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Implementation of Effective Supply Chain Management Practice in the National Oil Corporation in Developing Country: An Integrated BWM-AROMAN approach

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ABSTRACT

This study introduces an approach to assess the adoption of an effective supply chain management practice (SCMP) in the petroleum sector, a vital component of any country's economy. Enhancing the sector's performance requires an effective implementation of the SCMP to address performance-related issues in a sustainable manner. For that, the best-worst method (BWM) determined the weights of four identified challenges to effective SCMP in the sector and subsequently, the alternative ranking order method accounting for two-step normalization (AROMAN) evaluated four alternatives to overcome these challenges. To show the applicability of our approach, the national oil corporation in Kenya is considered as case study. Results show that collaboration between supply chain actors for the provision of transport and distribution is the most appropriate alternative for an effective SCMP for the national oil corporation.

1. Introduction

The global oil and gas industry, operating through a complex network that spans the globe, has a significant impact on our daily lives [1]. This network includes a supply chain (SC) that extends across multiple countries, playing a critical role in transporting crude oil from wells to refineries and delivering finished products to customers. Disruptions in this SC can have serious consequences. Supply chain systems (SCS) within this industry involve concerted relationships among different SC levels, with organizations sharing practices to ensure smooth operations. Before implementing supply chain management (SCM), companies must first demonstrate supply chain orientation (SCO),

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which focuses on individual firms' ability to collaborate effectively within the SC [2]. To evaluate the efficiency of SCS, companies require performance metrics [3]. Munir et al. [4] argued that both cost and service leadership must be reached within a company for an efficient SC. However, most performance metrics in this company focus on internal aspects and do not fully consider how the company can enhance profitability, highlighting a gap in measuring efficiency [5].

The oil industry confronts growth challenges from regulations, political threats, and competition [6]. Intense competition for resources has pushed many companies to explore and produce in harsh, in costly environments [7]. Despite continuing discoveries of oil reserves, efficiently bringing them into production and delivering products at a minimal cost remains a key hurdle [8]. A robust supply chain management program is crucial for tackling this challenge [9].

Managing SC issues is a major issue in Kenya's oil industry. Kimani [10] emphasized the challenge of managing SCS, particularly in providing timely and satisfactory service to customers. Persistent oil scarcity prompted Osoro [3] to outline the problems impacting SCS's performance in Kenya's petroleum industry. Luthra et al. [11] noted that current research falls short of meeting the needs of oil companies. Agami et al. [12] highlighted inaccuracies in previous experimental findings on SCS performance metrics. Alquist et al. [13] criticized the focus on financial measures, suggesting a need for broader performance analysis. Despite this, Kenya lacks sufficient research on managing challenges that affect the SCS performance. Bartlomiejczuk [14] highlighted the petroleum industry as one of the world's complicated sectors, influencing daily life through services. This underscores the importance of petroleum products to economies. Diesel and gasoline power most road transport, while oil plays a significant role in power generation, accounting for a considerable portion of Africa's electricity production [15]. Understanding the reasons for inadequate performance in the petroleum industry, leading to fuel scarcity, is crucial for Kenya's energy sector. This study aims to do so.

The motivation of our study is as follows. Various methods are used to evaluate criteria weight based on decision makers' subjective point of views. The Level Based Weight Assessment (LBWA) reduces the need for extensive pairwise comparisons, remains manageable with numerous criteria, and allows for flexible expression of preferences [16]. The FUll Consistency Method (FUCOM) effectively minimizes redundancy in comparisons but lacks validation studies [17]. BWM, needs less data and offers better consistency in pairwise comparisons, making it more efficient [18]. However, there's a research gap in its application to assess challenges in petroleum sector SCMP effectiveness. Various methods exist for ranking alternatives. For example, Pamučar and Ćirović [19] introduced the Multi-Attributive Border Approximation Area Comparison (MABAC), known for consistent outcomes and simplicity. The Measurement of Alternatives and Ranking according to the COmpromise Solution (MARCOS) technique introduced by Stević et al. [20] ranks options as a compromise solution, remaining robust with changing attribute scales. The Multi Attributive Ideal-Real Comparative Analysis (MAIRCA) offers a stable solution with linear normalization, known for accuracy [21]. The Alternative Ranking Order Method Accounting for Two-Step Normalization (AROMAN) developed by Bošković et al. [22], excels in both quantitative and qualitative assessment, integrating dual normalization procedures and a straightforward ranking approach. For this reason, AROMAN approach is used in our study to rank alternatives that can overcome the challenges in petroleum sector SCMP effectiveness.

