# A Comprehensive Evaluation Framework for Assessing Vaccine Supply Chain Performance Using Real Time Data

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## Abstract

This study proposes a quantitative evaluation model for comparative analysis of vaccine supply chain (VSC) performance while considering multiple regions input real time data that is both subjective as well as objective in nature. Performance indicators (PIs), capable of taking subjective as well as objective inputs, are constructed to capture the VSC development status and categorized under different objectives. A combination of CRITIC and VIKOR method are used to define weights of the performance criteria and rank the alternatives regions respectively, while analysing objective and subjective weights. Whereas, the spherical fuzzy extension of CRITIC and VIKOR method was used to interpret the subjective performance information provided the VSC managers at the respective region. The ranks obtained are then compared for each region to identify the regions observing conflicting narratives based on objective and subjective information. Also, further investigation of VSC in such regions can highlight reasons responsible for conflicting narratives.

## Keywords:
Vaccine supply chain, Evaluation framework, Spherical fuzzy set, CRITIC, VIKOR

## Introduction

Vaccines prevent the spread of disease causing viruses, thereby reducing healthcare cost, unprecedented loss of lives, disabilities and stunted growth in children (Lewis et al. 2008). Vaccines are perishable in nature and experience loss in efficacy if not stored/transported in the prescribed environment thereafter causing direct impact on health and well-being of beneficiaries receiving it (WHO 2018). Hence, delivery of these vaccines to the beneficiaries through immunization programs is achieved through a complex and critical supply chain whose efficiency ensures equitable vaccination coverage. There are several dimensions of a vaccine supply chain (VSC) and monitoring their performance through adequate performance indicators (PIs) helps in maintaining the required efficiency (Chandra and Kumar 2019). Also, a comparative analysis of VSC performance in different geographical alternatives helps in achieving the best overall outcome, for a given amount of resources, by identifying reasons of outperformance for some regions and pinpointing areas of concern for regions that are not performing well on a relative scale.

The issues associated to VSC like vaccine storage and distribution, demand forecasting, vaccine wastage, managing vaccine stocks, creating vaccine awareness, human resource management and training, immunization financing, community engagement and associated costs are all dynamic in nature and interrelated. Many of these issues along with several other related issues have been clustered into broad dimensions and correlation between them is studied using empirical techniques (Chandra and Kumar 2019; 2021; Alam at al. 2021; Haidri et al. 2017). VSC managers, researchers and policy makers continuously strive to come up with solutins to deal with these issues. The insights obtained from these solutions are then utilized for strategic planning of ways to address these issues which would eventually lead to improvement of VSC performance. In order to assess the effectiveness of a solution in managing VSC isues, it is critical to identify the key PIs and observe an improvement or deterioration in them. For example if PIs associated to vaccine wastage are observing relatively good scores, that indicates measures taken to mitigate vaccine wastage are effective. The introduction of technology based solution namely electronic vaccine intelligence (eVIN) system in certain Indian states proved to be effective improving VSC performance by observing improvement in PI like vaccine wastage and vaccine stockout that reduced by around 80% (Gurnani et al. 2022).

PIs can take subjective or objective responses. Generally objective PIs whose responses are deterministic in nature and involve no hesitancy are used to judge the effectiveness of a solution. Whereas objective PIs do not necessarily capture the actual scenario. For example, it is observed that wastage of vaccine doses at some center is reported to be negative which indicates that number of people vaccinated is more than the number of vaccine doses allocated to that center. But while calculating the cumulative vaccine wastage for a region having multiple centers, which incorporates negative vaccine wastage at a couple of centers, these PIs fail to represent the actual picture. Hence, a more robust evaluation framework can be contructed by including subjective PIs that capture various dimensions of VSC while assessing its performance.

