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Application of AHP and TOPSIS for the evaluation of Indian railway supply chain parameters

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Indian railways is a major public transportation system in India and one of the world's largest and busiest rail networks. It is owned and run by the Indian government. This study presents an alternate method for assessing the entire operating performance of the Indian railway supply chain. To improve inventory control and customer service, we must examine how Indian railways operates from a supply chain standpoint. Indian railways benefits from the research as it makes it possible to categorize different government procurement-related difficulties. It examines inventory issues and provides recommendations for public procurement. As a result of this research, Indian railways decision-makers will be able to create an evaluation and relationship management model, allowing them to make procurement the main driver of their supply chain. We propose a supply chain model to evaluate service expectations and quality. We have identified various issues of the integration system, financial behavior, and management perspective related to supply chain management and analyzed various factors affecting availability, railway service quality, and reliability for effective supply chain management. The study employs the analytical hierarchy process (AHP), TOPSIS, and fuzzy rule base analysis.

Keywords: Supply chain management, Indian railway, Availability, Quality of railway service, Reliability, AHP, TOPSIS, Fuzzy rule

1 Introduction

Over the years, the Indian railways have played a crucial role in meeting the transportation requirements and driving the economic growth of the country, Ketchen Jr. David[10]. With its impressive size and reach, Indian railways has established itself as one of the leading national railway systems globally, poised to achieve world-class status shortly. Logistics and transportation are important factors to consider when calculating the total cost of a product or service, logistics and transportation are important considerations. Ensuring timely and cost-effective delivery of a specific product or service to end consumers has become an essential requirement in today's globalized world. Establishing a strong system to manage the flow of various goods, services, and information within the Indian railways supply chain is crucial for smooth operations. Indian railways optimal supply chain design is gaining significant attention from supply chain management scholars and practitioners, Cai J.[5]. Due to the need to view the Indian railway system as a cohesive unit, developing efficient models and strategies to prioritize the flow of goods has posed a significant challenge for the Indian railway system. Indian railways is currently reassessing its approach to improve efficiency and effectiveness by reviewing the integrated system, financial behavior, and management viewpoint. Indian railways is re-evaluating its internal operations, such as servicing, warehousing, materials management, and distribution, to improve their efficiency and effectiveness, Olsson, N.[13]. Due to the increasing rate of urbanization, there is a rising need for transport, specifically in the railway sector. Within this industry, the railway station plays a crucial role in welcoming and handling passengers. Dealing with waste and plastic trash presents major environmental hurdles. The main contributors to environmental challenges related to plastic waste are our disposable culture and the lack of an effective waste management system. Lack of resources, outdated technology, lack of management support, and poor system efficiency all contribute to the system's inability to generate positive outcomes. The problem stems from personal habits and a lack of adequate infrastructure for the proper disposal of solid waste. We have identified

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issues within the collection, transportation, and disposal systems, as well as noticeable amounts of plastic waste found at railway stations. Despite their best efforts, Indian railways has been facing persistent challenges in resolving supply chain management issues. The objective of this study is to examine the supply chain of the Indian railways (IR).

2 Materials and Methods

2.1 Supply chain management

To maintain internal sustainability, the supply chain must be able to adapt and adjust based on external factors. According to the World Resources Institute, managers are increasingly focused on integrating and coordinating practices throughout the supply chain. This is driven by the growing awareness among supply chain firms of consumer demands for environmentally friendly goods and services, Bhanot[4]. Emphasizing environmental sustainability and implementing effective global supply chain management (GSCM) strategies can provide supply networks with a competitive advantage. Research in this field examines the role of supply chain management in implementing environmental measures across the supply chain, emphasizing its ability to bridge boundaries. Secure emphasizes the importance of considering transaction costs when aiming to enhance environmental sustainability in the supply chain, Rahimi[14]. Environmental law and regulation, as well as customer demands, play a significant role in shaping the adoption of sustainable practices. There is a lack of consensus regarding the influence of environmental regulation on company competitiveness. Consumers have the opportunity to access goods and services through an organization's supply chain, Ranjan[15]. It creates a connection between the starting point and the endpoint in terms of material movement. The process of managing the flow of raw materials from storage to the final consumer involves various stages, including storage, loading, and shipping. Therefore, the efficient movement of goods has become essential for the smooth operation of the entire process and plays a vital role in driving a nation's economic development, Vidoni[17]. The speed and ease of transporting people and goods within a nation determine the efficiency of its transport system. Various modes of transportation are utilized to provide freight services, such as railroads, highways, planes, and ships illustrates the management of the Indian railway system, showcasing the various flows that are involved. To enhance performance, Indian railways employs efficient techniques that optimize various aspects of their operations, such as supply chain features, integration, and customer service (Fig. 1). New research suggests that the effectiveness of managing the flow of goods and services may vary depending on the structure or situation. Consequently, different countries may adopt a variety of strategies when it comes to managing their supply chains.

2.2 Management of the supply chain and the railway system

Indian railways, a transportation and freight-moving firm. The Ministry of railways is responsible for the management and operations of India Railways, which is a government-owned company. The Railway Board holds the highest authority in India's decision-making process, with its chairman serving as a cabinet minister, Rosberg[16]. The railway board oversees various aspects of operations, including policy formation, goal setting, performance monitoring, cadre planning, and centralized procurement of high-value products, such as whole rolling stock, from the central purchasing agency. Supply chains link the provision of raw materials to the final delivery of a product or service to a customer. Acquiring raw materials, managing their storage, coordinating their transportation, and delivering them to the end customer are all integral components of the overall process. Transport has become a crucial element in managing the flow of goods and services, Hassan[8]. The establishment of a

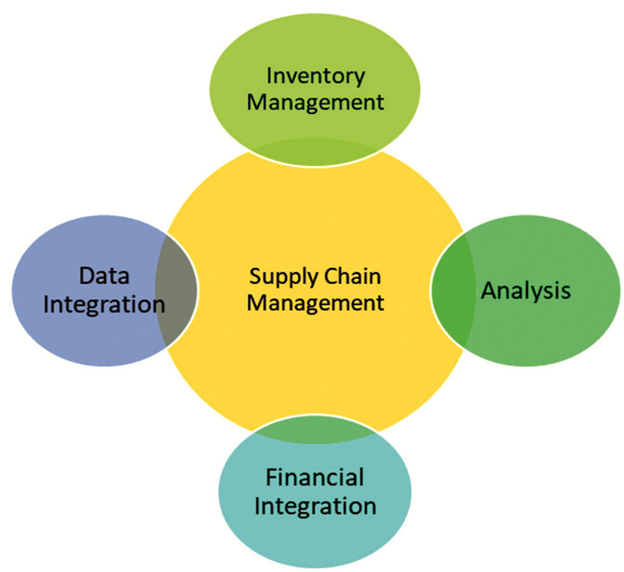

Fig. 1 — Supply chain management for Indian railways.

nation's transport infrastructure is a crucial foundation for its overall progress. When a nation's transport system operates efficiently, it demonstrates the ease of travel and movement of goods across the country. Different modes of transportation are utilized for freight services, including railways, highways, rivers, and airplanes. Members of the rail transportation board who oversee mechanical engineering and material management have the important task of managing various types of rolling stock, including wagons, coaches, and diesel locomotives, Cullinane[6]. This research provides insightful information for Indian shop management. Making wise choices to increase productivity and profitability may be facilitated by having a thorough understanding of the performance-influencing variables and efficiency levels. There is room for improvement in certain shops, especially when it comes to allocating resources and streamlining operating procedures. The retail industry in India may benefit from more research and strategic initiatives based on these observations, Agrawal[2].Performance has evolved into a role focused on managing the flow of goods and services and has become its independent organization. The effectiveness and efficiency of an action can be measured using performance metrics. Decisions and actions can be influenced by the data provided by performance measurement systems. This tool has a significant impact on shaping strategic goals, measuring performance, and planning for the future. Many supply chain failures can be attributed to the absence of an effective measuring system. Thus, the main hurdle is to attain a suitable level of performance. To enhance the company's performance and competitiveness. We analyze the key performance indicators of IR in comparison to a typical automobile firm to gain a deeper understanding and evaluate the efficiency of the inbound supply chain.

