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Research paper

A Multi-Criteria Decision-Making Approach for Evaluating Business Excellence Frameworks for The Indian Automotive Sector: A Qualitative Assessment

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Abstract

The Indian automotive component sector is undergoing rapid transformation. It is driven by intensified global competition, stringent OEM expectations, and the accelerated adoption of Industry 4.0 technologies. Classical Business Excellence Frameworks (BEFs)—such as EFQM, the Malcolm Baldrige National Quality Award (MBNQA), and the Deming Prize—have traditionally supported excellence initiatives; however, their suitability within today's digitally evolving and culturally complex Indian manufacturing context remains unclear. Based on these gaps, an Extended Business Excellence Framework (EBEF) was developed, integrating digital transformation, information standardization, sustainability, and enhanced PDCA cycles. This study evaluates these various BEFs using qualitative practitioner insights and structured Multi-Criteria Decision-Making (MCDM) methods. Semi-structured interviews with 15 senior automotive leaders identified six major evaluation criteria: ease of implementation, cultural adaptability, effectiveness, efficiency, speed and cost . Using real-number TOPSIS and COPRAS analyses, the EBEF consistently outperformed classical BEFs, with sensitivity and volatility analysis confirming its robustness. The findings offer a contemporary, industry-aligned excellence model capable of supporting Indian automotive suppliers in transitioning to Quality 4.0 environments.

Keywords: *Business Excellence Frameworks; Industry 4.0 and Quality 4.0; Automotive Supplier Development; EFQM; MBNQA; Deming Prize; Multi-Criteria Decision-Making (MCDM); TOPSIS; COPRAS; Digital Transformation; Extended Business Excellence Framework (EBEF).*

1. Introduction

The Indian automotive component sector has emerged as one of the most dynamic contributors to global manufacturing competitiveness, supported by a dense network of Tier-1 and Tier-2 suppliers integrated into the global automotive value chain. Over the last decade, the industry has witnessed significant pressures driven by increasing customer expectations, global competition, digital transformation, and the stringent quality requirements mandated through IATF 16949 and OEM-specific standards (Liu & Gao, 2009; Shah & Ward, 2007). Organizations within this sector are expected to deliver zero-defect products consistently, ensure supply-chain responsiveness, maintain robust process control, and address sustainability expectations—demands that continuously stretch existing quality and operational management systems.

Business Excellence Frameworks (BEFs) have historically played a pivotal role in supporting organizational improvement and strategic performance alignment. Models such as the European Foundation for Quality Management (EFQM) Excellence Model, the Malcolm Baldrige National Quality Award (MBNQA), and the Deming Prize (TQM by JUSE) provide structured approaches to leadership, process maturity, stakeholder engagement, and results measurement (Porter & Tanner, 2004; Oakland & Tanner, 2007; Kanji, 2001). Each framework has been adopted globally in multiple industries, demonstrating their capability for systematically improving organizational performance (Conti, 1996; Neely, 2007). However, with the emergence of Industry 4.0 technologies—such as cyber-physical systems, IoT, digital twins, and artificial intelligence—the nature of operational excellence has fundamentally changed (Lee, Bagheri & Kao, 2015; Lasi et al., 2014; Rojko, 2017).

Despite their historical effectiveness, classical BEFs were conceptualized before the advent of digitalization and thus do not explicitly incorporate modern requirements such as real-time data integration, automation, digital traceability, information standardization, and predictive quality analytics—capabilities that are becoming indispensable for global competitiveness (Sony & Naik, 2020; Sader, Husti &

Daroczi, 2021). This has resulted in increasing concerns regarding their contemporary relevance, especially within rapidly evolving manufacturing domains like the Indian automotive sector.

The Indian automotive context also presents a unique cultural and operational set of challenges, hierarchical decision-making structures, diverse workforce competencies, varying levels of process discipline, and resource limitations across MSMEs (Singh & Khanduja, 2018; Tari, 2005). Studies consistently highlight challenges such as the difficulty of adopting documentation-heavy frameworks, gaps in digital maturity, and reduced capability to implement complex performance measurement systems (Bhamu & Sangwan, 2014; Moeuf et al., 2018). As a result, even organizations familiar with classical BEFs often struggle to deploy them effectively.

Given these challenges, two major gaps emerge from existing literature:

1) Classical BEFs do not sufficiently address Industry 4.0 or Quality 4.0 requirements, limiting their relevance in digitally transforming organizations (Marr, 2015; Schoeman, 2022).
2) There is a lack of research evaluating BEFs within the Indian automotive supplier context, especially from the combined perspectives of practitioner insights and structured analytical comparison (Dahlgaard-Park, 2011).

To address these gaps, this study undertakes a comprehensive evaluation of EFQM, MBNQA, and the Deming Prize using a practitioner-driven qualitative approach and a structured Multi-Criteria Decision-Making (MCDM) analysis. Based on these findings, the new Business Excellence Framework was developed as a modern, integrated model that strengthens organizational competitiveness. It combines digital transformation, information standardization, sustainability priorities, and enriched PDCA cycles to enhance data-driven decision-making, process consistency, long-term value creation, and continuous improvement. Together, these elements help us fill the gaps and propose a new Business Excellence Framework that is simple, streamlined and ready for future needs of todays' manufacturing industries.

Through interviews with senior automotive industry leaders, six key evaluation criteria emerged: ease of implementation, cultural adaptability, effectiveness, efficiency, speed and cost. The study employs TOPSIS and COPRAS analyses to compare the suitability of classical BEFs against the proposed EBEF. This dual-method evaluation provides a robust, balanced assessment that captures both qualitative insights and quantitative decision logic. The findings demonstrate that the EBEF offers greater alignment with the digital, cultural, and operational needs of Indian automotive suppliers, while classical BEFs exhibit limitations when evaluated through modern performance lenses.

The contributions of this study are threefold. First, it presents a more contextually relevant and digitally integrated Extended Business Excellence Framework (EBEF) tailored to meet current industry demands. Second, it offers an evidence-based evaluation of classical business excellence frameworks, specifically tailored to the Indian automotive context. Third, it demonstrates the application of a hybrid analytical approach that combines qualitative criteria with numerical Multi-Criteria Decision-Making (MCDM) techniques to assess the overall suitability and robustness of the proposed model. This establishes a practical, future-ready foundation for automotive suppliers committed to enhancing the robustness and maturity of their excellence systems.

2. Literature Review

This section reviews the established Business Excellence Frameworks (BEFs) and the contextual challenges encountered by Indian automotive suppliers. It concludes by identifying gaps that justify the need for an Extended Business Excellence Framework (EBEF).