This paper proposes an evaluation framework for VSC performance in multiple geographical regions that includes a combination of spherical fuzzy set (SFS), CRITIC (criteria importance through inter-criteria correlation) and VIKOR (VIekriterijumsko KOmpromisno Rangiranje) method. SFS are used to capture the uncertainty and vagueness in subjective responses collected against the subjective PIs defined under the various VSC dimensions. CRITIC method is applied to get the weights for various PIs by including the correlation between the various PIs based on the objective data as well as crisp values corresponding to subjective data collected against them. There afterwith the help of VIKOR method, various geographical alternatives or regions are ranked separately based on their objective data inputs as well as crisp values corresponding to subjective data inputs. Performance scores (PS) under the various VSC dimensions are obtained in this process for all regions. These PS reflect the key VSC dimension contributing to a region's outperformance or underperformance on a relative scale. Also the regions that observe severe rank difference obtained corresponding to the subjective as well as objective data inputs are critical regions for which the objective and subjective PSs under various VSC dimensions are contrasted to pinpoint the VSC dimensions responsible for anomaly.

## 1.1 Objective

The research objective of this paper is to construct an evaluation index including objective as well subjective PIs under the various VSC dimensions and thereafter propose a theoretical framework that evaluates the VSC performance on a relative scale in various geographical alternatives or regions highlighting the following details:

1. weights for various PIs by including the objective data as well as crisp values corresponding to subjective data collected against them using the CRITIC method.
2. rank obtained for the various geographical alternatives using VIKOR and SF based VIKOR corresponding to both objective and subjective data respectively.
3. comparing the objective ranks with subjective ranks for a state to identify states with high variation and explore reasons for the variation using performance scores of dimensions.

Section 2 elaborates the literature supporting VSC performance evaluation based on live data and its application. Section 3 talks about the methodology with the mathematical formulation. Subsection 3.1 validates the methods with case studies of Ranchi district, which is situated in the eastern region of India. Section 4 discusses the result of mathematical operations. Finally, the conclusion of the research article is mentioned in section 5.

## Literature Review

VSC performance has been captured extensively in literature. Topics like issues (Chandra and Kumar 2018), challenges (Alam et al. 2021), barriers and enablers (Chandra et al. 2021) of VSC, prioritizing these issues, constructing PIs for various objectives of VSC performance (Chandra and Kumar 2021). Several other studies highlighted impact of isolated factors like strategic vaccine distribution, location of cold storage (Tavanna et al. 2021), demand and supply optimization (Doung et al. 2021) on VSC performance. None of these studies include an evaluation framework for assessing VSC performance in multiple regions and hence, this paper addresses this research gap. Zhao et al. (2020) have proposed an evaluation model for national electric power development based on subjective evaluation using the primary evaluation index and objective evaluation using PIs belonging to secondary evaluation index. In this study, instead of a multi-level evaluation index, single layered evaluation index is developed by constructing PIs for various VSC performance objectives which include objective as well as subjective responses. This improves robustness of the evaluation model by reducing complexity.

Weights can be assigned to various criteria during a decision making process using the two commonly used methods viz. ENTROPY and CRITIC. Inconsistency among the criteria and the internal correlation between them is overlooked while weight determination using the ENTROPY method (Huang et al. 2018). On the other hand, the variations observed for a criteria considering various alternatives and conflict of a criterion with other criteria are both taken into account by the modified version of the CRITIC method, improving its relevance and objectivity in determining criteria weights (Joosep et al. 2020). Hence, CRITIC method was adopted in our evaluation model for assigning weights to various PIs.

The weights of PIs determined by applying the CRTIC method is then used to rank the states. TOPSIS and VIKOR are widely used method for ranking the alternatives (Faith 2021). Yoon (1987), pointed out that although the TOPSIS method considers two 'reference' points (the positive and the negative ideal solution), it fails to consider the relative distances from these points. Hence, the best alternative based on the ranking index used in TOPSIS might not be the closest to the ideal solution. Opricovic (1988), proposed the VIKOR method based on Lp-metric to overcome the flaws of TOPSIS. The ranking index used in VIKOR is based on absolute closeness to the ideal solution and gives rational and compromise solutions. Hence, VIKOR method was adopted in our evaluation model for ranking the states.