The contribution of this study is the introduction for the first time in literature of a new integrated methodology consisting of BWM and AROMAN techniques to assess the challenges to the petroleum sector SCMP effectiveness and rank alternatives to overcome these challenges, with National oil corporation in Kenya as case study.

2. Literature

Different approaches have been applied in studies to explore different facets of petroleum industry, especially SCM. For instance, Kumar and Barua [23] used AHP and VIKOR approaches with R programming to arrange green practices, identifying investment in renewables, risk prevention for environmental accidents, and tackling oil and methane leaks as top priorities. Fazli et al. [24] pinpointed major risks in the crude oil supply chain, employing DEMATEL to assess their relationships and ANP to evaluate importance and recommend response strategies. They emphasized regulatory and environmental risks as pivotal and endorsed a transference and cooperation policy as the optimal response. Ahmad et al. [25] evaluated the significance of external influences on sustainable supply chain management (SSCM) in the oil and gas sector. Through the BWM approach, they scrutinized data to determine the combined importance of these influences. Their results highlight economic and political stability as the foremost factors. Karbassi Yazdi et al. [26] used MCDM to identify SCM contracts in the oil and gas industry, tackling uncertainty. Gardas et al. [27] pinpointed and examined how determinants of SSCM impact the operational and business performance (OPR) of a specific supply chain in the Indian setting. Kumar and Barua [28] used MCDM methods to pinpoint key risk factors and their connections across the petroleum industry sectors. Kumar and Barua [29] assessed supply chain challenges within the petroleum industry and created a model to analyze these challenges from both company and consumer viewpoints. Nasri et al. [30] introduced an innovative approach to address sustainable supplier selection by integrating various MCDM methods, and the Anderson-Peterson rating model. Gidiagba et al. [31] crafted a holistic solution model using integrated MCDM, offering an alternative approach for supplier selection in the oil and gas industry. Wang et al. [32] introduced an innovative decision-support framework for planning and managing the bioethanol supply chain network amidst uncertainties. Ransikarbum et al. [33] integrated various MCDM methods to assess sourcing decisions in a hydrogen supply chain within a Thai case study, employing group decision-making analysis for policy insights. Studies on the petroleum industry in Africa has been carried out in countries such as Ivory Coast [34] and Algeria [35], as well as at regional levels in West Africa [36], and sub-Saharan African [37]. Despite these endeavors, only a small group of researchers have endeavored to tackle the challenges associated with SCM in Africa's petroleum sector [38-40].

To surpass the shortcomings of prior studies, it is essential to take a managerial approach that explicitly considers various criteria. This approach should involve a thorough identification of challenges hindering effective SCMP in the petroleum industry, along with an exploration of strategies to overcome these challenges, aiming for more effective decision-making outcome [41-46]. MCDM techniques, renowned for their capacity to handle intricate issues and integrate various criteria, are ideally suited for this undertaking [47-49].

3. Methodology

Two sub-sections are presented bellows.

3.1 Best Worst Method

BWM, introduced by Rezaei [18], has gained popularity among scholars for its efficiency in requiring fewer pairwise comparisons and its ability to handle inconsistencies promptly. BWM and its extensions have proven effective in diverse fields as can be seen in Table 1.

The method is widely used in sustainability research due to its high precision and dependability [54, 55]. The following section outlines its steps.

Step 1. Identification and definition of criteria as C_1, C_2,…., C_n by experts (Es).

Step 2. Identification of best and worst criteria by Es.

Step 3. Pairwise assessment by Es to assess the choice of most significant criterion over other criteria via a 9-point rate. The presentation of comparison results is shown as $A_B = (a_{B1}, a_{B2}, \ldots\ldots a_{Bn})$ where a_{Bj} is the choice of the most important criterion B over the criterion j and $a_{BB} = 1$.

Step 4. Performance of pairwise comparison between the worst criterion and other criteria. The results of the comparison are shown as $A_W = (a_{1W}, a_{2W}, \ldots\ldots a_{Bn})^{\mathsf{T}}$

where a_{jw}-is the choice of the criterion j over the worst criterion W and a_{ww}=1.