2.1. Classical business excellence frameworks (BEFs)

Business excellence frameworks have long served as foundational tools for organizations seeking structured, holistic approaches to improving performance, developing capabilities, and enhancing stakeholder value. Among these, the EFQM Excellence Model, Malcolm Baldrige National Quality Award (MBNQA), and the Deming Prize are the most globally recognized and widely implemented. However, as manufacturing sectors—especially automotive supply chains—undergo rapid technological transformation, the suitability of traditional excellence models has come under increasing scrutiny. Scholars argue that while these frameworks have historically delivered significant improvements, they fall short in capturing the requirements of digital-era operations, predictive analytics, cyber-physical systems, and sustainability-driven competitiveness.

2.1.1. EFQM excellence model

The EFQM Excellence Model provides a comprehensive structure built on leadership, strategy, partnerships, people, and processes (Porter & Tanner, 2004). The 2020 revision emphasizes adaptability, transformation capability, and stakeholder value (EFQM Foundation, 2020), reflecting an attempt to modernise the model. Yet several limitations persist. Researchers highlight the model's heavy documentation requirements, complex assessment processes, and dependence on highly trained evaluators, making it difficult for resource-constrained MSMEs to adopt (Bunney & Dale, 1997; Zink, 2008). More importantly, EFQM provides insufficient operational direction for incorporating digital technologies, real-time production data, cyber-physical systems, and automated analytics within its enabler structure. Hence there is a significant gap in progressing towards digitally advanced manufacturing environments.

2.1.2. Malcolm Baldrige national quality award (MBNQA)

The MBNQA framework similarly emphasizes leadership, strategy, customer focus, measurement, analysis, knowledge management, and workforce capability (NIST, 2021). It is broadly appreciated for its strategic clarity and its strong orientation toward organisational learning and innovation. However, the MBNQA framework is considered resource-intensive and documentation-heavy, requiring substantial managerial capability to implement effectively (Neely, 2007). Despite its strengths, it does not sufficiently incorporate digital tools or Industry 4.0 practices such as IoT-enabled monitoring, machine-data alignment, or predictive quality analytics—areas now fundamental to competitive manufacturing operations.

2.1.3. Deming prize

The Deming Prize, rooted in classical Total Quality Management, offers strengths in PDCA discipline, statistical control, and a philosophy of continuous improvement (Deming, 1986). Although historically relevant in Asian manufacturing contexts due to cultural alignment with collective learning and disciplined operations, scholars point to several limitations. The Deming approach lacks integration of digital tools, offers minimal focus on sustainability, and provides limited guidance for data-driven or AI-based manufacturing systems (Sila &

Ebrahimpour, 2005; JUSE, 2020). Its traditional TQM orientation does not adequately address Industry 4.0 requirements, such as digital traceability, automated inspection, edge analytics, or cyber-physical production systems.

2.2. Industry 4.0 and digital transformation

As organizations increasingly transition toward smart manufacturing, Industry 4.0 represents a paradigm shift involving cyber-physical systems, real-time analytics, intelligent automation, and interconnected supply chains (Lasi et al., 2014). These technologies enable predictive defect detection, digital part traceability, remote monitoring, and enhanced process resilience (Kagermann, 2013; Moeuf et al., 2018). Despite these advancements, traditional excellence models provide limited guidance on digital maturity, IoT integration, big-data environments, or automated quality loops. Studies indicate a growing implementation gap for firms attempting to align legacy excellence practices with digital-era operational requirements (Sony & Naik, 2020).

2.3. Quality 4.0 and new models of excellence

Parallel to Industry 4.0, the concept of Quality 4.0 has emerged, focusing on integrating digital technologies with classical quality principles to enhance prediction, autonomy, and decision intelligence. Quality 4.0 encompasses digital audits, automated compliance, AI-driven analytics, and advanced statistical automation (Schoeman, 2022). However, classical excellence frameworks do not sufficiently address these elements. The absence of digital PDCA loops, automated measurement systems, and AI-enabled quality processes limits the applicability of traditional models for assessing organisational maturity in technologically evolving supply chains.

2.4. Cultural and operational context of indian automotive suppliers

Within the Indian context, automotive suppliers face unique cultural and operational challenges, including variable managerial capability, high cost sensitivity, differing levels of automation, and heavy dependence on OEM requirements. These factors significantly influence the feasibility of implementing excellence models that require high documentation, sophisticated assessment capability, or strong digital foundations. Consequently, the disconnect between traditional frameworks and operational realities becomes more pronounced, limiting their diagnostic relevance and practical applicability in the Indian automotive supply ecosystem.

2.5. Comparative analysis of ISO 9001, MBNQA, EFQM, and deming prize frameworks

The comparison of ISO 9001, MBNQA, EFQM, and the Deming Prize across foundational criteria demonstrates that while all frameworks converge on core themes such as customer focus, leadership, process discipline, and fact-based decision-making, they apply these principles through different managerial philosophies. ISO 9001 emphasises structured compliance and process control, whereas MBNQA adopts a strategic and performance-oriented perspective. EFQM integrates purpose, culture, and stakeholder engagement as drivers of long-term value creation, while the Deming Prize reflects a strong TQM tradition grounded in Kaizen, employee involvement, and disciplined problem-solving. Collectively, the table highlights shared conceptual roots but distinct operational expressions across the four models.

Table 1: Comparative Mapping of Major Business Excellence Framework

S. No	QMS – ISO 9001	Malcolm Baldrige National Quality Awards	European Foundation for Quality Management	Deming Prize – JUSE
1	Customer Focus	Leadership	Directions – Purpose, vision & strategy	Process thinking
2	Leadership	Strategy	Directions – Organisation culture & leadership	Customer Satisfaction
3	Engagement of people	Customer focus	Executions – Engaging Stakeholders	Total Employee involvement
4	Process Approach	Measurement analysis and Knowledge	Executions – Creating Sustainable Value	Strategic thinking
5	Improvement	Workforce	Executions – Driving Performance and Transformations	Integrated systems
6	Evidence-based decision making	Operation	Results – Strategic Operational Performance	Decision based on facts
7	Relationship Management	Results	Results – Stakeholder perceptions	Continual Improvement Projects
8				Effective Communications

Table 2: Comparative Analysis of Major Business Excellence Framework

Dimension / Criteria	EFQM (Porter & Tanner, 2004; EFQM, 2020)	MBNQA (NIST, 2021)	Deming Prize / JUSE TQM (Deming, 1986; JUSE, 2020)	ISO 9001 : 2015
Philosophical Base	Holistic, stakeholder value, strategy-led	Organisational performance excellence	TQM, PDCA, statistical quality	Compliance-driven automotive QMS
Primary Focus	Purpose, culture, transformation, sustainability	Leadership, strategy, customer, knowledge	Continuous improvement, process discipline	Defect prevention, standardisation
Strengths	Holistic, flexible, transformation-oriented	Structured, innovation-driven, results focus	Process discipline, data orientation	Strong process controls, supplier assurance
Documentation Requirement	High	High	Moderate–High	Very High
Digital Integration Coverage	Limited; general strategy-level	Limited; conceptual	Minimal; traditional TQM	Limited; mainly compliance-based
Sustainability Coverage	Strong (EFQM 2020)	Moderate	Weak	Limited
Industry 4.0 Alignment	Weak	Weak	Very weak	Weak–Moderate (traceability)
Applicability to MSMEs	Low–Moderate	Low	Moderate	Low