## 3.Methodology

### 3.1 Evaluation Index

The list of PIs included under the various VSC performance objectives in the evaluation index, as mentioned in **Table 1**, are constructed on the basis of literature review (Chandra and Kumar 2021; Chandra and Kumar 2019; Gurnani et al. 2022; Gurd and Gao 2007; MHFW 2018) and field survey. The data for objective PIs will be collected from vaccination centers and responses for subjective PIs will be collected from some qualified personnel who is observing the vaccination process in the region defined as alternatives for performance evaluation.

**Table 1.** List of objective as well as subjective PIs for assessing VSC performance

| Objective | PIs with objective response | PIs with subjective response |
|---|---|---|
| Operating Cost | Storage Cost | How well was the storage cost managed? |
| | Procurement Cost | How well was the procurement cost managed? |
| | Manpower Cost | How well was the manpower cost managed? |
| | Transport Cost | How well was the transport cost managed? |
| Healthcare Financing | Budget allocated – budget demanded | How sufficient is the allocated budget? |
| Customer Satisfaction | Average distance travelled to a vaccine center in a region | How sufficient are the number of allocated |
| | Number of complaints registered | How successful are we in reducing the frequency of comlaints? |
| | Number of complaints addressed | How fine is the complaint adressal system? |
| | Number of beneficiaries turned away | How well is the vial size vs number of beneficiary available conundrum managed? |
| Effective Communication | Expenditure made on communicating vaccination related news and awareness message | How well was the awareness regarding vaccination drive comuunicated to the beneficiaries of deprived section? |

| | | |
|---|---|---|
| | Number of people who could successfully book vaccination slots and got reminder messages for vaccination | How well did the slot booking system work? |
| Supply and Demand | **Transport and storage capacity utilization** | **How well was the transport and storage capacity is managed?** |
| | **Demand forecast accuracy in percentage** | **How well were the demand forecasted in a period given the predictability of scenarios?** |
| | **Number of doses administered** | **How well was the vaccine demand managed in a period?** |
| | **Reduction in percentage of stockouts** | **How well were the vaccine stockouts managed?** |
| | **Percentage of vaccine shipments delivered on time** | **How well was the vaccine delivery system working?** |
| Resource utilization | Frequency of cold chain equipment failure | How well are the cold chain equipment failure handeled? |
| | Average utilization of storage/ transortation capacity | How well is the utilization of storage/ transortation capacity? |
| | Vaccine wastage | How well is the vaccine wastage managed? |
| Human Capital | Number of personnels who have undergone latest training module | How well is the training helping in improving employee productivity? |
| | Number of personel satisfied with the workplace health hazard management | How well are the employees protected against the occupational hazards associated to vaccination process? |
| | Number of personnels satisfied with the innumeration they recieve | How well are the healthcare workers paid as compared to the industry standards? |
| | Employee attrition rate | How well is the employee attrition rate being managed? |
| Information Capitol | Expenditure on incorporating new technology for information management | How well has the expenditure on information management technology improved the transparency and accuracy in data collection? |
| | Frequency of faulty/missing data entry reported | How well is the faulty/missing data entry |

Note: The case study included the current study only includes the highlighted PIs

**Spherical Fuzzy Sets**

Spherical Fuzzy Sets (SFSs) are an extension of ordinary fuzzy sets developed by (Kutlu and Kaharman 2019). SFSs captures the components of Neutrosophic Fuzzy Sets (NSs) (Samarandache 2003), and Pythagorean Fuzzy Sets (PFSs) (Yager 2013) and improves upon them by defining a membership ($\mu$), nonmembership ($v$) and hesitancy ($\pi$) factors of the broader membership function to lie on a spherical surface in a limiting manner. Hence, the condition $0 \leq \mu^2 + v^2 + \pi^2 \leq 1$ must hold true in the SFSs. SFSs enable a larger preference domain for decision-makers. This independently assigns the parameters in a larger domain area thereby offering a large predilection realm for decision makers. The functionality to define component of hesitancy for a region with respect to a criterion just like membership and non-membership functions by decision-makers is enabled in SFSs (Gul et al. 2020). SFSs is unique as it combines the positive sides of PFSs and NSs and eliminates their limitations (Kutlu and Kaharman 2019). SFS concept is applied to various multi criteria decision making problems effectively for representing vagueness through mathematical operations in recent years. Preliminaries of the SFSs that are relevant to this study are given in the following definitions (Kutlu and Kaharaman 2019):