Step 5. Calculation of optimal weights for all criteria (W_1^*, W_2^*,… W_n^*).

For each pair of $\frac{W_B}{W_j}$ and $\frac{W_j}{W_W}$, the requisite that $\frac{W_B}{W_j} = a_{Bj}$ and $\frac{W_j}{W_W}$=a_{jW} should be met by the optimal weight.

To ensure these equations are valid, the objective is to minimize the absolute maximum variation $\left|\frac{W_B}{W_j} - a_{Bj}\right|$ and $\left|\frac{W_j}{W_w} - a_{jW}\right|$ for all j. Moreover, considering the non-negativity constraint and the summation condition of weights, the formulation of the following problem is made:

$$\text{Min} \max_j \left\{ \left|\frac{W_B}{W_j} - a_{Bj}\right|, \left|\frac{W_j}{W_w} - a_{jW}\right| \right\} \tag{1}$$

s.t:

$\sum_j W_j = 1, W_j \geq 0$ for all j

The model can be transformed as:

Minξ

s.t:

$$\left|\frac{W_B}{W_j} - a_{Bj}\right| \leq \xi, \text{ for all j}$$
$$\left|\frac{W_j}{W_w} - a_{jw}\right| \leq \xi, \text{ for all j} \tag{2}$$
$$\sum_j W_j = 1,\ W_j \geq 0 \text{ for all j}$$

The Consistency ratio (CR) of BWM can be described by ξ^*, with its consistency index (CI) values calculated using Eq. (3).

Table 1
BWM related studies

Authors	Objective	Methodology
Bouraima et al. [50]	Wind energy deployment	BWM, SF-CRITIC-VIKOR
Torkayesh et al. [51]	healthcare sector assessment	BWM-LBWA-CoCoSo
Görçün and Doğan [52]	Mobile crane choice	BWM, CoCoSo
Stević et al. [53]	Roundabout establishment	R-BWM-CoCoSo
Torkayesh et al. [54]	Digital supplier selection	BWM, WASPAS
Hashemkhani Zolfani et al. [55]	Temporary hospital selection	CRITIC, CoCoSo
Our study	Effective supply chain management practices in petroleum sector	BWM, AROMAN

Table 2 displays the CI for BWM models with varying numbers of decision criteria [18].

$$\text{CR}=\frac{\xi^*}{CI} \tag{3}$$

CR with small value is preferred which showed adequate consistency

Table 2
Consistency indexes

a_{BW}	1	2	3	4	5	6	7	8	9
CI	0	0.44	1.00	1.63	2.30	3.00	3.73	4.47	5.23

3.2 AROMAN method

In the method, an adequate classification is made through the consideration of both the significance of criteria and their associated weights. Despite being relatively new, this method has attracted significant interest and has been applied in various contexts as can be seen in Table 3.

Table 3
AROMAN approach related studies

Authors	Goal	Methodology
Bošković et al. [22]	Electric vehicle selection issue	AROMAN
Alrasheedi et al. [56]	Durable wastewater treatment technology	IVIF-AROMAN
Pishahang et al. [57]	Wildfire risk evaluation	AROMAN
Nikolić et al. [58]	Postal network durability	IT2F-AROMAN
Čubranić-Dobrodolac et al. [59]	Professional driver choice	DEMATEL, F-AROMAN
Bošković et al. [60]	Cargo bike delivery scheme choice	AROMAN
Kara et al. [61]	Durable cities competitiveness	MEREC-AROMAN
Dobrodolac et al. [62]	Durable delivery model choice	AROMAN
Our study	Effective supply chain management practices in petroleum sector	BWM-AROMAN

Six steps have characterized this method as follows.