Major Limitations / Gaps	Complex, resource intensive, limited digital alignment	Documentation-heavy, weak operational digital guidance	Lacks digital, sustainability, automation emphasis	Compliance focus; weak strategic and transformational orientation

The dimension-level analysis in Table 2 further reinforces the varied orientations of these frameworks. EFQM stands out as holistic and transformation-driven, but it requires substantial resources and offers limited specificity for digital operations. MBNQA provides a structured, innovation-oriented approach but remains documentation-heavy and weakly aligned with Industry 4.0. The Deming framework excels in process discipline but lacks provisions for sustainability, automation, and digital integration. ISO 9001 delivers strong compliance and defect-prevention capability yet remains narrow, audit-centric, and limited in strategic and sustainability depth.
Despite these differences, all four frameworks share common gaps:

- Limited integration of digital transformation requirements, including IoT, analytics, and automation.
- Insufficient guidance for real-time, data-intensive manufacturing environments.
- Minimal emphasis on sustainability and ESG-linked performance.
- Weak alignment with the operational and cultural realities of emerging economies such as India.

As a result, these frameworks—while conceptually aligned—do not fully meet the excellence requirements of modern automotive suppliers operating within digitally advancing, globally competitive, and resource-constrained environments.

2.6. Gaps identified in the literature

The literature consistently highlights four key gaps:
a) Classical BEFs are not digitally integrated and lack support for Industry 4.0 and Quality 4.0 (Sony & Naik, 2020).
b) Limited research evaluates BEFs within the Indian automotive supplier ecosystem
c) Few studies combine qualitative practitioner insights with MCDM techniques for BEF evaluation (Poyhonen, 2003).
d) There is no Business Excellence Framework tailored for Indian Automotive Industry 4.0 context
These gaps form the rationale for developing the EBEF and conducting a comparative MCDM-based evaluation.

2.7. Proposed extended business excellence framework (EBEF)

Given the gaps emerging from existing literature, this study has proposed an Extended Business Excellence Framework (EBEF). Building on established models such as EFQM, MBNQA, and the Deming Prize, the proposed model provides a harmonized and digitally aligned framework. It emphasizes rotating PDCA cycles, Daily Management (SDCA), Policy Management (Hoshin Kanri), Lean Six Sigma, Digital Transformation, and Sustainability. Based on literature on Industry 4.0 and Quality 4.0, a new Extended Business Excellence Framework (EBEF) was developed. The EBEF aims to bridge gaps in classical BEFs by explicitly incorporating digital transformation, data standardization, sustainability, and implementation simplicity.

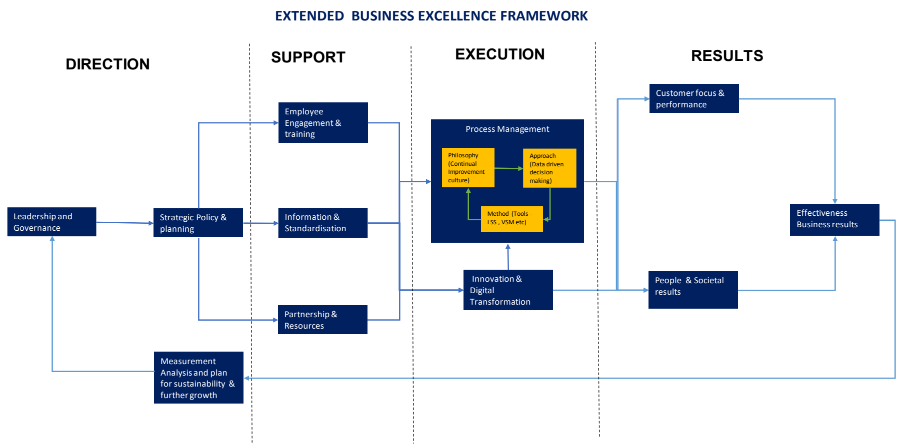

Fig. 1: Proposed Extended Business Excellence Framework (Reproduced from Our Earlier Publication , Eugene. J and Arivazhagan , 2024)

2.7.1. Rationale for EBEF

Classical Business Excellence Frameworks show several limitations when assessed against the digital, operational, and cultural requirements of the Indian automotive sector. They offer limited integration of emerging technologies such as IoT, AI, and analytics and they rely heavily on documentation-driven processes that are unsuitable for MSMEs. Furthermore, they demonstrate weak alignment with the hierarchical, people-centric culture prevalent in Indian industries. Moreover, they provide insufficient emphasis on sustainability and future readiness, lack standardised digital information flow, and often result in slow PDCA cycles due to manual data handling. These limitations are consistent with observations reported in global literature (Schoeman, 2022).

2.7.2. Structure of the EBEF

The EBEF consists of six interconnected pillars:
1) Innovation & Digital Transformation (IDT). Includes IoT, automation, predictive analytics, digital twins, and data-driven decision-making. Supports real-time monitoring, predictive defect detection, and digital audit trails.
2) Information Standardisation (IS). Focuses on consistent data structures, traceability, digital document control, and integration of shop-floor systems. Addresses common issues of inconsistent or unverified manufacturing data.
3) Sustainability & Future Growth (SFG). Incorporates ESG expectations, environmental performance, resource optimisation, and long-term capability building (Lozano, 2007).

4) Enhanced PDCA Alignment (PCA). Strengthens the traditional PDCA cycle by incorporating digital tools that enable automated process data capture, rapid root-cause analysis, and real-time corrective-action closure. This approach retains the foundational principles of the Deming philosophy while modernising their application for digitally driven operational environments.
5) Philosophy & Methodology in Process Management (PMPM). Combines Lean, Six Sigma, Kaizen, and digital quality methods (Quality 4.0). Addresses process variation, standardisation, and waste elimination.
6) Business Excellence Outcomes (BEO) measure performance across multiple dimensions, including zero-defect quality, on-time delivery, digital maturity, customer satisfaction, sustainability performance, and operational cost reduction. Collectively, these outcomes ensure strong alignment with OEM expectations as well as global manufacturing benchmarks.

2.7.3. Summary of EBEF advantages

Compared with classical BEFs, the EBEF integrates digital transformation directly into organisational excellence, supports simplified implementation suitable for MSMEs, and aligns with the cultural and operational realities of Indian automotive firms. It also incorporates sustainability and future capability, retains the strengths of TQM and the PDCA philosophy while modernising their application, and offers a measurable, scalable, and OEM-auditable structure.