2.3 Analytic hierarchy process (AHP)

AHP ensures that the selection process is transparent and straightforward. This approach highlights both the strengths of various solutions to a Multi-Criteria Decision Making (MCDM) problem and the advantages of those solutions. While the AHP technique may rely on subjective input, the necessary information can be gathered from the decision-maker of a company through direct questioning or the use of a questionnaire, Awasthi[3]. It is widely recognized in the literature that several factors contribute to the complexity of the supplier selection decision-making process: The supplier selection process can be quite challenging, requiring a careful and thorough decision-making approach Adeodu[1]. It offers the benefit of illustrating how potential shifts in priority at higher levels can affect the importance of criteria at lower levels. Additionally, it offers the buyer a comprehensive understanding of the criteria, their functions at lower levels, and their objectives at higher levels. In addition, it is crucial to consider the advantages of AHP in terms of its stability and adaptability when faced with changes and additions to the hierarchy, Ipinazar[9]. The method's ability to prioritize criteria based on the buyer's requirements enables a more accurate selection of suppliers. The AHP technique utilizes a natural, pair-wise comparison to evaluate criteria or alternatives and identify the most optimal choice. It utilizes a well-established and validated number system for this purpose, which has been extensively tested and proven in real-world situations involving physical and decision-making scenarios. This scale is used to evaluate and compare individual preferences based on ratios. Each option can be assigned a scale weight to create an additive weight that follows a linear pattern, Kirytopoulos[12]. For example, the paper can be utilized to compare and prioritize the options, helping you make a well-informed decision. It serves as a powerful operational research tool for structuring complex multi-criterion issues or judgments in various fields, including logistics, marketing engineering, and education. In addition to utilizing readily available expert judgment data, it can address discrepancies in expert opinions and perspectives (inconsistencies). The AHP can be implemented with the assistance of Expert Choice Software, Wang[18]. By breaking down the decision into its components, we can structure our thinking and determine our priorities (refer to Fig. 2).

This study focuses on identifying the optimal alternative from the information in the decision matrix. Comparing the M options to the N decision criteria together poses a slightly different challenge. Having a scale of numbers is crucial for making comparisons, as it allows us to gauge the relative importance or dominance of one element over another based on the criterion or quality being compared.

2.4 Parameters selection

In this section, we will explore the key factors that contribute to an efficient system for managing the flow of goods and services in the Indian railway

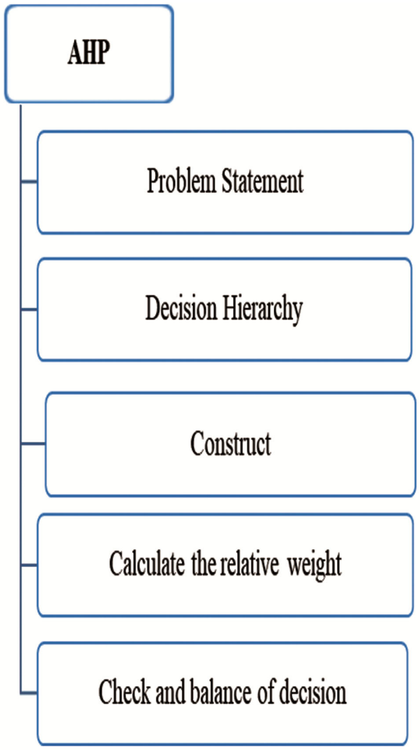

Fig. 2 — AHP flow chart.

system. The AHP quantification involves a 3 * 3 variable, which has been accepted by several experts from various perspectives.

2.5 Proposed AHP model

Begin by gathering input from three experts in railway decision-making and constructing a model based on their assessments. Four pairwise comparison matrices need to be created using the crude AHP approach, with the consistency ratio being calculated for each matrix. It's crucial to keep in mind that this applies to all of the mentioned factors (availability, service quality on the train, reliability, system integration management, and cost). Therefore, any pairwise comparison matrix can be utilized in Fig. 3.

Saaty introduced the AHP technique two decades ago, and it has since become a popular method for making decisions involving multiple attributes in various industries. It is a way of considering all important factors when making decisions. Pairwise assessments of all competing objectives are necessary, requiring the use of subjective judgments. Consequently, a ratio scale is employed to establish a hierarchy of comparative values. We break down the AHP procedure into two stages. The design step sets up a clear hierarchy, followed by the evaluation phase where different options are compared through

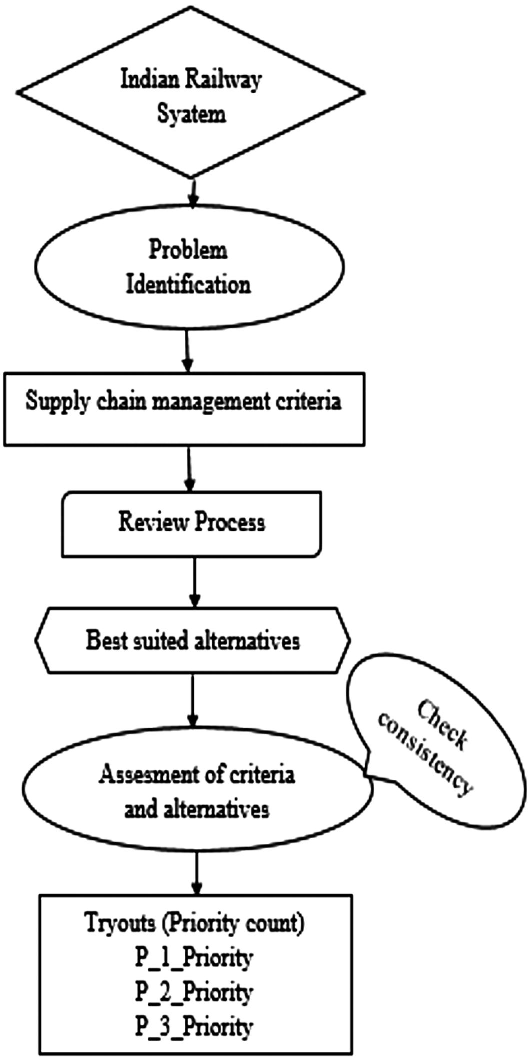

Fig. 3 — Proposed AHP model.

pairwise comparisons. To build a hierarchy, an estimator needs to possess previous experience and expertise in the specific field, without the need for any prior knowledge of actual data. The highest level in the hierarchy represents the ultimate goal. If, for instance, we're looking to determine which method can generate the most precise predictions, it would be a solid starting point. We evaluate the overall impact of each option on the dimension being considered based on the perceived contribution of each option. We utilize a ratio scale obtained from the generated matrix and apply an eigenvector technique. To accomplish this, we utilize a normalized column average. We utilize a cost comparison to determine the relative weights for each available option. It's a method of measuring the relative significance of each choice to the shared property at the higher level. We

