindoust et al. (2012); Kuo et al. (2010)
	Resource and energy consumption	The use of non-renewable, or less often, renewable resources	Amindoust et al. (2012); Sarkis and Dhavale (2015)
	Green technology innovation	The ability to continuously update environmental technologies to achieve the goal of minimizing the sum of product life cycle costs	Awasthi, Chauhan, & Goyal (2010); Chiou, Hsu, and Hwang (2008); Yeh and Chuang (2011)

applications of BWM has seen a drastic growth in different areas including supplier selection and development (Rezaei, van Roekel, & Tavasszy, 2018); complex bundling configurations (Rezaei, Hemmes, & Tavasszy, 2017); urban sewage sludge (Ren, Liang, & Chan, 2017); social sustainability of SCs (Badri Ahmadi et al., 2017); logistics performance evaluation (Rezaei et al., 2018); cloud service selection (Nawaz et al., 2018); and evaluation of sustainable design for household furnishing materials (Hashemkhani Zolfani & Chatterjee, 2019).

The basic steps of BWM method are as follows (Rezaei, 2015, 2016):

Step 1: Selecting and identifying criteria in a common way; literature review, expert ideas, and other probable ways.

Step 2: Identifying and selecting the best and worst criteria and as it an expert based method should be done based on experts' ideas and decisions.

Step 3: Designing the preferences matrix based on comparing the best criterion over all others by applying for numbers between 1 and 9.

$$A_b = (a_{1B}, a_{2B}, a_{3B}, \dots, a_{nB}). \quad (1)$$

Step 4: Designing the preferences matrix based on comparing the worst criterion over all others by applying for numbers between 1 and 9.

$$A_w = (a_{1W}, a_{2W}, a_{3W}, \dots, a_{nW}). \quad (2)$$

Step 5: Relative importance of criteria through calculating the final and optimal weights for the criteria. The weights will show the same as:

$$\text{Min max}_j \left\{ \left| (w_B / w_j) - a_{Bj} \right|, \left| (w_j / w_w) - a_{jw} \right| \right\}. \quad (3)$$

Subject to $\sum_j w_j = 1$

where $w_j \geq 0$ for all values of j .

Eventually, consistency calculations will be the last step. The same as AHP there is a consistency index which is shown in Table 2. Consistency ratio should be calculated as follow:

$$\text{Consistency..ratio} = \frac{\xi}{\text{Consistency.index}} \quad (4)$$

Table 2. Consistency Index table for BWM method

abw	1	2	3	4	5	6	7	8	9
Consistency index (max ξ)	0.00	0.44	1.00	1.63	2.30	3.00	3.73	4.47	5.23

2.2. Combined Compromise Solution (CoCoSo) method

Combined Compromise Solution (CoCoSo) method (Yazdani, Zarate, Zavadskas, & Turskis, 2018) is based on the integration of two most popular MCDM methods namely Simple Additive Weighting (SAW) and Exponentially Weighted Product (MEP). The CoCoSo method consists of the following three easy steps and it is implemented after obtaining the criteria weights through the application of the CRITIC method.

Step 1: Estimation of the sum of weighted comparability (S_i) sequence and power-weighted comparability sequences (P_i) for each alternative respectively:

$$S_i = \sum_{j=1}^n (w_j r_{ij}). \quad (5)$$

$$P_i = \sum_{j=1}^n (r_{ij})^{w_j} \quad (6)$$

Step 2: Computation of relative weights of the alternatives:

In this step, three aggregated appraisal scores are used to generate relative performance scores of the alternatives, using the following equations:

$$a) \quad k_{ia} = \frac{P_i + S_i}{\sum_{i=1}^m (P_i + S_i)}; \quad (7)$$

$$b) \quad k_{ib} = \frac{S_i}{\min_i S_i} + \frac{P_i}{\min_i P_i}; \quad (8)$$

$$c) \quad k_{ic} = \frac{\lambda(S_i) + (1-\lambda)(P_i)}{(\lambda \max_i S_i + (1-\lambda) \max_i P_i)}; \quad 0 \leq \lambda \leq 1. \quad (9)$$

Eqn. (7) basically expresses the arithmetic mean of sums of WSM and WPM scores, while Eqn. (8) signifies the sum of relative scores of WSM and WPM compared to the best alternative. Finally, Eqn. (9) computes a balanced compromise score of WSM and WPM models. In Eqn. (9), the value of λ (usually the threshold $\lambda = 0.5$) ranges from 0 to 1 and is chosen by the decision-maker.

Step 3: The final ranking of the alternatives is determined based on k_i values:

Higher k_i values indicate a better position of the alternatives in the ranking pre-order.

$$k_i = (k_{ia} k_{ib} k_{ic})^{\frac{1}{3}} + \frac{1}{3} (k_{ia} + k_{ib} + k_{ic}). \quad (10)$$

3. Case study

In order to reveal the potentiality of the proposed model, a supplier selection case study for Steel Alborz Company in Iran has been considered. The company is one of the most reputed companies in the Middle East with stainless steel export collaboration in more than 40 countries. In this section, BWM has been primarily applied for evaluating the relative importance of the criteria. Seven evaluation criteria and six alternative suppliers have been considered for this case study, as exhibited in Table 3. For this example, quality adoption (C_1) is the most important criterion, whereas, employee education (C_7) is the least important criterion.