3. Methodology

This study adopts an exploratory, qualitative-driven research design combined with structured multi-criteria decision-making (MCDM) techniques. The approach is consistent with research on performance excellence that integrates practitioner judgement with analytical comparison (Poyhonen, 2003; Triantaphyllou, 2000). The objective was to understand the contextual suitability of classical BEFs in the Indian automotive component sector and develop an Extended Business Excellence Framework (EBEF) grounded in practitioner insights and digital transformation requirements.
A three-stage methodology was followed, beginning with qualitative data collection through semi-structured interviews, followed by thematic analysis to derive the relevant evaluation criteria, and culminating in the development of the Extended Business Excellence Framework (EBEF) along with a numerical evaluation using TOPSIS and COPRAS. This mixed qualitative–analytical approach enabled the study to combine experience-based insights from senior practitioners with a structured, quantifiable comparison across competing excellence models.

3.1. Sampling

Purposive expert sampling was adopted, as it is well suited for qualitative studies that prioritise deep, experience-based insights over population generalisation (Palinkas et al., 2015). A total of fifteen senior automotive industry professionals participated, representing Tier-1 component suppliers, Tier-2 MSME manufacturers, OEM quality and supplier development teams, and practitioners with exposure to EFQM, MBNQA, TQM, the Deming Prize, and ISO 9001/IATF 16949. Eligibility criteria required a minimum of 20 years of automotive industry experience, hands-on involvement in implementing at least one Business Excellence or TQM model, direct responsibility for quality, operations, or business excellence, and familiarity with digital transformation initiatives. This approach ensured that the resulting evaluation criteria accurately reflected the operational, cultural, and technological realities of the Indian automotive ecosystem.

3.2. Data collection

Semi-structured interviews were selected for their flexibility and effectiveness in capturing rich practitioner insights (Kvale, 1996). The discussions covered perceptions of EFQM, MBNQA, and Deming models, their applicability to Indian suppliers, challenges in implementation, digital and cultural gaps, factors influencing model selection, and expectations from a modern excellence framework. Each interview lasted between 45 and 75 minutes and was recorded and transcribed for analysis. Thematic data saturation was achieved at the twelfth interview, aligning with established qualitative research norms, although data collection was extended to fifteen participants to strengthen robustness and ensure comprehensive coverage. Data saturation confirmed at 12^{th} interview as no new themes, codes emerged therafter. An ethics paragraph was added detailing informed consent, confidentiality measures, anonymization, and secure data handling.

4. Thematic analysis

The study employed Braun and Clarke’s (2006) six-step approach to thematic analysis:
1) Familiarisation with the data
2) Generation of initial codes
3) Searching for themes
4) Reviewing themes
5) Defining and naming themes
6) Producing the thematic mapping

Through iterative coding and aggregation of practitioner insights, several recurring challenges and expectations related to evaluation outcomes of BEF identified.
Key practitioner observations included:
The interviews revealed several recurring insights: experts noted the excessive complexity of EFQM and MBNQA for MSMEs, the strong PDCA discipline embedded in the Deming model but its limited digital readiness, and a general lack of guidance on digital integration and automation across all three frameworks. Participants also emphasised a cultural mismatch between Western-designed excellence models and Indian shop-floor realities, along with the difficulty of quantifying certain classical BEF constructs such as leadership and societal value. Collectively, these observations underscored the need for a simple, scalable, and digitally oriented framework suited to the Indian automotive context.

4.1. Emergence of six evaluation criteria

The thematic analysis followed a systematic multi-stage coding process in which interview transcripts were examined line-by-line to identify repeated patterns, practitioner concerns, and frequently emphasised operational needs. During open coding, all statements related to excellence model experiences, deployment challenges, and contextual factors were extracted. These codes were then grouped through axial coding into broader meaning clusters such as simplicity, cultural fit, workflow efficiency, and affordability. Finally, through selective coding, these clusters were consolidated into the core themes that appeared consistently across the interviews and formed the basis for the MCDM criteria. Using the exact wording from the thematic analysis table, the six criteria derived were:

1) Ease of Implementation – emerging from repeated emphasis on simplicity, reduced training, and process clarity, reinforcing that simplified deployment enhances adoption.
2) Cultural Adaptability – grounded in practitioner discussions about local fit, employee acceptance, and organisational culture, showing that culturally aligned models sustain engagement.
3) Effectiveness – derived from observations about measurable KPIs, improved outcomes, and strategic impact, demonstrating what constitutes true excellence performance.
4) Efficiency – reflecting themes related to streamlined workflow and resource optimisation, which maximise productivity and ensure quality consistency.
5) Speed – arising from comments on decision-making agility and reduced lead time, highlighting the need for accelerated organisational responsiveness.
6) Cost – linked directly to affordability, ROI considerations, and resource economy, ensuring long-term financial sustainability for MSMEs and suppliers.

These six themes—identified repeatedly and independently across participants—formed the validated evaluation criteria used in the TOPSIS and COPRAS analysis. Since coding was conducted by a single researcher, inter-rater comparison was not applicable. To ensure analytical rigor, the researcher used an iterative coding approach, repeatedly revisiting the transcripts and refining codes to maintain internal consistency. Additionally, the coding structure and theme definitions were reviewed and validated by the supervisory author, ensuring methodological robustness even without multiple coders.

These criteria are consistent with prior research on excellence adoption barriers in developing economies (Singh & Khanduja, 2018; Sony, 2020).

5. Multi-Criteria Decision-Making (MCDM) Analysis

To compare the three classical Business Excellence Frameworks (EFQM, MBNQA, and the Deming Prize), the ISO 9001 Quality Management System model, and the proposed Extended Business Excellence Framework (EBEF), a Multi-Criteria Decision-Making (MCDM) approach was adopted. Two well-established MCDM techniques were applied: TOPSIS (Hwang & Yoon, 1981) and COPRAS (Zavadskas & Kaklauskas, 2000). Both methods were executed using the same decision matrix and the same criteria weights derived from thematic analysis, but they differ in their underlying ranking philosophy—TOPSIS by identifying the alternative closest to the ideal solution and farthest from the negative-ideal, and COPRAS by proportionally evaluating the significance and utility of each alternative. Including ISO 9001 in the comparison enabled a more comprehensive and practical evaluation, as it represents the most widely implemented quality management standard in the global and Indian automotive supplier ecosystem and serves as a foundational maturity baseline for many MSMEs.

The five alternatives evaluated are:

- A_1– EFQM
- A_2– MBNQA
- A_3– Deming Prize
- A_4– ISO9001
- A_5– EBEF (Proposed Framework)

Table 3: Six Benefit Criteria

Outcome		Beneficial	Non Beneficial
C1	Implementation Ease	√	
C2	Adaptability (cultural)	√	
C3	Effectiveness	√	
C4	Efficiency	√	
C5	Speed	√	
C6	Cost		√

All criteria except Cost are treated as benefit criteria, meaning that higher values indicate better performance, whereas Cost is treated as a non-beneficial criterion, where lower values are preferred as shown in Table 3.