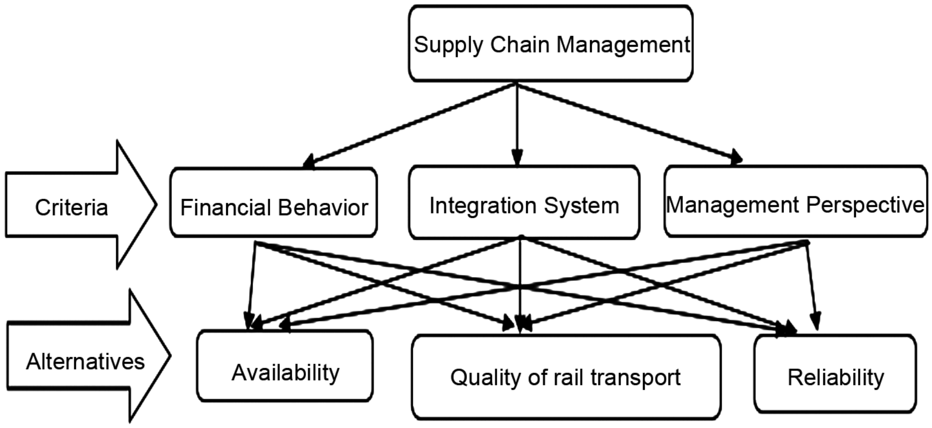

Fig. 4 — Criteria and alternatives for IR SCM.

go through this process for every property at a specific level to reach the desired result. We will reassess the three techniques (integration system, financial behavior, and management perspective) to ensure their quality. We will also assign weightings to each verification (availability, quality of railway service, and reliability) on the SCM dimension, as shown in Fig. 4. In the next stage, it is important to compare attributes at the next level with the common attribute immediately above them. The issue is divided into machine algorithms to address the model dependency, as demonstrated. To identify the optimal parameters (availability, quality of railway service, and reliability), a thorough analysis using the AHP method requires numerous pairwise comparisons. The Analytics Hierarchy Process (AHP) methods often struggle to generate reliable comparison values, especially when dealing with complex problems that involve numerous variables, such as the integration system, financial behavior, and management perspective, as well as factors like availability, quality of railway service, and reliability. The discrepancies highlighted by a ratio consistency value are crucial when creating a pairwise comparison matrix for reliability.

2.6 Stages

2.6.1 Stage- 1: Objectives

2.6.2 Stage- 2: Alternatives

In the Analytical Hierarchy Process (AHP), multiple pairwise comparisons are based on a standardized comparison scale of nine levels. Let C= {Cj|j=1, 2... n} be the set of criteria. The result of the evaluation matrix in which every element a_{ij} (i, j=1, 2... n) is the quotient of weights of the criteria, as shown:

Table 1 — Criteria description for IR SCM.

Label	Description
Integration System	Model 1
Financial Behavior	Model 2
Management Perspective	Model 3

Table 2 — Alternatives Declarations for IR SCM.

Label	Description
Availability	Impact Level 1
Quality of railway service	Impact Level 2
Reliability	Impact Level 3

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix}, \quad = a_{11} = 1, \quad a_{ji} = 1/a_{ij}, \quad a_{ij} \neq 0. \quad \ldots (1)$$

2.6.3 Stage-3: Pairwise comparison

To evaluate the models, we applied AHP rating scales to the criteria. Since availability, quality of railway service, and reliability require maximization and range from 0 to 1 (in this case, from 0.0042477 to 0.31280248), we used the rating scale in Table 1. As seen in Table 2, the Eigenvalue resulted in 1.0959 with an ideal Max_C_weight of 0.534892241. Nonetheless, two other attributes also stand out: reliability came in a close second with a score of 0.312. Table 2 displays the average consistency index, derived from the model's output during the test phase. Table 1 shows the weight obtained from previous observations' model output. When compared to the inconsistency of the alternatives (which depend on availability, quality of railway service, and reliability), you can figure out the weight of this model that helped make accurate predictions.

2.6.4 Stage- 4: Pairwise comparison criteria (financial behavior)

An effort has been made in these contributions to emphasize the significant impact of supply chain management and thoroughly evaluate the Analytic Hierarchy Process as a well-established decision-making tool. The contribution emphasizes the various areas of application within the selected themes. Tables 3 and 4 can be utilized to determine the normalized value and the constancy index, which assist in evaluating the consistency of the Indian railway system in terms of supply chain management. Table 5 presents the consistency variables in a format that includes an Eigenvector and a consistency ratio.

2.6.4 Stage- 5: Pairwise comparison criteria (management perspective)

Table 6 assigns the weight based on observation and behavior and compares it to the inconsistency of the alternatives, which depends on availability, quality of railway service, and reliability. We can calculate this using a tree model that manages to play a positive role in correct predictions while also calculating the normalized metrics Table 7.

Table 3 — Weight for model 1.

Financial Behavior	Availability	Quality of railway service	Reliability
Availability	1.00	1.21	1.25
Quality of railway service	0.81	1.00	1.27
Reliability	0.78	0.77	1.00

Table 4 — Normalized metrics for model 1.

	Availability	Quality of railway service	Reliability
Availability	0.382665	0.406489	0.3558920
Quality of railway service	0.313751	0.333196	0.3615899
Reliability	0.303684	0.260307	0.2823210

Table 5 — Normalized metrics for model 2.

	Availability	Quality of railway service	Reliability
Availability	0.146056	0.136841	0.100421
Quality of railway service	0.119718	0.112001	0.102901
Reliability	0.115915	0.087501	0.078901

Table 6 — Index Value for model 1.

Max_C_weight	0.3816453
Criteria Count	3
Eigenvalue	1.003567
Consistency Index	0.998321
Random Index	19.71
Consistency Ratio	0.050947
Check If (CR<0.10)	TRUE

In Table 6, the index resulted in the best value with an ideal Max weight of 0.5032, mainly because it was the highest evaluated in the metrics: 0.160234 and 0.144708. However, there are two other alternatives for the model that also stand out, and availability comes in a close second with a score of 0.160. Table 8 and 9 displays the average consistency index, calculated from the test phase outputs of the alternatives using normalized metrics

3 Results and Discussion

To address the issue of the AHP pairwise comparison matrix's inconsistency, this research established three models: the integration system, financial behavior, and management perspectives. We begin by performing simulations to train, validate, and test the two methodologies. However, when it comes to minimizing CR, the integrated system operates from a managerial perspective, providing highly accurate forecasts for previously unidentified inputs. Financial behavior, on the other hand, tends to converge at a slower pace. The AHP assessments are included in the final table for each model. After analyzing the three original input element models, it is clear that there is a strong correlation between financial behavior and management perspective. Below, we provide some insights and important points to consider. A study was conducted to evaluate the effectiveness of the Analytic Hierarchy Process (AHP) and MLP approaches in extracting criteria weights for models and alternatives.

Table 7 — Weight for model 2.

Management Perspective	Availability	Quality of railway service	Reliability
Availability	1.00	1.33	1.37
Quality of railway service	0.77	1.00	1.37
Reliability	0.75	0.73	1.00

Table 8 — Normalized metrics for model 3.

	Availability	Quality of railway service	Reliability
Availability	0.160235	0.144718	0.097111
Quality of railway service	0.123212	0.109457	0.098338
Availability	0.117345	0.079314	0.071232

Table 9 — Index Value for model 2.

Max_C_weight	0.399321
Criteria Count	3
Eigenvalue	1.006275
Consistency Index	0.996867
Random Index	19.56
Consistency Ratio	0.050934
Check If (CR<0.10)	TRUE

We also conducted a comprehensive evaluation study of the Analytic Hierarchy Process (AHP) and MLP approaches to extract the weights of criteria for models and their alternatives.