Table 3. Decision matrix for sustainable supplier selection (source: composed by authors)

Supplier	Price	Quality	Energy consumption	Green design	Delivery speed	CSR	Employee education
S ₁	10	8	8	10	2	0.7	8
S ₂	4	2	6	8	2	0.75	6
S ₃	1	1	8	6	2	0.65	6
S ₄	10	10	8	10	8	0.85	8
S ₅	2	4	6	6	2	0.75	6
S ₆	10	6	8	8	8	0.85	8

Now, while applying the BWM, the best criterion (C_1) and the worst criterion (C_6) are first identified and then preferences of the best criterion over other criteria along with preferences of other criteria over the worst criterion are designated using a 1–9 scale, as shown in Tables 4 and 5, respectively.

Table 4. Preferences of the best criterion over other criteria (source: composed by authors)

Comparison	C ₁	C ₂	C ₃	C ₄	C ₅	C ₆	C ₇
Best to others (Best criterion: C ₁)	3	1	5	4	6	5	7

Table 5. Preferences of the worst criterion over other criteria (source: composed by authors)

Comparison	C ₁	C ₂	C ₃	C ₄	C ₅	C ₆	C ₇
Worst to others (Worst criterion: C ₆)	6	4	4	5	4	3	6

Next, using Eqn. (3), the optimal weights of the seven considered sustainable supplier selection criteria are obtained, as given in Table 4. The mathematical model of Eqn. (3) is solved using BWM EXCEL SOLVER which is an optimization tool. Moreover, using Eqn. (4), the consistency ratio is calculated as 0.2788 which refers to very consistent comparisons (Table 6).

Table 6. Criteria weights as determined using BWM (source: composed by authors)

Criteria	C ₁	C ₂	C ₃	C ₄	C ₅	C ₆	C ₇
Weight	0.1859	0.2788	0.1115	0.1394	0.0929	0.1115	0.0796
Ksi*	0.2788						

The next step to solve this sustainable supplier selection problem is to follow the mathematical steps of CoCoSo method, as described in Section 3.2. At first, the sum of the weighted comparability sequence (S_i) and the power weight of comparability sequences (P_i) are computed using Eqns. (7) and (8) respectively, as exhibited in Table 7. As stated earlier, for the CoCoSo method, different ranking scores are computed and ultimately an accumulated index produces a ranking of the alternative sustainable suppliers. Those formulas are introduced through Eqns. (7)–(9) respectively and the results are also shown in Table 7. Finally, Eqn. (10) gives the total preorder of the alternative suppliers based on the calculated values of k_i ,

Table 7. Calculated score values in CoCoSo method (source: authors' calculations)

Supplier	S_i	P_i	k_{ia}	k_{ib}	k_{ic}	k	Rank
S ₁	3.4209	4.0808	0.1426	3.5671	0.6463	2.1421	4
S ₂	4.6326	6.0653	0.2119	6.1541	0.9605	3.5202	2
S ₃	4.8197	6.1626	0.2153	6.0401	0.9760	3.4932	3
S ₄	1.7568	2.1641	0.0756	2.0000	0.3427	1.1790	6
S ₅	4.6912	6.1858	0.2162	6.3396	0.9796	3.6149	1
S ₆	3.3653	3.9585	0.1383	3.3719	0.6269	2.0428	5

Table 8. Calculated score values in CoCoSo method (source: authors' calculations)

Supplier	$\lambda = 0$	$\lambda = 0.1$	$\lambda = 0.2$	$\lambda = 0.3$	$\lambda = 0.4$	$\lambda = 0.5$	$\lambda = 0.6$	$\lambda = 0.7$	$\lambda = 0.8$	$\lambda = 0.9$	$\lambda = 1.0$
S ₁	4	4	4	4	4	4	4	4	4	4	4
S ₂	2	2	2	2	2	2	2	2	2	2	2
S ₃	3	3	3	3	3	3	3	3	3	3	3
S ₄	6	6	6	6	6	6	6	6	6	6	6
S ₅	1	1	1	1	1	1	1	1	1	1	1
S ₆	5	5	5	5	5	5	5	5	5	5	5

From the ranking preorder, as obtained according to the descending order of the k values (Table 5), it is observed that supplier 5 (S₅) is the most favorite candidate while S₄ (supplier 4) is the worst one among others. Table 8 shows the sensitivity analysis based on the varying λ values in a range of 0 to 1. From this table, it is clearly seen that for the entire range of λ values, there is no change in the position of any alternatives and S₅ remains the best one throughout the analysis, thus establishing its superior performance and acceptance over other alternatives.

Based on sensitivity analysis, it can be seen the final ranking and answer is reliable and robust.

Conclusions

Sustainability became a new area in different fields. SCM as one of the most important topics of Industrial Engineering field is totally related because of many topics such as Carbon Footprint. As mentioned in the literature Sustainability is a new trend in the SCM field and it can be predicted as the most important and key issue in the future of the field. Supplier selection and specially selecting the most sustainable one is an important title in SCM. The MADM field has been developing this area since many years ago and used to be always a suitable tool and approach for solving this real

problem of the industry. In this study, a new brand hybrid MADM model proposed and presented which can be considered as an exceptional contribution of the research.

This paper presents a simple evaluation of a new hybrid novel MADM model encompassing BWM and CoCoSo methods for the selection of sustainable suppliers. This integrated application is presented a new hybrid MADM model for the first time and is based on a straight forward analysis that engages very few mathematical calculations. A sensitivity analysis has shown to confirm the robustness of the ranking results. This study can be extended for similar exercises in different segments too. This new hybrid model can be applied and developed in other decision-making problems and fields. In the future and further studies, this new hybrid model can be compared with other older hybrid MADM models to check which one is more robust.

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