5.1. TOPSIS: method and detailed computations

Criteria were derived through thematic analysis of interviews with fifteen senior leaders, and the same experts assigned weights using a 1–9 scaling scheme. With the decision matrix and weights finalized, the analysis proceeded.

Table 4: Rating Scale

Rating	Scale
Vey Poor (VP)	1
Poor (P)	2
Fair (F)	3
Below Average (BA)	4
Average (A)	5
Above Average (AA)	6

Good (G)	7
Very Good (VG)	8
Excellent (E)	9

The resulting decision matrix $X = [x_{ij}]$for the five alternatives is shown in Table 5.

Table 5: Initial Decision Matrix $X = [x_{ij}]$

Alternative /Framework	C_1 Ease of Implementation	C_2 Cultural Adaptability	C_3 Effectiveness	C_4 Efficiency	C_5 Speed	C_6 Cost
A_1 – ISO 9001	6	6	2	1	5	6
A_2 – EFQM	4	4	5	4	4	4
A_3 – MBNQA	4	4	5	4	4	4
A_4 – Deming Prize	4	4	6	6	3	5
A_5 –EBEF	6	6	6	6	6	6

The criteria weights were retained from the expert judgment:

$$w = [w_1, \dots, w_6]$$

$$w_1 = 0.1,\ w_2 = 0.1,\ w_3 = 0.25,\ w_4 = 0.25,\ w_5 = 0.10,\ w_6 = 0.20$$

All weights are non-negative and sum to 1:

$$\sum_{j=1}^{6} w_j = 1.00$$

Criteria C_1–C_5 (Ease of Implementation, Cultural Adaptability, Effectiveness, Efficiency, Speed) are benefit criteria, where higher scores are preferable. Cost (C_6) is a non-beneficial criterion, so lower values are preferred
Step 1: Normalisation of the Decision Matrix
TOPSIS begins by normalizing the data, applying weights, identifying ideal solutions, and computing separation and closeness coefficients to obtain the final ranking of the business excellence models.
For each criterion C_j, vector normalisation is applied:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}$$

where

x_{ij}= raw score of alternative ion criterion j,
r_{ij}= normalised value,
$m = 5$ alternatives.
Example for C_1(Ease of Implementation):

$$\sqrt{\sum_{i=1}^{5} x_{i1}^2} = \sqrt{6^2 + 4^2 + 4^2 + 4^2 + 6^2} = \sqrt{120} = 10.954$$

Thus,

$$r_{11} = \frac{6}{10.954} = 0.548, r_{21} = r_{31} = r_{41} = \frac{4}{10.954} = 0.365, r_{51} = \frac{6}{10.954} = 0.548$$

Applying the same calculation across all criteria gives the normalised matrix $R = [r_{ij}]$(rounded to three decimals) in Table 6.

Table 6: Normalised Decision Matrix R

Alternative	C_1	C_2	C_3	C_4	C_5	C_6
A_1 ISO 9001	0.5477	0.5477	0.1782	0.0976	0.4951	0.5283
A_2 EFQM	0.3651	0.3651	0.4454	0.3904	0.3961	0.3522
A_3 MBNQA	0.3651	0.3651	0.4454	0.3904	0.3961	0.3522
A_4 Deming	0.3651	0.3651	0.5345	0.5855	0.2970	0.4402
A_5 EBEF	0.5477	0.5477	0.5345	0.5855	0.5941	0.5283

(Normalisation denominators: $C_1, C_2: \sqrt{120}; C_3: \sqrt{126}; C_4: \sqrt{105}; C_5: \sqrt{102}; C_6: \sqrt{129}$).
Step 2: Weighted Normalised Matrix
Each normalised value is multiplied by its corresponding weight:

$$v_{ij} = r_{ij} \cdot w_j$$

For example, for ISO 9001 under C_1(with $w_1 = 0.10$):

$$v_{11} = 0.548 \times 0.1 = 0.0548$$

The resulting weighted normalised matrix $V = [v_{ij}]$is presented in Table 7.

Table 7: Weighted Normalised Matrix V

Alternative	C_1	C_2	C_3	C_4	C_5	C_6
A_1 ISO 9001	0.0548	0.0548	0.0445	0.0244	0.0495	0.1057
A_2 EFQM	0.0365	0.0365	0.1114	0.0976	0.0396	0.0704
A_3 MBNQA	0.0365	0.0365	0.1114	0.0976	0.0396	0.0704
A_4 Deming Prize	0.0365	0.0365	0.1336	0.1464	0.0297	0.0880
A_5 EBEF	0.0548	0.0548	0.1336	0.1464	0.0594	0.1057

Step 3: Ideal and Negative-Ideal Solutions
For benefit criteria (C_1–C_5), the ideal solution contains the maximum value in each column and the negative-ideal the minimum. For the cost criterion (C_6), the ideal solution is the minimum value and the negative-ideal the maximum.

$$A^+ = \{v_1^+, \dots, v_6^+\}, A^- = \{v_1^-, \dots, v_6^-\}$$

For benefit criteria C_1–C_5:

$$v_j^+ = \max_i v_{ij},\ v_j^- = \min_i v_{ij}.$$

For the cost criterion C_6:

$$v_6^+ = \min_i v_{i6},\ v_6^- = \max_i v_{i6}.$$

Table 8: Ideal and Negative-Ideal Values

Criterion	v_j^+(Ideal)	v_j^-(Negative-ideal)
C_1	0.0548	0.0365
C_2	0.0548	0.0365
C_3	0.1336	0.0445
C_4	0.1464	0.0244
C_5	0.0594	0.0297
C_6 (Cost)	0.0704	0.1057

Note that for the Cost criterion, the smallest value (0.070) is ideal, the largest (0.106) is negative-ideal.

Step 4: Separation Measures
For each alternative, the separation from the ideal and negative-ideal solutions is calculated

$$S_i^+ = \sqrt{\sum_{j=1}^{6} (v_{ij} - v_j^+)^2}, S_i^- = \sqrt{\sum_{j=1}^{6} (v_{ij} - v_j^-)^2}$$

The resulting values (rounded) are shown in Table 9.

Table 9: Separation Measures S_i^+ and S_i^-

Alternative	S_i^+	S_i^-
A_1 ISO 9001	0.1554	0.0325
A_2 EFQM	0.0627	0.1056
A_3 MBNQA	0.0627	0.1056
A_4 Deming	0.0431	0.1521
A_5 EBEF	0.0352	0.1561

Because EBEF does not have the lowest Cost value, its distance from the ideal is not zero, but it is still closest to the ideal overall.
Step 5: Closeness Coefficient and Ranking
The closeness coefficient for each alternative is:

$$C_i = \frac{S_i^-}{S_i^+ + S_i^-}, 0 \le C_i \le 1$$

A higher C_i indicates greater proximity to the ideal solution.