In this assessment, our initial focus was on forecasting the optimal factors for efficient management of the supply chain. We utilized MLP algorithms to achieve accurate results, aiming to address challenges within the Indian Railway system. In the second step, we utilized the AHP process to demonstrate the interdependence of variables such as precision, recall, and sensitivity. In the Clarity concept, our main focus has been on a specific segment, encompassing the availability, quality, and reliability of railway service. Figure 5 depicts the weight based on the model, revealing that financial behavior and management perspectives were the most prominent factors.

3.1 Proposed model using TOPSIS

By utilizing the TOPSIS method, one can evaluate the AHP index value of alternatives by considering how closely they resemble an ideal solution. Table 10 below demonstrates the effectiveness of TOPSIS in addressing MCDM problems. These studies demonstrate the ability to verify the outcomes of the AHP model using this method alone or in conjunction with others. Table 10 demonstrates the use of TOPSIS to address MCDM challenges. Research indicates that this approach can be implemented independently or in combination with other techniques to tackle the challenges. For comparison, the results obtained from the AHP approach were compared to the findings of the study. We are intrigued by TOPSIS and other methods for addressing MCDM problems.

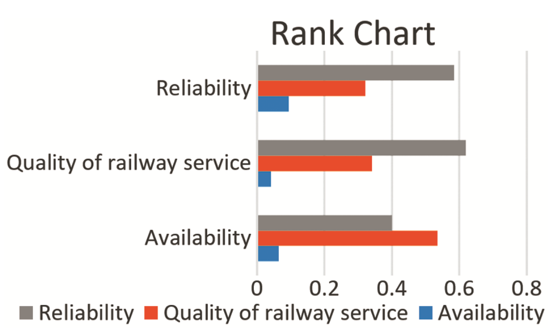

Fig. 5 — Final weight and ranking of the proposed models through the AHP method.

By utilizing the TOPSIS method, one can evaluate the AHP index value of different alternatives by comparing them to an ideal solution. Table 11 below demonstrates the effectiveness of TOPSIS in addressing MCDM problems. These studies demonstrate the ability to verify the outcomes of the AHP model using this method alone or in conjunction with others. Table 9 demonstrates the use of TOPSIS to address MCDM challenges. Research indicates that this approach can be implemented independently or in combination with other strategies to tackle the challenges. For comparison purposes, the results obtained from the AHP approach were compared to the findings of the study. We are intrigued by TOPSIS and other methods for addressing MCDM problems.

Using the TOPSIS technique in MCDM situations, such as ranking the options, can yield many benefits. The TOPSIS technique has benefits in terms of its capacity to quickly select the best options and handle contradictory circumstances. Next, you can enter the judgment data immediately, eliminating the need for complex computations. For example, Table 12 lists TOPSIS grade and rank preferences, whereas Table 13 lists top-ranking conventional TOPSIS ranks. Only the first two slots of the proposed and standard TOPSIS differ. According to the relative proximity coefficient, the ranking order will change. Figure 6 depicts the distance between the positive and negative results of the suggested approach, as shown by the dotted lines. There is a large difference (suggested model) between positive and negative distances. As a result, the technique guarantees an optimum ranking. Figure 7 compares the new approaches.

We normalized the decision matrix in Table 13 of this article using the concepts of normal distribution. We illustrate the statistical standardization with

Table 11 — Normalized matrix for TOPSIS approach.

	Availability		
Integration System	0.22218	0.200711	0.195117
Financial behavior	0.531646	0.535229	0.573361
Management Perspective	0.817306	0.820515	0.79573

Table 10 — Assign weight for TOPSIS approach.

Weightage	0.534892	0.381695	0.399443	Term	Fuzzy Number
	Availability	Quality of railway service	Reliability	Very Low	1,1,3
Integration System	1.4	1.59	1.79	Low	1,3,5
Financial behavior	3.35	4.24	5.26	Average	3,5,7
Management Perspective	5.15	6.5	7.3	High	5,7,9
				Very High	7,9,9

Table 12 — Assign weight for model 3.

Weightage	0.534892	0.381695	0.399443		
	Availability	Quality of railway service	Reliability	Si+	Si-
Integration System	0.118321	0.07453	0.077984	0.405466745	0.239910534
Financial behavior	0.284435	0.213564	0.229725	0.243227653	0.232613877
Management Perspective	0.437212	0.327673	0.317859	0.239912344	0.405467435
V+	0.437176	0.327721		0.077878	
V-	0.118852	0.07672		0.317851	

Table 13 — Range with Fuzzy rule.

SCM Factors	High	Low
Availability	(0.160234, 0.23678, 0.3699)	(0.097011, 0.144708 0.23566)
Quality of Services	(0.12139, 0.24563, 0.3216)	(0.109627, 0.098438, 0.2136)
Reliability	(0.117819, 0.25693, 0.3697)	(0.07944, 0.071332, 0.3256)

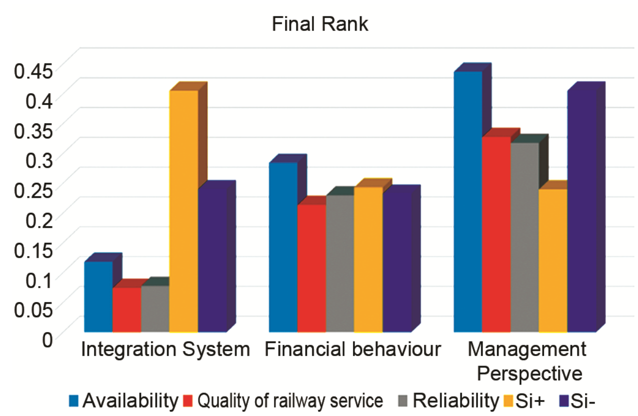

Fig. 6 — Final Criteria Ranking of the models through the AHP method.

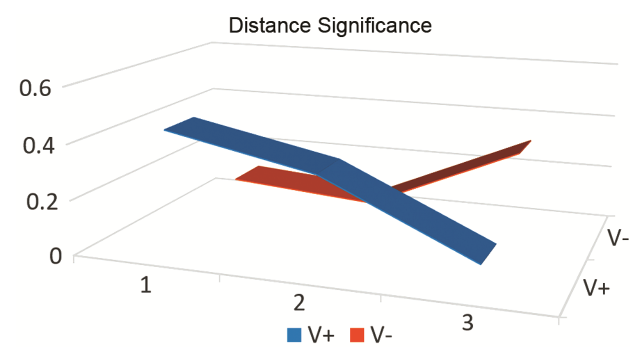

Fig. 7 — Distance Significance of the models through the AHP method.

weight. The following is an explanation of the processes involved in this methodology, along with their respective outcomes on our choice matrix.