Step 1. Decision-matrix formulation Y_{mxn} with the input data y_{11},..., $y_{2j}, \dots, y_{mn}$ (Eq. 4).

$$Y = \begin{bmatrix} y_{11} & \cdots & y_{1j} & \cdots & y_{1n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ y_{21} & \cdots & y_{2j} & \cdots & y_{2n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ y_{m1} & \cdots & y_{mj} & \cdots & y_{mn} \end{bmatrix}, i = 1,2, \dots, m, j = 1,2, \dots, \text{n}. \tag{4}$$

Step 2. After constructing the decision-making issue matrix, the normalization of data is made, which consists of linear (Eq. 5) and vector (Eq. 6) normalization to obtain aggregated normalized matrix (Eq. 7)

$$P_{ij} = \frac{y_{ij} - \min_i y_{ij}}{\max_i y_{ij} - \min_i y_{ij}}, i = 1, 2, \dots, m;\ j = 1,2, \dots, n. \tag{5}$$

$$P_{ij}^{*} = \frac{y_{ij}}{\sqrt{\sum_{i=1}^{m} y_{ij}^{2}}}; i = 1, 2, \dots, m, j = 1, 2, \dots, n. \tag{6}$$

$$P_{ij}^{norm} = \frac{\mu P_{ij} + (1-\mu) P_{ij}^{*}}{2}; i = 1,2, \dots, m;\ j = 1, 2, \dots, n. \tag{7}$$

where P_{ij}^{norm}- Aggregated averaged normalization; μ- Weighting factor changing from 0 to 1. μ =0.5 for our case.

Step 3. Calculation of this step via Eq. (8)

$$\widehat{P_{ij}} = W_{ij} \cdot P_{ij}^{norm}; i = 1,2, \dots, m;\ j = 1, 2, \dots, n. \tag{8}$$

Step 4. Calculation of sum normalized weighted values via (Eq. 9) and (Eq. 10), respectively

$$D_i = \sum_{j=1}^{n} \widehat{P_{ij}}^{(min)}; i = 1,2, \dots, m;\ j = 1, 2, \dots, n; \tag{9}$$

$$U_i = \sum_{j=1}^{n} \widehat{P_{ij}}^{(max)}; \; i = 1,2,\ldots,m; \; j = 1,2,\ldots,n. \tag{10}$$

Step 5. The sum of D_i and U_i values are raised to the δ and 1- δ levels, respectively.

$$D_i^{\wedge} = D_i^{\delta} = \left(\sum_{j=1}^{n} \widehat{P_{ij}}^{(min)}\right)^{\delta}; \tag{11}$$

$$U_i^{\wedge} = U_i^{1-\delta} = \left(\sum_{j=1}^{n} \widehat{P_{ij}}^{(max)}\right)^{1-\delta} \tag{12}$$

where: δ- coefficient level framed in [0,1]

Step 6. Computation of variation between $U_i^{\wedge}$ and $D_i^{\wedge}$ and application of the final ranking equation S_i bellows:

$$S_i = e^{(U_i^{\wedge} - D_i^{\wedge})} \tag{13}$$

4. Case study

In this study, four challenges in implementing effective SCMP in Kenya's petroleum industry are identified. These challenges include deficient information technology (C1), poor supply chain design (C2), people issue like dishonesty, distrust, and non-commitment (C3), and inadequate partnerships/collaboration (C4). Four strategies are suggested (Figure 1) to tackle these challenges.