Table 10: Closeness Coefficients and TOPSIS Ranking

Alternative	C_i	Rank
A_5 EBEF	0.816	1
A_4 Deming Prize	0.779	2
A_2 EFQM	0.627	3
A_3 MBNQA	0.627	3 (tie)
A_1 ISO 9001	0.173	5

As per TOPSIS, EBEF ranks as the most preferable model, followed by Deming Prize, then EFQM and MBNQA, with ISO 9001 providing the lowest overall composite performance when all six criteria—including the non-beneficial Cost criterion—are considered.

5.2. COPRAS: method and detailed computations

COPRAS (Complex Proportional Assessment) evaluates alternatives based on their proportional contribution to beneficial criteria (Zavadskas & Kaklauskas, 2000). For the COPRAS analysis, the same criteria (Table 3), rating scale (Table 4), and decision matrix (Table 3) used in the TOPSIS evaluation were used to ensure methodological consistency.
Step 1: Normalisation by Column Sums
For each criterion, COPRAS uses linear normalisation:

$$d_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}}$$

Column sums for COPRAS normalisation:

$\sum C_1 = 24$, $\sum C_2 = 24$, $\sum C_3 = 24$, $\sum C_4 = 21$, $\sum C_5 = 22$, $\sum C_6 = 25$.

For example, for C_1:

$$\sum_{i=1}^{4} x_{i1} = 6 + 4 + 4 + 4 + 6 = 24$$

$$d_{11} = \frac{6}{24} = 0.25, d_{21} = \frac{4}{24} = 0.167, d_{31} = \frac{4}{24} = 0.167, d_{41} = \frac{4}{24} = 0.167, d_{51} = \frac{6}{24} = 0.25$$

Applying this to across all criteria yields the normalised matrix $D = [d_{ij}]$:

Table 11: COPRAS Normalised Matrix D

Alternative	C_1	C_2	C_3	C_4	C_5	C_6
A_1 ISO 9001	0.2500	0.2500	0.0833	0.0476	0.2273	0.2400
A_2 EFQM	0.1667	0.1667	0.2083	0.1905	0.1818	0.1600
A_3 MBNQA	0.1667	0.1667	0.2083	0.1905	0.1818	0.1600
A_4 Deming	0.1667	0.1667	0.2500	0.2857	0.1364	0.2000
A_5 EBEF	0.2500	0.2500	0.2500	0.2857	0.2727	0.2400

Step 2: Weighted Normalised Matrix
Each normalised value is multiplied by the criterion weight:

$$q_{ij} = d_{ij} \cdot w_j$$

For EFQM on C_1:

$$q_{11} = 0.25 \times 0.10 = 0.025$$

The weighted matrix $Q = [q_{ij}]$is shown in Table 12.

Table 12: COPRAS Weighted Matrix Q

Alternative	C_1	C_2	C_3	C_4	C_5	C_6
A_1 ISO 9001	0.0250	0.0250	0.0208	0.0119	0.0227	0.0480
A_2 EFQM	0.0167	0.0167	0.0521	0.0476	0.0182	0.0320
A_3 MBNQA	0.0167	0.0167	0.0521	0.0476	0.0182	0.0320
A_4 Deming	0.0167	0.0167	0.0625	0.0714	0.0136	0.0400
A_5 EBEF	0.0250	0.0250	0.0625	0.0714	0.0273	0.0480

Step 3: Beneficial and Non beneficial Sums S_i -Sums for Benefit and Cost Criteria
Benefit sums for each alternative (C_1–C_5):

$$S_i^+ = \sum_{j \in \text{benefit}} D_{ij}$$

Cost sum (only C_6):

$$S_i^- = \sum_{j \in \text{cost}} D_{ij} = D_{i6}$$

Table 11: Sum of Benefit and Cost

Alternative	S_i^+	S_i^-
A_1 ISO 9001	0.1055	0.0480
A_2 EFQM	0.1512	0.0320
A_3 MBNQA	0.1512	0.0320
A_4 Deming	0.1809	0.0400
A_5 EBEF	0.2112	0.0480

Minimum cost sum:

$S_{min} = \min_i S_i^- = 0.032$(EFQM and MBNQA).

Step 4. Relative Significance
In COPRAS, the relative significance Q_i(for mixed benefit–cost) is defined as follows:

$$Q_i = S_i^+ + \frac{\sum_k S_k^-}{S_i^- \cdot \sum_k (1/S_k^-)}$$

$\sum S^-$=0.2000, $\sum(1/S^-)$=(1/0.048 +1/0.032+ 1/0.32+1/0.04+ 1/0.048) =129.167

Table 13: Relative Significance Q_i

Model	S^+	S^-	Q_i
ISO 9001	0.1055	0.0480	0.1377
EFQM	0.1512	0.0320	0.1996
MBNQA	0.1512	0.0320	0.1996
Deming Prize	0.1809	0.0400	0.2196
EBEF	0.2112	0.0480	0.2435

Step 4. Compute Utility degree and COPRAS Ranking

$$U_i = \frac{Q_i}{\max Q_i} \times 100\%$$

Since max $(Q_i) = 0.2435$(EBEF):

- $U_5 = 0.2435/0.2435 = 1.000 \Rightarrow 100\%$
- $U_4 = 0.2196/0.2435 = 0.902 \Rightarrow 90.2\%$
- $U_2 = 0.1996/0.2435 = 0.8199 \Rightarrow 81.99\%$
- $U_3 = 0.1996/0.2435 = 0.8199 \Rightarrow 81.99\%$
- $U_1 = 0.1377/0.2435 = 0.5657 \Rightarrow 56.57\%$

Table 15: COPRAS Utility Scores and Ranking

Alternative	Utility U_i(%)	Rank
A_5EBEF	100.0	1
A_4Deming	90.2	2
A_2EFQM	82	3
A_3MBNQA	82	3
A_1ISO 9001	56.5	5

Even in COPRAS, like TOPSIS, EBEF clearly ranks as the best-performing framework.

5.2. Rank consistency -spearman's rank correlation analysis

To evaluate the degree of agreement between the TOPSIS and COPRAS ranking outcomes, Spearman's rank correlation coefficient (ρ) was calculated. As shown in Table16, both methods produced identical rankings for all five business excellence models/ frameworks. Consequently, the rank differences (d_i) were zero for every alternative, resulting in a total squared rank difference of $\Sigma d_i^2 = 0$.

Table16: Comparative Rankings of BEF Based on TOPSIS and COPRAS

Model	TOPSIS Score (Ci)	TOPSIS Rank	COPRAS Score (Uj)	COPRAS Rank	d_i	d_i^2
ISO 9001	0.17312	5	0.5657	5	0	0
EFQM	0.62740	3	0.8199	3	0	0
MBNQA	0.62740	3	0.8199	3	0	0
Deming Prize	0.77911	2	0.9020	2	0	0
EBEF	0.81592	1	1.0000	1	0	0
d_i= TOPSIS rank - COPRAS Rank					$\Sigma d_i^2 = 0$	

Spearman's correlation formula is given by:

$$\rho = 1 - \frac{6\Sigma d_i^2}{n(n^2-1)}$$

Substituting $\Sigma d_i^2 = 0$, we obtain:

$$\rho = 1 - \frac{6(0)}{n(n^2-1)} = 1.$$

A coefficient of ρ = 1 signifies perfect concordance between the TOPSIS and COPRAS rankings. This complete alignment indicates that both MCDM techniques provide mutually reinforcing results, thereby affirming the robustness, reliability, and consistency of the comparative evaluation of the business excellence models/ frameworks.