Normal distribution converts the basic values of various statistics to standard values between -3.59 and +3.59 by decreasing the mean of the meter and dividing the output of this function by the standard deviation of the data, as demonstrated in the formula:

Zij is the standard value of each data point, j is the more favorable and reasonable content of each criterion that has been chosen by experts of the organization, and so is the standard deviation of each criterion that is derived using the following formula.

$$Z\,j = \frac{r_{ij}-\mu \;\; J=1,2,\ldots m; i=1,2,\ldots,n}{S_x} \quad \ldots (2)$$

$$Sx = \frac{(r_{ij}-\mu)\;\; J=1,2,\ldots m; i=1,2,\ldots,n}{n-1} \quad \ldots (3)$$

3.2 Adequate justification for the proposed model

The tables above illustrate the priorities determined by the group decision-maker's assessments. It showcases the dependability of the selection criterion for managing the supply chain. Therefore, we recommend that decision-makers in manufacturing firms should integrate the preceding criteria into their approach to managing the flow of goods and services. Based on the AHP evaluation, the inconsistency also referred to as CR is 0.10. This suggests that the evaluations conducted by the group (accepted parameters for managing the railway system in India) are consistently reliable. Measuring the relevant parameters for the Indian railway system is not enough; they must also be empirically validated through other approaches to ensure effective performance. To accomplish this, we utilized the TOPSIS method to assess the precision of the suggested model. We demonstrate the reliability of the relevant factors in Tables 2 and 3 by applying consistency ratio conditions. Next, we utilized the TOPSIS approach to evaluate the precision by using two constants (V- and V+). The observation has led to established parameters, and the model plays a crucial role in the supply chain management system of Indian railways. To enhance the efficiency of the Indian railway system, it is crucial to improve the effectiveness of its operational processes. Indian railways have implemented innovative techniques to enhance their management of the supply chain. The suggested approach can also assist logistics organizations, supply chain partners, and customers in managing risk. The concept is validated through simulation.

3.3 Proposed validation using fuzzy fiction

Our fuzzy ranking model requires some basic notions. The next sub-sections explain these principles, and Fig. 8 presents the suggested model in three stages. In this work, the importance of selection criteria and sub-criteria, as well as the supplier's performance, is based on decision-makers' opinions. As a result, we created two membership functions: one for estimating criteria and sub-criteria weights, and another for the supplier's sub-criteria performance. This study uses trapezoidal and triangular membership functions. The study introduces a neuro-fuzzy controller designed to minimize errors in processing sun data and detect uncertainties in weather conditions. Performance evaluation was conducted using MATLAB simulation. A comparison between the neuro-fuzzy controller and a fuzzy logic controller revealed that the neuro-fuzzy controller outperformed the latter, demonstrating superior performance. This suggests that the neuro-fuzzy controller offers enhanced capabilities in handling sun data processing and weather uncertainty detection, E.M.H. Arif[7]. The paper introduces a novel fuzzy rule learning system, FRLC (Fuzzy Rule Learning through Clustering), for predicting solar radiation using meteorological data. FRLC utilizes linguistic modifiers and fuzzy clustering techniques. The performance of FRLC is compared with various machine learning algorithms including multilayer feed-forward neural networks, radial basis function neural networks, support vector regression, and adaptive neuro-fuzzy inference systems. Results indicate that FRLC surpasses all algorithms in interpretability, providing a linguistic knowledge base that enhances understanding for domain experts Khalid Bahani[11]. To deal with human imprecision and uncertainty in decision-making using linguistic terms and degrees of membership, Zadie invented fuzzy set theory. A fuzzy set has graded membership. A normalized membership function is 0-1. These grades indicate an element's fuzzy-set stability. To express fuzzy sets mathematically, consider set X. Set description: X = x1, x2... Xn, (1), where xi is in X. A membership value expresses each element's fuzzy set membership.

Fuzzier: Membership functions convert crisp inputs into fuzzy inputs. Several membership function forms describe fuzziness;

Rules: FIS's key component is "Rules." Experts in each field define fuzzy "if-then" rules. x1 and x2 are variables, y is a solution variable, and a1, b1, and c1 are fuzzy linguistic concepts.

In this work, the importance of selection criteria and sub-criteria, as well as Supply Chain Management performance, are based on decision maker opinion. Thus, we built up two membership functions, one for estimating criteria and sub-criteria weights and another for sub-criteria performance. First, four fuzzy sets of membership functions are applied to FIS inputs and outputs. "Availability," "Service Quality," and "Reliability" are fuzzy sets of language rating variables. Figure 8 shows high and low outputs.

3.4 Fuzzy rules

Here, we build a prototype fuzzy inference system for use in SCM. In a FIS, linguistic variables typically define the membership functions of input and output variables. The inference system will use the supply chain sources listed in the previous section as input variables. The system's output variables will reflect the results of several risk indicators. The fuzzy inference system evaluates the indicators' values based on the level of risk that could arise from a set of predefined sources. We model language values as input/output variables with triangle membership functions. Figures 9 and 10 display the input and output variables, respectively, along with the fuzzy

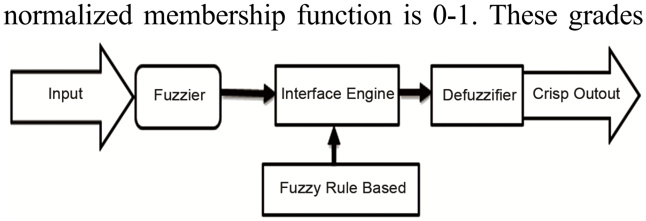

Fig. 8 — Data flow in Fuzzy system for SCM in IR.

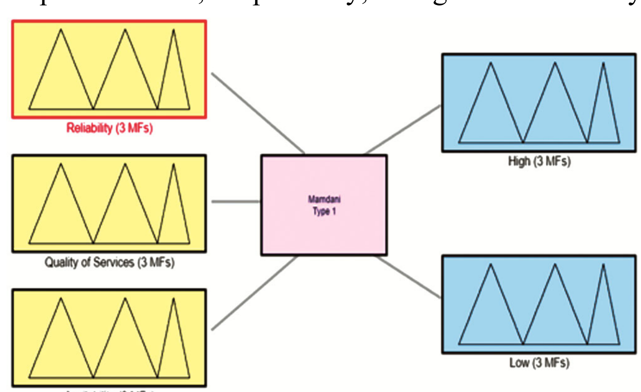

Fig 9 — Member function Fuzzy system for SCM in IR.

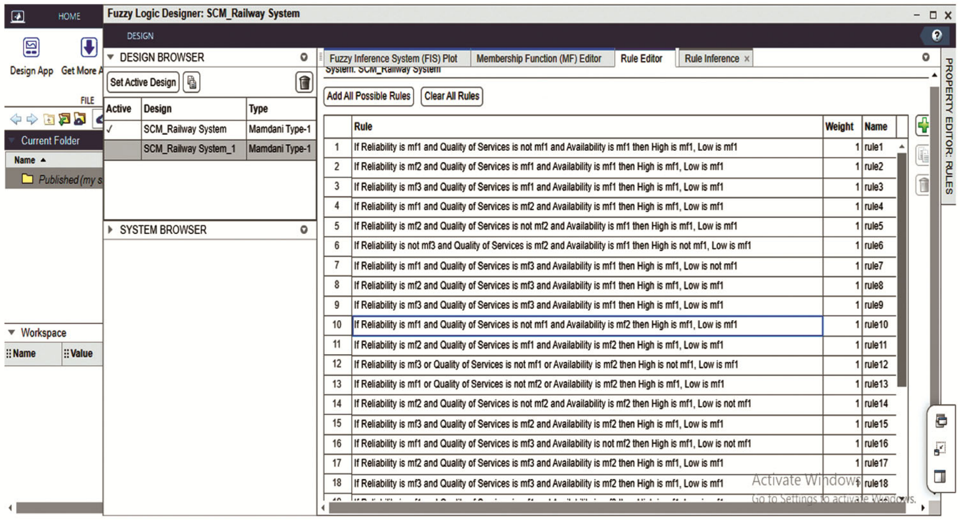

Fig. 10 — Fuzzy rule 1.