Definition 1. A spherical fuzzy set $\tilde{A}_s$ of the universe of discourse U is given by

$$\tilde{A}_s = \{\langle u, (\mu_{\tilde{A}_S}(u), \vartheta_{\tilde{A}_S}(u), \pi_{\tilde{A}_S}(u)) \mid u \in U \rangle\} \quad (1)$$

where

$\mu_{\tilde{A}_S}: U \to [0,1], \vartheta_{\tilde{A}_S}: U \to [0,1], \pi_{\tilde{A}_S}: U \to [0,1]$ and

$$0 \leq \mu^2_{\tilde{A}_s} + \vartheta^2_{\tilde{A}_s} + \pi^2_{\tilde{A}_s} \leq 1 \; \forall u \in U \quad (2)$$

The responses to subjective PIs are collected in linguistic terms which are mentioned in **Table 2** along with the abriviations. The corresponding spherical fuzzy numbers are constructed as per equation (1) and (2) and is shown alongside the linguistic terms in **Table 2**.

**Table 2.** Adopted scale scale for SF-VIKOR and SF-CRITIC method (Erdogan et al., 2021).

| Linguistic term | Abbreviation | Corresponded SF number |
|---|---|---|
| Bad | Ba | (0.1, 0.9, 0.1) |
| Below Average | BAv | (0.25, 0.75, 0.15) |
| Average | Av | (0.5, 0.5, 0.25) |
| Above Average | AAv | (0.75, 0.25, 0.15) |
| Good | Go | (0.9, 0.1, 0.1) |

## CRITIC Method and its Spherical Fuzzy extension

After the data for objective and subjective PIs elaborated in **Table 1** for all the regions, following steps are followed to get the PIs weight for respective cases. Step 1 and 2 are used for data collected against subjective PIs whereas subsequent steps can be applied to both subjective as well as objective PIs.

Step 1: Construct the linguistic direct relation matrix $(M)_{i\times j}$, based on **Table 2** where $i$ represents the number of alternative regions with I as total number of alternatives and $j$ represents the PIs with J as the total number of alternatives. Thereafter convert the linguistic terms to their corresponding spherical fuzzy numbers based on **Table 2.**
Step 2: Convert the SFNs to the crisp values $(a)_{i\times j}$ belonging to $[A]$ matrix for the matrix calculations by using $\mathfrak{H}(I_A)$ function, whereas the $[A]$ matrix for objective PIs are obtained by just proper compilation of required objective data

$$\mathfrak{H}(I_A) = \frac{\mu_A^2 - v_A^2 - \frac{\pi_A^2}{2}}{2} \quad (4)$$

Step 3: Find out z-score normalized values of PI columns in $A$ matrix using corresponding column average $(\overline{a_j})$ and standard deviation $(\sigma_j)$ where $a_{ij}$.

$$z_{ij} = \frac{a_{ij} - \overline{a_j}}{\sigma_j} \quad (5)$$

Step 4: Independence coefficient of all PIs is calculated with the help of Pearson correlation coefficients ($r_{kl}$) (eq (6)) between PIs using normalized evaluation matrix from step 3 as per eq (7). The independence coefficient measures the degree of conflict between two PIs.

$$r_{kj} = \frac{\sum_{i=1}^{I}(z_{ik} - \overline{z_k})(z_{ij} - \overline{z_j})}{\sqrt{\sum_{i=1}^{I}(z_{ik} - \overline{z_k})^2}\sqrt{\sum_{i=1}^{I}(z_{ij} - \overline{z_j})^2}} \qquad (k = 1,2, \dots, J;\ j = 1,2, \dots, J) \qquad (6)$$

$$\eta_j = \sum_{k=1}^{J}(1 - r_{kj}) \qquad (7)$$

Step 5: Weight for the $j^{th}$ PI is obtained as per eq (10) with the help of $c_j$ obtained as per eq (9) multiplying the coefficient of variation ($v_j$) of each PI (obtained using eq (8)) with corresponding $\eta_j$ obtained in step 4. The larger value of $w_j$ indicates the higher amount of information assigned to the corresponding PI. Calculate criteria weights for both objective and subjective data.