5.3. Rank consistency -correlation analysis between TOPSIS and COPRAS scores

To further examine the strength and direction of the association between the TOPSIS and COPRAS quantitative scores, a correlation analysis was performed using the deviations of each model's performance from their respective mean values. The required intermediate values, including the cross-product of deviations and the squared deviations of both variables, are summarized in Table 17.

Table 17: Intermediate Values for Correlation Analysis between TOPSIS and COPRAS

Model / Framework	TOPSIS Score (Ci)	Ci – C̄	COPRAS Uj	Uj – Ū	(Ci – C̄)(Uj – Ū)	(Ci – C̄)²	(Uj – Ū)²
ISO 9001	0.17312	-0.43147	0.57	-0.2558	0.11037	0.186168	0.0654
EFQM	0.62740	0.02281	0.82	-0.0016	-0.00004	0.000521	0.0000
MBNQA	0.62740	0.02281	0.82	-0.0016	-0.00004	0.000521	0.0000
Deming Prize	0.77911	0.17452	0.90	0.0805	0.01406	0.030456	0.0065
EBEF	0.81592	0.21133	1.00	0.1785	0.03772	0.044659	0.0319
Averages	0.60459	—	0.82149	—	0.16207	0.262323	0.10379

.

The Pearson-type correlation coefficient (r) was computed using the standard formula:

$$r = \frac{\sum(C_i - \bar{C})(U_j - \bar{U})}{\sqrt{\sum(C_i - \bar{C})^2 \times \sum(U_j - \bar{U})^2}}$$

Using the values obtained from Table 17:

$$\sum(C_i - \bar{C})(U_j - \bar{U}) = 0.16207, \sum(C_i - \bar{C})^2 = 0.262323, \sum(U_j - \bar{U})^2 = 0.10379,$$

The correlation coefficient is calculated as:

$$r = \frac{0.16207}{\sqrt{0.262323 \times 0.10379}} = \frac{0.16207}{0.1650} \approx 0.982.$$

An r-value of 0.982 indicates an exceptionally strong positive linear correlation between the TOPSIS and COPRAS results. This high degree of alignment confirms that both methods produce consistent quantitative assessments of the business excellence models/frameworks, thereby reinforcing the reliability and stability of the comparative evaluation.

5.4. Sensitivity and volatility analysis

Sensitivity analysis examines how ranking stability shifts when the weights of evaluation criteria are modified. It is essential in MCDM to test robustness, especially when criteria weights are derived from qualitative inputs (Triantaphyllou, 2000). Because managerial priorities may differ across organisations, sensitivity analysis ensures that the recommended model remains strong even when decision conditions vary. Table 18 summarises the weight-adjustment scenarios (S1–S6) developed to assess the robustness of the evaluation outcomes against variations in criterion importance. These scenarios introduce systematic changes to the six benefit criteria—implementation ease, adaptability, effectiveness, efficiency, speed, and cost—to reflect plausible shifts in managerial priorities and operational contexts.

Table 18: Weight-Variation Scenarios Used for Sensitivity Analysis

Weight changes Scenario	Implementation ease	Adaptability	Effectiveness	Efficiency	Speed	Cost
Base	0.1	0.1	0.25	0.25	0.1	0.2
S1	0.3	0.1	0.2	0.1	0.2	0.1
S2	0.2	0.3	0.1	0.1	0.1	0.2
S3	0.1	0.2	0.3	0.2	0.1	0.1
S4	0.2	0.1	0.1	0.3	0.1	0.2
S5	0.1	0.1	0.2	0.1	0.3	0.2
S6	0.15	0.15	0.25	0.1	0.15	0.25

Table 19 presents the rankings obtained from TOPSIS and COPRAS under each scenario. The results show how alternative weight configurations influence the relative positions of the five business excellence models. The sensitivity index (SI) and volatility index (VI) were subsequently computed to quantify the degree of responsiveness and variability in model rankings across scenarios as in the Table 20.

Table 19: Ranking Outcomes Under Varying Weight Scenarios.

Model / Framework	Base TOPSIS rank	Base COPRAS rank	S1 TOPSIS rank	S1 COPRAS rank	S2 TOPSIS rank	S2 COPRAS rank	S3 TOPSIS rank	S3 COPRAS rank	S4 TOPSIS rank	S4 COPRAS rank	S5 TOPSIS rank	S5 COPRAS rank	S6 TOPSIS rank	S6 COPRAS rank
ISO 9001	5	5	5	5	2	2	5	5	5	5	5	5	5	5
EFQM	3	3	3	3	4	3	3	3	3	3	2	2	3	3
MBNQA	3	3	3	3	4	3	3	3	3	3	2	2	3	3
Deming Prize	2	2	2	2	3	5	2	2	2	2	4	4	2	2
EBEF	1	1	1	1	1	1	1	1	1	1	1	1	1	1

To assess the robustness of the model rankings, a sensitivity and volatility analysis was performed across seven weighting scenarios (Base, S1–S6). Each scenario modifies the relative importance of the six evaluation criteria to test how ranking outcomes respond to changes in decision-maker preferences.

Table 20: Sensitivity Indices, and Volatility Indices Under Varying Weight Scenarios.

Models/ Framework	TOP-SIS-SI	COP-RAS-SI	Interpretation	Models	TOP-SIS-VI	COP-RAS-VI	Interpretation
ISO 9001	0.143	0.143	Low sensitivity under both methods	ISO 9001	1.134	1.134	Highly volatile in both methods
EFQM	0.286	0.143	Moderate sensitivity in TOP-SIS and low sensitivity in COPRAS	EFQM	0.577	0.378	Moderate volatility in TOPSIS and COPRAS
MBNQA	0.286	0.143	Moderate sensitivity in TOP-SIS and low sensitivity in COPRAS	MBNQA	0.577	0.378	Moderate volatility in TOPSIS and COPRAS
Deming Prize	0.286	0.286	Moderate sensitivity in TOP-SIS and in COPRAS	Deming Prize	0.787	1.254	Highly volatile in both methods; rankings shift with change in weights
EBEF	0	0	Fully stable	EBEF	0	0	Robust

5.4.1. Sensitivity index (SI)

Quantifies the frequency with which the ranking of a given framework changes across the scenarios.

$$SI = \frac{\text{Number of ranking changes}}{\text{Total scenarios}}$$

With seven scenarios:

- 1 change → SI = 1/7 = 0.143
- 2 changes → SI = 2/7 = 0.286
- 0 changes → SI = 0

A higher SI indicates that the model's or framework's ranking is more affected by weight variations.