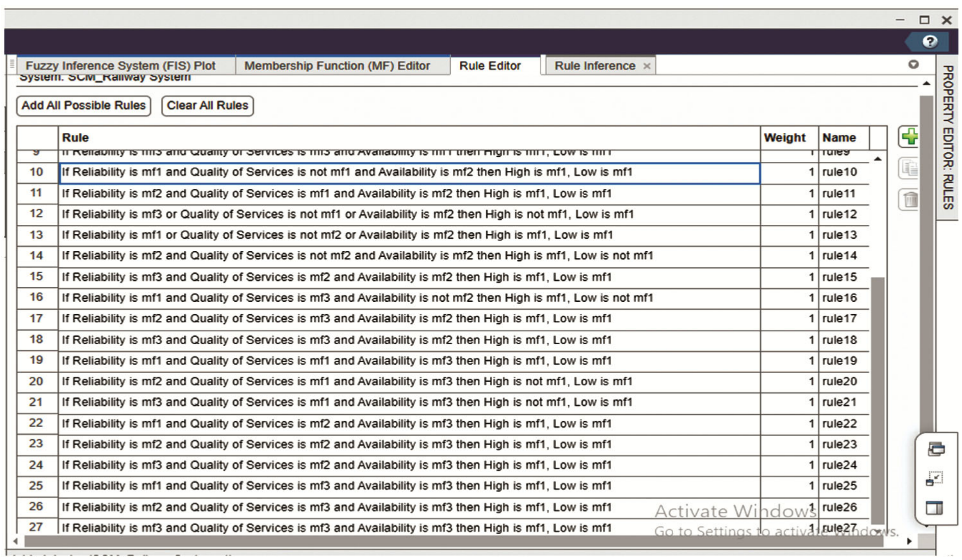

Fig. 11 — Fuzzy rule 2.

numbers representing the corresponding language variables. Once the linguistic variables determine the membership functions of input and output variables, we organize the fuzzy rules accordingly. The IF-THEN rules, which make up a set of fuzzy rules, generate output numbers in response to certain inputs. We develop a total of 30 rules to evaluate the values of the performance indicators. Under Fig. 9 and 10, you'll find several examples of structured rules.

This chapter compares fuzzy model findings for supply chain management, notes the advantages and limitations of the relevant approaches, and applies fuzzy methods based on the analysis. The initial part of the project involved creating a fuzzy logic-based decision support system for Indian railway SCM factors. Comparative analysis rules are shown below. Figures 12–18 show the fuzzy decision support system's basic elements (SM model, structure, input and output variables, number of membership functions, curve form). Figure 9 shows the model's membership functions, while Table 5 lists their parameters. Figure 10 shows the second portion of the procurement decision-support system. Figure 11 shows the output variable of the decision support system for both fuzzy models based on input variables. Table 6 shows the main characteristics of a fuzzy-ANFIS-based decision support system. Comparative analysis compares model outcomes. Model error is the comparison criterion.

Fuzzy inference system constructed using MATLAB's fuzzy logic toolbox. Figures 12, 13,

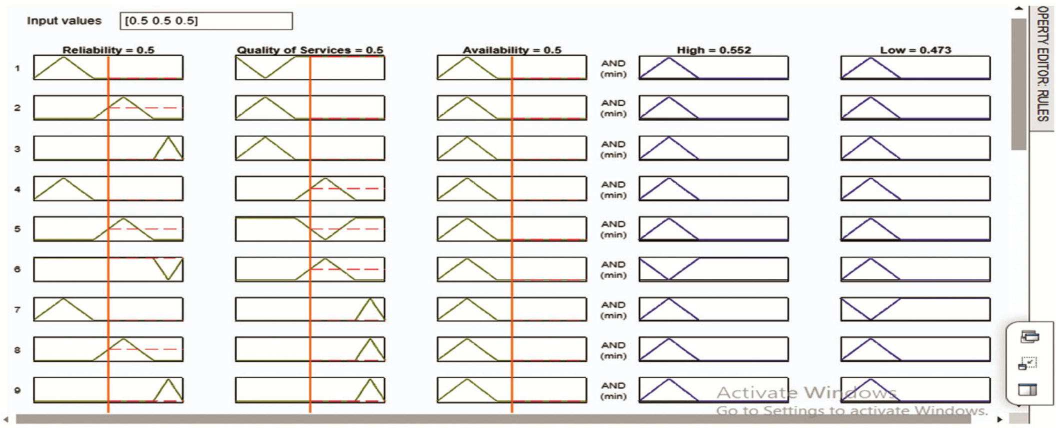

Fig. 12 — Rule inference impact (Rules 1 to 9).

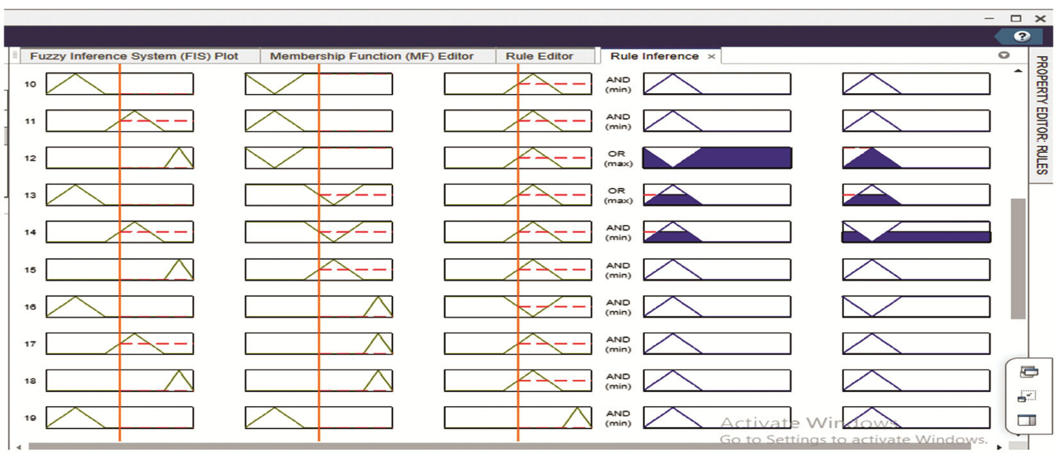

Fig. 13 — Rule inference impact (Rules 9 to 17).

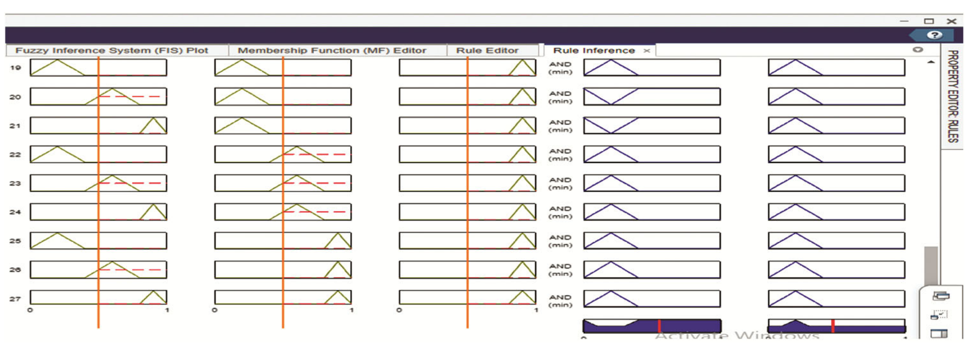

Fig. 14 — Rule inference system (Rules 17 to 27).

and 14 exhibit 3D surface rule views of fuzzy logic modeling rules for SCM factors. Each view is an input-output response surface. The figure shows it. Service reliability and quality affect efficiency greatly. Figure 12 shows that these factors affect the railway system more than other factors. Figures 13 and 14 indicate that availability, quality of services, and reliability regulate rinse time. High production is directly linked to service availability and reliability.