$$v_j = \frac{\sigma_j}{\bar{x}_j}\ ,\ j = 1, 2, . . . , J \qquad (8)$$

$$c_j = \eta_j\, v_j \qquad (9)$$

$$w_j = \frac{c_j}{\sum_{j=1}^{J} c_j} \qquad (10)$$

## Spherical Fuzzy extension of VIKOR Method

Step 1: Construct the linguistic decision matrix $(\mathrm{D})_{i\times j}$ based on **Table 2**.

Step 2: Convert linguistic terms to their corresponded SFNs based on **Table 2**.

Step 3: Aggregate the SF influence matrices by using Spherical Weighted Arithmetic Mean (SWAM) based on eq (3).

Step 4: Determine the spherical fuzzy positive ideal solution (SF-PIS).
Benefit Criterion | $X_j^* = \{C_j, \max_i(\mu_j), \min_i(v_j), \min_i(\pi_j) \mid i = 1,2 \dots I\}$
Cost Criterion | $X_j^* = \{C_j, \min_i(\mu_j), \max_i(v_j), \max_i(\pi_j) \mid i = 1,2 \dots I\}$

Step 5: Determine the spherical fuzzy negative ideal solution (SF-NIS).
Benefit Criterion | $X_j^- = \{C_j, \min_i(\mu_j), \max_i(v_j), \max_i(\pi_j) \mid i = 1,2 \dots I\}$
Cost Criterion | $X_j^- = \{C_j, \max_i(\mu_j), \min_i(v_j), \min_i(\pi_j) \mid i = 1,2 \dots I\}$

Step 6: Calculate the Regret measure ($R$) using eq (11).

$$R_h = \max_j(w_j \cdot D) = \max_j\left(w_j \cdot \frac{D(\tilde{X}_{ij}, \tilde{X}_i^*)}{D(\tilde{X}_i^-, \tilde{X}_i^*)}\right) \qquad (11)$$

7: Calculate the Utility measure (S) using eq (12).

$$S_h = \sum_{j=1}^{J} w_j \cdot D = \sum_{j=1}^{J} w_j \cdot \frac{D(\tilde{X}_{ij}, \tilde{X}_i^*)}{D(\tilde{X}_i^-, \tilde{X}_i^*)} \qquad (12)$$

Crisp values for $S_h$ and $R_h$ are calculated using eq (4).

8: Calculate the Q function using eq (13) using the crisp values of $S_h$ and $R_h$.

$$Q_i = \frac{\alpha(S_i - S^b)}{(S^w - S^b)} + \frac{(1-\alpha)(R_i - R^b)}{(R^w - R^b)} \qquad (13)$$

Where $\alpha$ is a factor to manage the weights enjoyed by $S_h$ and $R_h$. For a generalized study it is assumed to be 0.5. If $Q_{h_2} - Q_{h_1} \leq \frac{1}{j-1}$ And $R_{h_2} > R_{h_1}$ And $S_{h_2} > S_{h_1}$, $A_1$ is the best choice, or else both alternatives are the best choice. $\alpha = 0.5$ in this paper.

Step 9: Rank the alternatives

Eventually obtained ranks based on subjective and objective data are compared for all regions to identify the regions with maximum variation in the ranks. Thereafter, the performance scores calculated for each block.

## Case Study

The objective data was collected for monitoring the 'supply and demand' criteria of VSC from the office of district immunization officer of Ranchi district in India for six blocks denoted as B1, B2, B3, B4, B5 and B6, whereas subjective responses for these blocks were collected from vaccine cold chain managers of respective blocks. These data points against the five objective and subjective PIs (as highlighted in Table 1) are shown in **Table 3**. The five PIs associated to 'capacity utilization', 'forecast accuracy', 'doses administered', 'stockout percentage' and 'timely delivery' are represented as X1, X2, X3, X4 and X5 in subsequent tables respectively. The steps for obtaining the ranks of various regions based on objective data have been adopted from Rai et al., (2022) which proposes a combination of modified CRITIC and VIKOR. To analyse the subjective responses, the spherical fuzzy extension of CRITIC and VIKOR as mentioned in the methodology section of this paper is adopted.