The Sensitivity Index (SI) reflects the frequency with which a model's/ framework's ranking changes across different weighting scenarios. Low SI values (0–0.143) indicate strong stability and minimal responsiveness to weight variations, moderate SI values (0.143–0.286) suggest limited fluctuations within acceptable bounds, and high SI values (>0.286) signal that rankings are highly dependent on weighting assumptions.

5.4.2. Volatility index (VI)

Captures the magnitude of ranking fluctuations for each framework across scenarios. It is computed as the standard deviation of ranks obtained using TOPSIS and COPRAS

$$VI = \sqrt{\frac{\sum(r_i - \bar{r})^2}{n}}$$

Where

- r_i= rank in each scenario
- $\bar{r}$= mean rank
- $n = 7$scenarios

A VI closer to 0 indicates highly stable rankings, whereas higher values denote greater instability.

The Volatility Index (VI) measures the magnitude of ranking variation, where low values (approximately zero) denote high robustness, moderate values indicate controlled fluctuations, and high values (>1) represent considerable instability.

6. Discussion

Together, the Sensitivity Index (SI) and Volatility Index (VI) provide a comprehensive assessment of ranking robustness by capturing both the consistency and magnitude of changes across weight-variation scenarios. The analysis shows that the Extended Business Excellence Framework (EBEF) demonstrates zero sensitivity and zero volatility, confirming exceptional robustness under all weighting variations in both TOPSIS and COPRAS. In contrast, ISO 9001 and the Deming Prize model display high volatility, indicating susceptibility to shifts in criteria importance, while EFQM and MBNQA exhibit moderate sensitivity and volatility, reflecting partial stability with occasional rank variations. These findings align with prior observations that structured excellence models respond differently to managerial priorities (Mohammad & Mann, 2010), whereas compliance-oriented systems tend to fluctuate under changing strategic weights (Psomas & Antony, 2015). Complementing the robustness analysis, the comparative evaluation using TOPSIS and COPRAS (Zavadskas & Kaklauskas, 1996) produced identical baseline rankings, with EBEF outperforming ISO 9001, EFQM, MBNQA, and the Deming Prize. The strong correlation between the two methods ($r \approx 0.982$) and perfect rank concordance ($\rho = 1$) demonstrate strong methodological agreement, consistent with earlier findings that TOPSIS and COPRAS often converge under well-structured criteria sets (Opricovic & Tzeng, 2004; Zavadskas et al., 2014). Collectively, the SI–VI diagnostics and MCDM concordance confirm the reliability of the analytic approach and position EBEF as a structurally resilient and superior excellence framework for the Indian automotive component sector.

7. Conclusion

This study demonstrates that TOPSIS (Hwang & Yoon, 1981) and COPRAS (Zavadskas & Kaklauskas, 1996) yield highly convergent evaluations of business excellence frameworks, as evidenced by strong correlation and consistent ranking across all weighting scenarios. Both methods consistently identify the Extended Business Excellence Framework (EBEF) as the most stable and resilient model, with sensitivity and volatility analysis confirming its robustness under changing evaluation conditions. EBEF's performance advantage is attributable to its expanded architecture, which incorporates classical excellence principles found in EFQM (EFQM, 2020), MBNQA (NIST, 2023), ISO 9001 (ISO, 2015), and the Deming Prize model (JUSE, 2019), while integrating contemporary organisational imperatives such as agility, digital readiness, sustainability, and stakeholder value creation. This aligns with theoretical perspectives emphasising dynamic capabilities (Teece et al., 1997), socio-technical integration (Trist & Bamforth, 1951), and organisational learning (Senge, 1990), all of which support frameworks that adapt effectively to evolving environmental demands. Overall, the integrated TOPSIS–COPRAS evaluation provides a rigorous and replicable methodology for assessing excellence models in multi-criteria contexts and reinforces the relevance of extended frameworks such as EBEF for modern industrial ecosystems.

8. Practical and Theoretical Implications

The findings show that the Extended Business Excellence Framework (EBEF) provides a more context-responsive and resilient basis for improvement than classical models. Firms can integrate EBEF into strategic planning, performance measurement, and assessment routines, consistent with established guidance (Oakland, 2014; Dahlgaard-Park, 2011). Its simplicity and digital alignment support MSME capability building and are aligned with Make in India priorities for competitiveness and technology adoption. The framework's emphasis on sustainability (Elkington, 1998) and digital capability (Frank et al., 2019) enables structured Industry 4.0 progression.

EBEF also offers OEMs a practical tool for supplier development, allowing them to benchmark suppliers on digital maturity, process discipline, and cultural adaptability. Sensitivity and volatility results provide managers with actionable insight into how strategic shifts influence the suitability of different excellence models. At a policy level, the findings underscore the importance of targeted government support—such as subsidies for digitalisation, traceability systems, and workforce upskilling—to accelerate MSME readiness for Industry 4.0.

Theoretically, this study contributes in three significant ways. First, it reinforces the convergent validity of TOPSIS and COPRAS as robust multi-criteria decision-making techniques (Behzadian et al., 2012), demonstrating their reliability in complex organizational evaluation contexts. Second, it provides empirical support for the superiority of extended excellence frameworks, aligning with literature advocating capability-based, learning-driven approaches to organisational excellence rather than static compliance-oriented models (Leonard-Barton, 1995; Nonaka & Takeuchi, 1995). Third, by systematically analysing the stability of model rankings under weight perturbations, the study advances methodological understanding of robustness in MCDM-based framework comparisons, an area highlighted as underexplored in previous reviews (Mardani et al., 2015).

9. Limitations

Despite its contributions, the study has limitations. Subjective weighting—derived from expert judgement—may introduce bias, although the sensitivity analysis mitigates this concern by testing model behaviour under varying conditions. Potential bias may also arise in framework selection and criteria structuring, as relevance varies across industries and cultural contexts. Additionally, MCDM techniques inherently rely on expert cognition, which may be influenced by domain familiarity or interpretive differences (Belton & Stewart, 2002). Future research may address these limitations by applying objective or hybrid weighting methods (such as entropy or CRITIC), validating EBEF across diverse sectors and geographies, conducting longitudinal assessments of framework implementation, and incorporating behavioural decision-making theories to examine how experts evaluate excellence criteria.

10. Future Research Directions

- Apply the approach across service sectors, digital manufacturing, and sustainability-driven industries.
- Integrate fuzzy MCDM, DEMATEL, or AHP to capture uncertainty and causal relationships.
- Conduct longitudinal validation through real organizational implementation of EBEF.
- Incorporate emerging criteria such as Industry 4.0 maturity (Frank et al., 2019), ESG alignment, and innovation readiness.

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