Figures 15-20 demonstrate how to reflect poor facilities for the Indian railway system and how it would respond under various scenarios. The input values are sensed by sensors, and then, using the suggested system, the responses of the sensors are fuzzified. This is followed by the application of if-

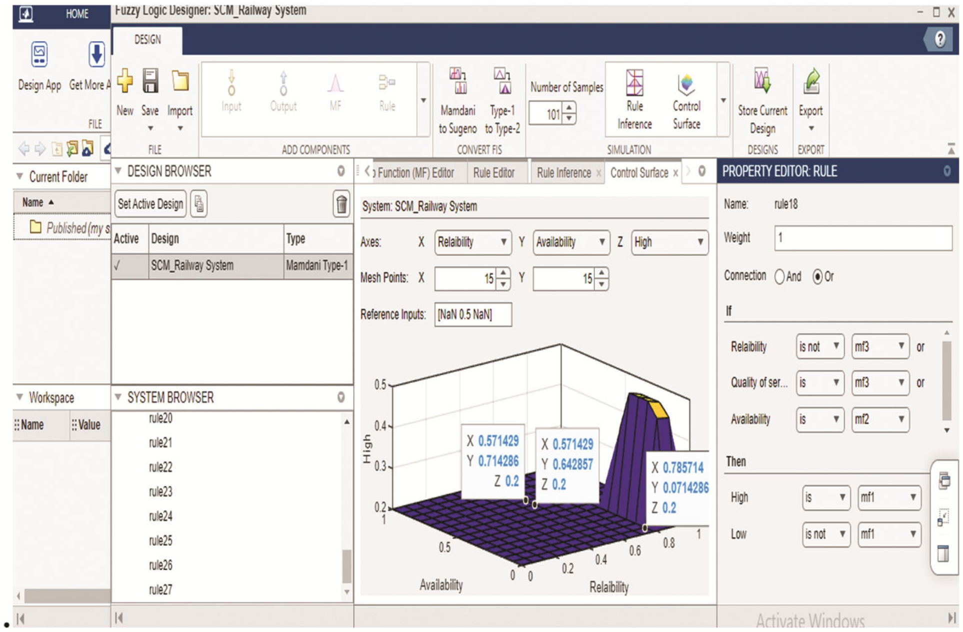

Fig. 15 — Control surface for SCM in IR (reliability, availability with high).

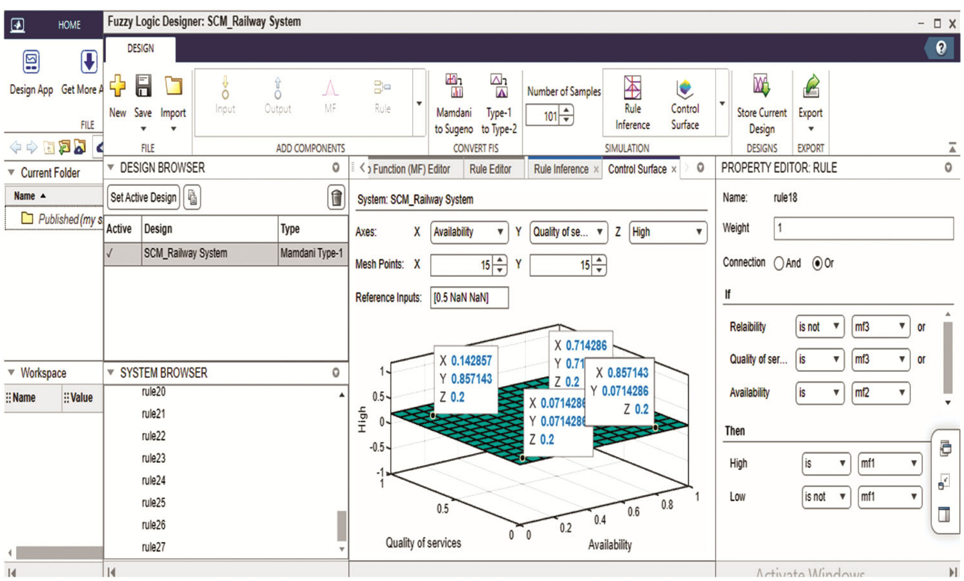

Fig. 16 — Control surface for SCM in IR (availability, quality of services with high).

then rules and aggregation, and finally, the output values are obtained using a de fuzzy fiction approach. Control surfaces can be arranged independently of one another, and a fuzzy rule base can be used to describe any surface that can be represented with a table. Because the rule basis will interpolate any points that are not explicitly specified, the number of characteristic points that are required to adequately define a particular control surface when using a fuzzy rule base is quite little in reality. When the nature of the interpolative process is understood, it is much simpler to build controllers with a minimal amount of rules. This results in controllers that are both simpler to read and more efficient in their operation. Control surfaces can be arranged independently of one another, and a fuzzy rule base can be used to describe any surface that can be represented with a table. A fuzzy rule base requires

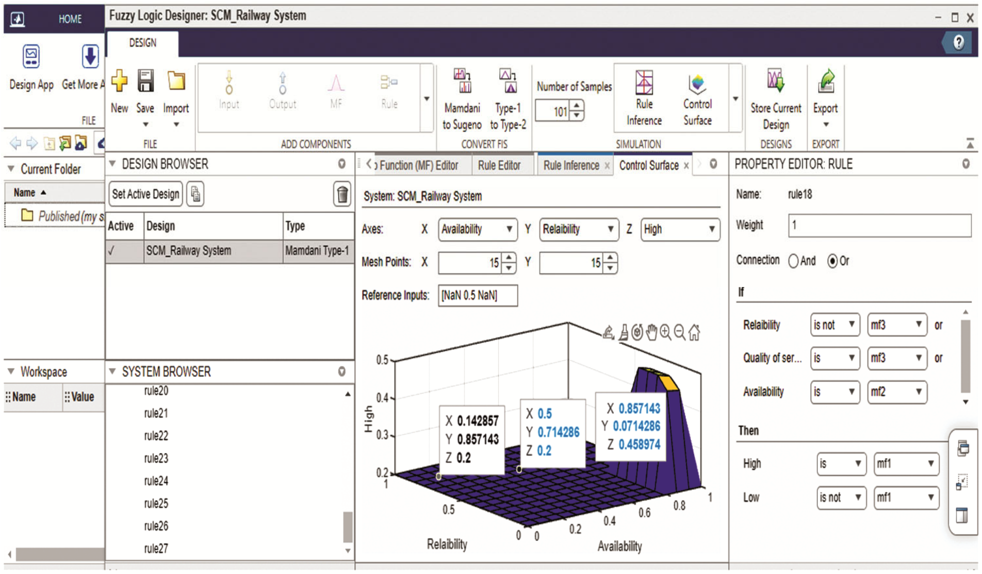

Fig. 17 — Control surface for SCM in IR (availability, reliability with high).