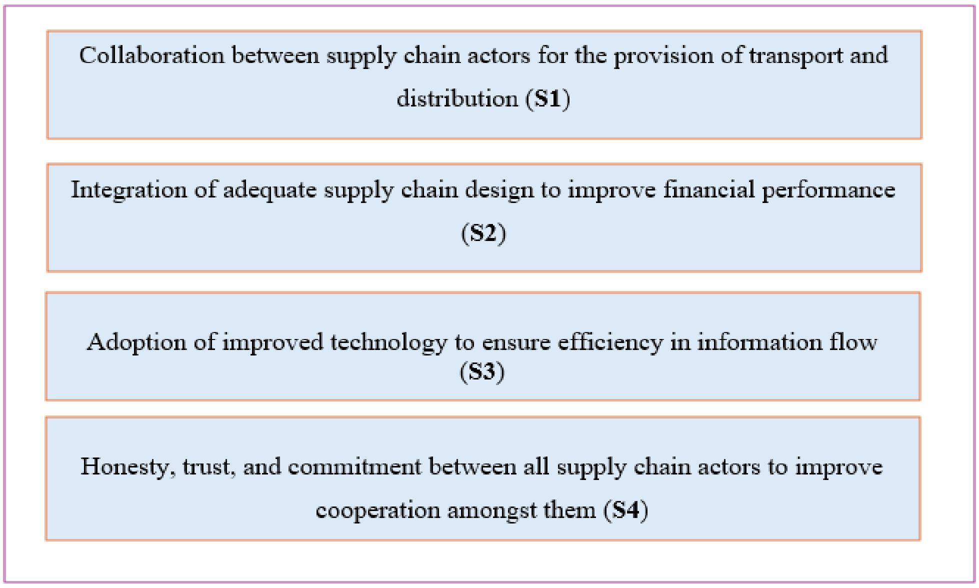

Fig.1. Strategies for effective SCMP in national oil corporation

4.1 Criteria weights

To determine criteria weights using BWM, three SCMP experts from Kenya's national oil corporation collaborate to assess the criteria importance, as shown in Table 4. Experts were chosen based on two key criteria: years of experience and level of education. Each expert possesses a minimum of ten years of experience and holds at least a master's degree.

Table 4
Criteria dataset

Criteria		C1	C2	C3	C4
E1	B	C4			
	W	C1			

E2	B	C4
	W	C1

E3	B	C3
	W	C1

Note: B-best; W-worst.

Tables A1 and A2 represent the best-to-others (BO) and others-to-worst (OW) vectors respectively are shown in appendix. Applying step 5, the criteria values are displayed in Table 5, and their classification are: C4 > C3 > C2 > C1.

Table 5
Criteria weights

	C1	C2	C3	C4
Criteria weights	0.093	0.150	0.348	0.409

4.2 Alternatives ranking

In this stage, using a scale from one to 7 points, the three expert's views are expressed in Table B in appendix. By employing the assessments outlined in Table B the input-data matrix is constructed (see Table 6).

Table 6
Original decision-making matrix

	C1	C2	C3	C4
S1	6.3333	6.3333	6.0000	5.6667
S2	5.3333	6.0000	5.3333	6.3333
S3	5.6667	5.6667	5.6667	6.6667
S4	6.3333	7.0000	6.0000	6.0000

After step 1, the input data is normalized. The resulting normalized values have been computed and are indicated in Tables C1 to C3 in appendix. Following that, the multiplication of the aggregated averaged normalized decision matrix by the values of criteria is set in Table 7.

Table 7
Aggregated average weighted normalized matrix

	C1	C2	C3	C4
S1	0.0357	0.0388	0.1310	0.0488
S2	0.0105	0.0283	0.0391	0.1227
S3	0.0189	0.0179	0.0851	0.1597
S4	0.0357	0.0596	0.1310	0.0858

With λ=0.2, the calculations for $\mathrm{L_i}$ and $\mathrm{A_i}$ values are carried out. The ultimate ranking is then computed, and Figure 2 and Table 8 showed the results. The obtained rank is S1 > S4 > S2 > S3. The first "S1-Collaboration between supply chain actors for provision of transport and distribution" alternative is seen to be the most appropriate strategy for effective SCMP in the national oil corporation Kenya, since it has scored the highest values, respectively.