**Table 3.** Data For objective and subjective PIs for the bocks

| Blocks | X1 | X2 | X3 | X4 | X5 |
|---|---|---|---|---|---|
| B1 | 0.065, Ba | 6.346, BAv | 1.278, Go | 4775, Go | 859, AV |
| B2 | 0.313, Ba | 16.886, Go | 0.557, Ba | 1905, Av | 48, Go |
| B3 | 0.06, Go | 5.450, Av | 0.102, Ba | 283, Ba | 694, Ba |
| B4 | 0.002, AAv | 14.143, BAv | 0.77, AAv | 1235, Ba | 176, Ba |
| B5 | 0.017, Go | 21.580, AAv | 0.41, AAv | 6857, Go | 761, Go |
| B6 | 0.014, Go | 16.852, Av | 0.414, Go | 308, AAv | 505, Av |

The CRITIC analysis of objective data does not require the crispification and hence following the equation (5) to (10), we obtain the weight of objective data. Whereas the subjective data is converted into SFNs which is then crispified using equation (4) as per the step 2 of section 3.2. Thereafter, as per step 3 to 5, the subjective weights are obtained. Both these weigts are mentioned in **Table 4**.

**Table 4.** Yearly weights of PIs obtained using the CRITIC method.

| Weight | X1 | X2 | X3 | X4 | X5 |
|---|---|---|---|---|---|
| Objective | 0.350 | 0.158 | 0.135 | 0.139 | 0.218 |
| Subjective | 0.329 | 0.142 | 0.122 | 0.199 | 0.207 |

Using the objective weights from Table 4 and data against objective PIs from Table 3, the VIKOR analysis is performed to obtain ranks of the blocks based on objective information. The performance score corresponding to the objective PIs for each block was calculated as the weighted deviation from the ideal situation as explained in step 4 and 5 of section 3.4. The R, S and Q values are obtained following the non-fuzzy steps of VIKOR mentioned in Rai et al. (2022), and is shown in Table 5 along with the performance scores under the PIs and compromised ranks.

**Table 5.** R, S and Q values along with performance scores and compromised ranks based on objective information

| Blocks | X1 | X2 | X3 | X4 | X5 | R | S | Q | Ranks |
|---|---|---|---|---|---|---|---|---|---|
| B1 | 0.301 | 0.153 | 0 | 0.043 | 0.281 | 0.551 | 0.303 | 0.427 | 2 |
| B2 | 0.108 | 0.095 | 0.083 | 0.101 | 0.044 | 0.751 | 0.005 | 0.378 | 2 |
| B3 | 0.304 | 0.158 | 0.135 | 0.114 | 0 | 1.000 | 0.729 | 0.864 | 4 |
| B4 | 0.349 | 0.110 | 0.058 | 0 | 0.095 | 0.851 | 0.987 | 0.919 | 4 |
| B5 | 0.338 | 0.069 | 0.099 | 0.124 | 0.211 | 0.678 | 0.978 | 0.828 | 3 |
| B6 | 0 | 0 | 0.012 | 0.076 | 0.190 | 0.000 | 0.000 | 0.000 | 1 |

Next the spherical fuzzy extension of VIKOR is applied to the expert responses of blocks under various subjective PIs mentioned in **Table 3**. Positive and negative ideal solution for the subjective responses are obtained as per step 4 and 5 under section 3.4. All the PIs included in the case study are of benefit type. The obtained positive and negative ideal solution for various blocks are shown in **Table 6** and the distances of the alternatives from the respective ideal situations are shown in **Table 7**. The R, S and Q values for the blocks were obtained following the steps 6, 7 and 8 of section 3.4 and are shown in **Table 8** along with associated compromised ranks.