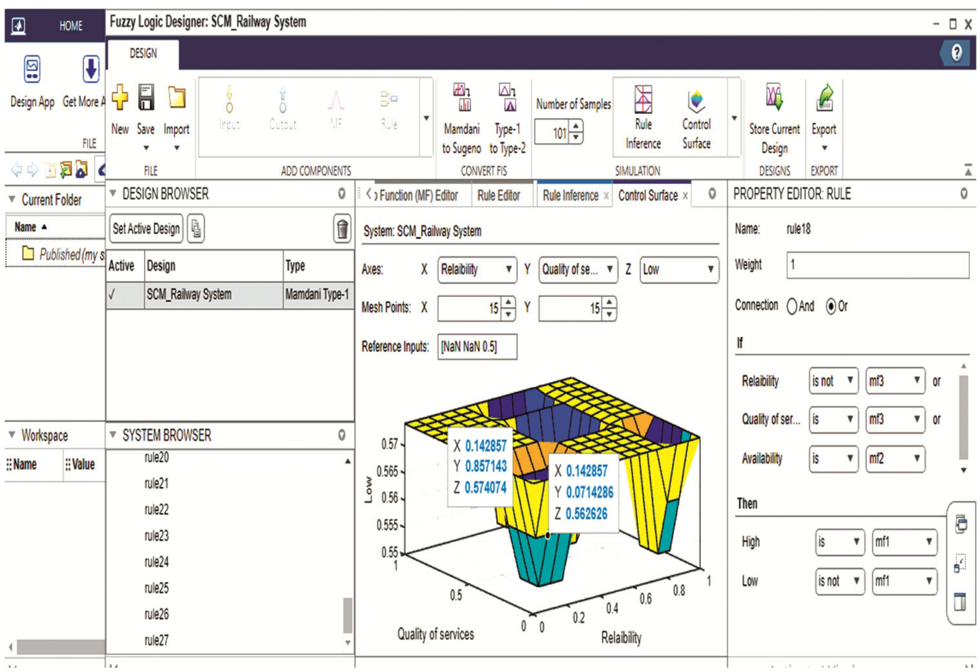

Fig. 18 — Control surface for SCM in IR (reliability quality of services with low).

fewer characteristic points to construct a control surface since it interpolates missing points. Understanding the interpolative technique helps create controllers with fewer rules and ranges making them easier to read and faster to operate.

4 Conclusion

The utilization of the analytic hierarchy process (AHP) and the technique for order of preference by similarity to ideal solution (TOPSIS) in assessing Indian railway supply chain parameters carries profound implications across various fronts. Firstly, it promises a substantial enhancement in efficiency within the railway system. By systematically analyzing and prioritizing various supply chain elements, such as vendor performance, inventory management, and transportation routes, AHP and TOPSIS facilitate targeted interventions to alleviate

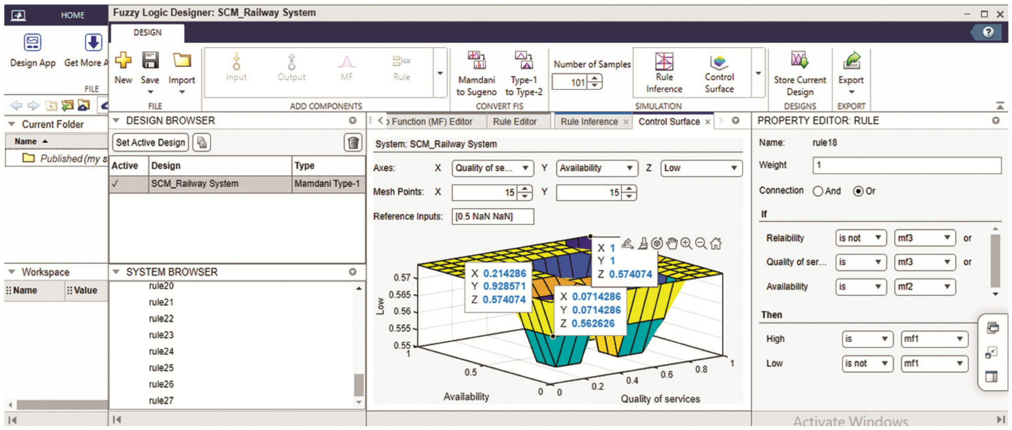

Fig. 19 — Control surface for SCM in IR (quality of services, availability with low).

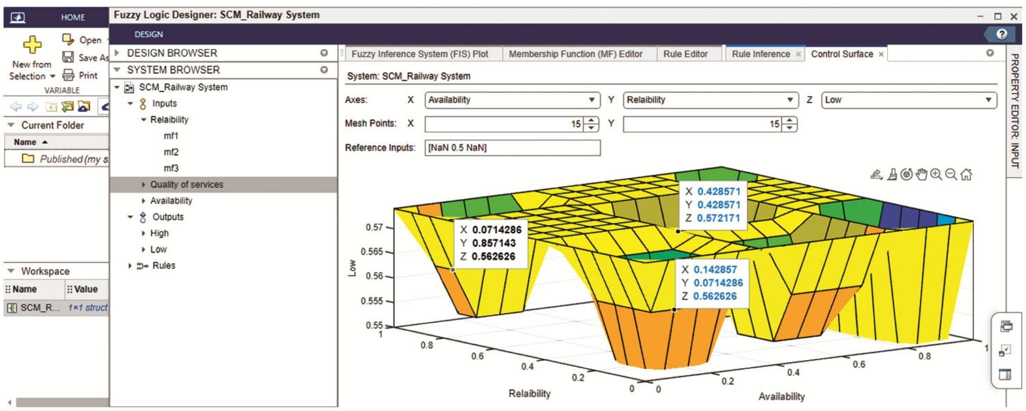

Fig. 20 — Control surface for SCM in IR (availability, reliability with low).

bottlenecks and streamline operations. Consequently, this optimization translates into cost reductions, improved service delivery, and heightened customer satisfaction levels. Moreover, the structured decision-making framework offered by these methodologies enables Indian railways to allocate resources judiciously, directing investments towards areas with the highest potential for impact. Such resource optimization not only fosters financial savings but also amplifies the railway's competitive advantage in the transportation sector. Additionally, the insights gleaned from AHP and TOPSIS evaluations can inform policy formulation, guiding governmental interventions aimed at bolstering the efficiency and sustainability of the railway supply chain. By integrating advanced technologies and sustainability criteria into the assessment process, Indian Railways can further fortify its position as a pioneering force in the global transportation landscape, driving not just economic growth but also environmental stewardship and social responsibility.

Tools such as TOPSIS and the Analytical Hierarchy Process (AHP) can aid in categorization decisions. The study divides its approach into five stages: selecting parameters based on expert opinions, identifying the most crucial criteria, analyzing the results using the AHP method and TOPSIS technique, and finalizing the best criteria for a highly recommended model. Sensitivity analysis showed that the results were reliable and consistent. It would help SCM provide an appropriate process within the Indian Railways quality system. We have also presented a statistical normalization method that may be used in multi-decision matrix selection situations. Assigning weights according to the relative importance of each criterion and taking into account elements like subjectivity, decision complexity, and uncertainty—all of which are present in the SCM selection process—are some of the benefits of using this method. The results demonstrate the need for a reliable and consistent approach to weighing criteria and identifying the most important linguistic traits. These claims have already been validated. The TOPSIS model produced a lower criterion value for Stage 1, Stage 3, and all other variables combined in this case study, and a higher criterion value for Stage 2. Additionally, the expert's competence and the provided linguistic values accurately determine the ultimate ranking order, with Stage 2 vendors expected to outperform those in Stages 1 and 3. Lastly, we observed the entire procedure (AHP) and used the Si+ and Si-values from the TOPSIS technique to confirm the findings. The results demonstrate the great significance of the suggested procedures and the validity of their parameter ranges. We apply fuzzy logic to the planned inquiry to support it. Process improvement is made simpler and more successful when using the suggested grey fuzzy logic technique to evaluate many performance metrics. The results of the simulation show that the suggested study on the SCM of the Indian railway system correctly and precisely tracked SCM parameters in all test cases. To assess service availability, reliability, and quality, SCM needs human interaction. As a result, the components are wiser and better.

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