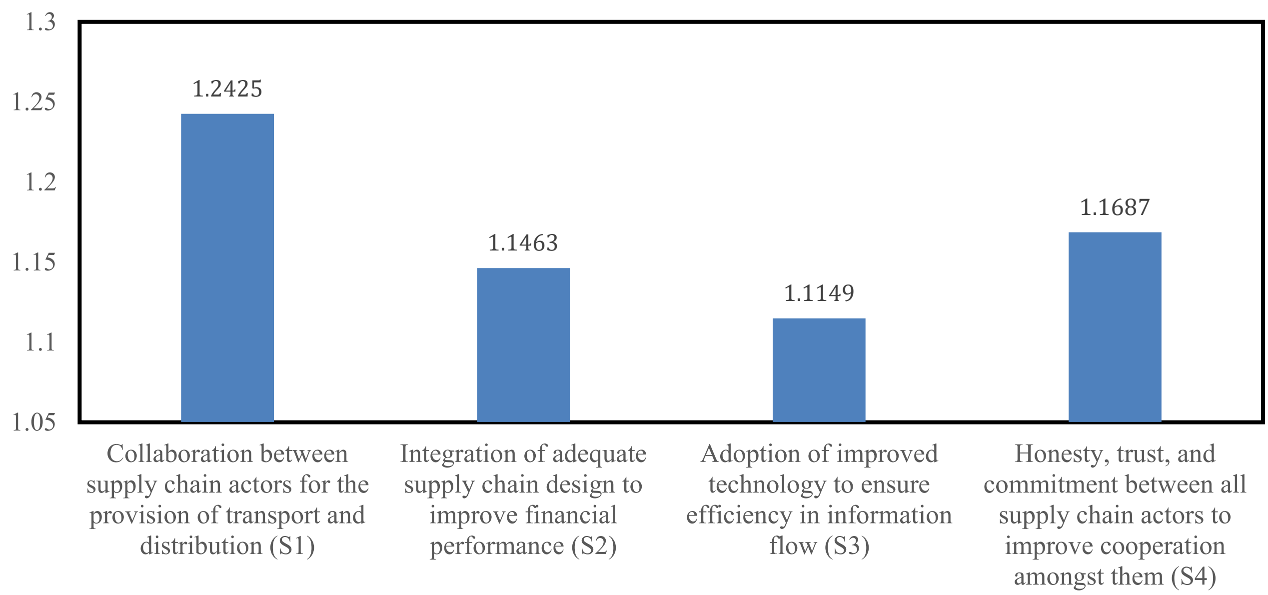

Fig. 2. Final rank of alternatives

Table 8
L_i and A_i values, differences, and final rank

L_i	A_i	A_i-L_i	Rank
0.5134	0.2963	0.2171	1
0.4016	0.2651	0.1366	4
0.4519	0.3432	0.1088	3
0.5134	0.3575	0.1559	2

5. Sensitivity Analysis

The sensitivity analysis is made via a variation of threshold value λ in [0, 1] range. The results are detailed in Table D in the appendix. Results indicated that the overall ranking of alternatives remains consistent. A graphical representation of alternative rankings is depicted in Figure 3.

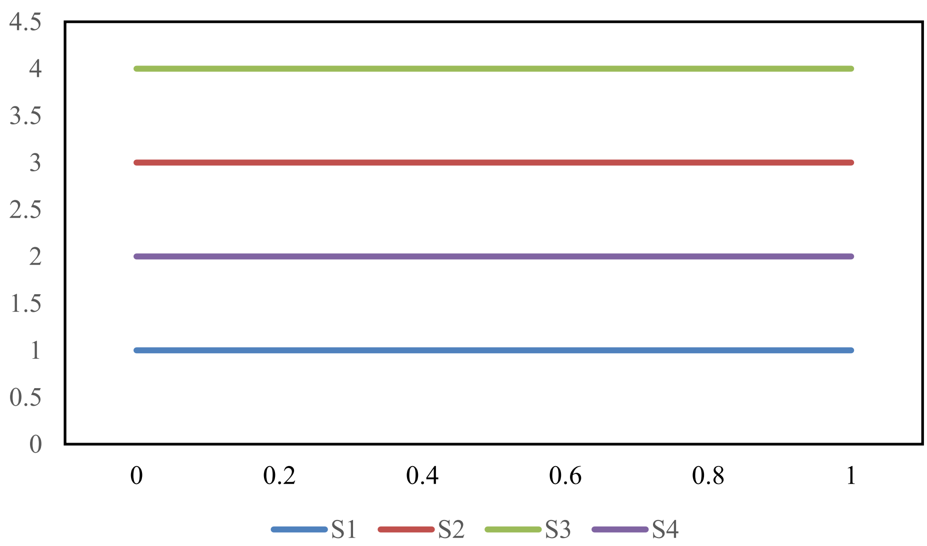

Fig. 3 Sensitivity analysis results

6. Findings and Discussion

This study is highly relevant to Kenya's national oil corporation, as it addresses the unique challenges that affect the efficiency of the SCMP in the sector. In this study, we used a new integrated method (BWM-AROMAN) to make decisions more accurately, especially when assessing critical challenges. This method also helped us improve normalization and sensitivity analysis. It fixed problems with traditional approaches and made expert opinions clearer and more homogeneous. The main challenge in the national oil corporation's SCM is inadequate partnerships and collaboration, aligning with Myers and Cheung [63] view that limited knowledge sharing among partners has more drawbacks than benefits. This raises concerns about sharing firms' strategies, which could be duplicated or shared with contestants, and about relying on external knowledge, which may reduce workability and increase vulnerability to variations in partners' priorities. Our methodology has determined that "collaboration between supply chain actors for the provision of transport and distribution (S1)" is the most appropriate option for our study. This selection is based on the premise that executives developing SC collaborations can reduce costs, enhance service, and obtain a competitive benefit. The strongest supply chains prioritize buyer-supplier relationships centered on delivering consistent value.