**Table 6.** SF-PIS and SF-NIS for various blocks

| Blocks | Positive ideal solution | Negative ideal solution |
|---|---|---|
| B1 | (0.357, 0.246, 0.137) | (0.129, 0.57, 0.196) |
| B2 | (0.442, 0.193, 0.112) | (0.23, 0.388, 0.181) |
| B3 | (0.485, 0.144, 0.118) | (0.074, 0.638, 0.205) |
| B4 | (0.085, 0.633, 0.217) | (0.193, 0.443, 0.169) |
| B5 | (0.162, 0.513, 0.173) | (0.372, 0.229, 0.126) |
| B6 | (0.356, 0.247, 0.145) | (0.048, 0.701, 0.217) |

**Table 7.** Distances of the alternatives from the ideal situation

| Blocks | X1 | X2 | X3 | X4 | X5 | X1 | X2 | X3 | X4 | X5 |
|---|---|---|---|---|---|---|---|---|---|---|
| | Distance to PIS | | | | | Distance to NIS | | | | |
| B1 | 0.40 | 0.19 | 0.02 | 0.00 | 0.29 | 0.40 | 0.19 | 0.02 | 0.00 | 0.29 |
| B2 | 0.29 | 0.07 | 0.00 | 0.18 | 0.25 | 0.29 | 0.07 | 0.00 | 0.18 | 0.25 |
| B3 | 0.00 | 0.65 | 0.24 | 0.56 | 0.62 | 0.00 | 0.65 | 0.24 | 0.56 | 0.62 |
| B4 | 0.16 | 0.14 | 0.11 | 0.22 | 0.00 | 0.16 | 0.14 | 0.11 | 0.22 | 0.00 |
| B5 | 0.17 | 0.07 | 0.35 | 0.21 | 0.02 | 0.17 | 0.07 | 0.35 | 0.21 | 0.02 |
| B6 | 0.02 | 0.00 | 0.23 | 0.38 | 0.48 | 0.02 | 0.00 | 0.23 | 0.38 | 0.48 |

**Table 7.** R, S, Q and rank values for various alternatives based on subjective inputs

| Values | AP | AS | MN | ME | MI | NA |
|---|---|---|---|---|---|---|
| S | 0.343 | 0.563 | 0.6076 | 0.525 | 0.496 | 0.536 |
| R | 0.044 | 0.066 | 0.0551 | 0.053 | 0.048 | 0.051 |
| Q | 0.00 | 0.921 | 0.754 | 0.573 | 0.38 | 0.532 |
| Rank | 1 | 5 | 4 | 3 | 2 | 2 |

**Table 6.** Comparison of ranks based on

| Blocks | Objective rank | Subjective rank |
|---|---|---|
| B1 | 2 | 1 |
| **B2** | **2** | **5** |
| B3 | 4 | 4 |
| B4 | 4 | 3 |
| B5 | 3 | 2 |
| B6 | 1 | 2 |

The comparison of ranks for the blocks based on subjective and objective values corresponding to the supply and demand criteria of VSC show that there is a significant difference for block B2. This indicates that there is difference in the performance narrative that is unfolding as the result of objective analysis and what the vaccine cold chain managers is observing in the block. Further analysis of inputs for this block suggests that X1 and X3 or PIs associated to capacity utilization and dose administered are areas of concern in this region and hence must be further investigated.

## Conclusion

In this study we have proposed a systematic framework to monitor the VSC performance using real time subjective and objective information. A combination of CRITIC and VIKOR method are used to define weights of the performance criteria and rank the alternatives regions respectively, while analyzing objective and subjective weights. Whereas, the spherical fuzzy extension of CRITIC and VIKOR method was used to interpret the subjective performance information provided the VSC managers at the respective region. The ranks obtained are then compared for each region to identify the regions observing conflicting narratives based on objective and subjective information. Also, this paper provides a comprehensive evaluation index, containing PIs that take both subjective and objective inputs for measuring the performance of various components of a VSC. As an extension of this study a sensitivity analysis can be performed wherein different weightages shall be given to subjective and objective information type. Also, a more comprehensive evaluation index can be developed by including more PIs.

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