7. Conclusion

This study introduced a new approach for implementing effective SCM in Kenya's petroleum sector. It presented four alternatives for SCM and four criteria, offering a practical framework for policymakers in making decisions related to petroleum development. Unlike antecedent studies that relied on statistical methods, this study introduced an integrated MCDM model, which provided a straightforward methodological framework for solving real-life decision-making issues. The BWM approach is used to establish the subjective weights of challenges while the AROMAN technique is applied to rank the alternatives. Sensitivity analysis confirmed our approach stability.

Adopting improved technology is the least favorable option, and integrating adequate supply chain design is the second least favorable. Conversely, the study indicated that honesty, trust, and commitment among all supply chain actors are the second most favorable choice, while collaboration among supply chain actors is considered the most favorable alternative.

While our study has made significant contributions, there are some limitations. First, the data is gathered from a small number of experts. Future research should consider increasing this number with diverse backgrounds. Second, the study did not consider the government regulations impacts though the study. Future study should be considered it. Third, the study has been done at national level. It will be grateful if future studies could be made at regional level or continental level. Finally, the methodology used in this study is in crisp environment. Future studies should consider using this approach under q-Rung Orthopair fuzzy environment [64, 65], and polytopic fuzzy environment [67].

Appendix

Table A1
BO assessment

E1	B to O	C1	C2	C3	C4
	C4	5	3	2	1
E2	B to O	C1	C2	C3	C4
	C4	5	4	2	1
E3	B to O	C1	C2	C3	C4
	C3	6	4	1	2

Table A2
OW assessment

E1		E2		E3	
O to W	C1	O to W	C1	O to W	C1
C1	1	C1	1	C1	1
C2	3	C2	2	C2	2
C3	4	C3	3	C3	5
C4	5	C4	4	C4	3

Table B
Evaluation of Alternative

S1	C1	C2	C3	C4	S2	C1	C2	C3	C4
E1	7	7	7	6	E1	6	7	6	7
E2	5	7	7	7	E2	6	4	5	6
E3	7	5	4	4	E3	4	7	5	6
Average	6.3	6.3	6.0	5.7	Average	5.3	6.0	5.3	6.3
S3	C1	C2	C3	C4	S4	C1	C2	C3	C4
E1	6	7	6	7	E1	7	7	7	7
E2	6	6	6	7	E2	7	7	4	4
E3	5	4	5	6	E3	5	7	7	7
Average	5.7	5.7	5.7	6.7	Average	6.3	7.0	6.0	6.0

Table C1
Linear normalization of the initial decision-making matrix

	C1	C2	C3	C4
S1	1.0000	0.5000	1.0000	0.0000
S2	0.0000	0.2500	0.0000	0.6667
S3	0.3333	0.0000	0.5000	1.0000
S4	1.0000	1.0000	1.0000	0.3333

Table C2
Vector normalization of the initial decision-making matrix

	C1	C2	C3	C4
S1	0.5338	0.5338	0.5057	0.4776
S2	0.4495	0.5057	0.4495	0.5338
S3	0.4776	0.4776	0.4776	0.5619
S4	0.5338	0.5900	0.5057	0.5057

Table C3
Aggregate average normalization (β= 0.5)

	C1	C2	C3	C4
S1	0.3834	0.2584	0.3764	0.1194
S2	0.1124	0.1889	0.1124	0.3001
S3	0.2027	0.1194	0.2444	0.3905
S4	0.3834	0.3975	0.3764	0.2098

Table D
Sensitivity Analysis Outcomes

λ	0	0.2	0.4	0.6	0.8	1
S1	2.2475	1.2425	0.8711	0.6643	0.5126	0.3812
S2	2.0994	1.1463	0.8121	0.6297	0.5008	0.3749
S3	2.0618	1.1149	0.7834	0.6105	0.4850	0.3717
S4	2.1845	1.1687	0.8198	0.6376	0.5008	0.3812

Conflicts of Interest

The authors declare no conflicts of interest.

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