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DIGITAL TRANSFORMATION AND QUALITY GOVERNANCE IN AUTOMOTIVE SUPPLY CHAINS: A FUZZY AHP-BASED PRIORITIZATION OF TQM CAPABILITIES

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***ABSTRACT*:**

Intense competition in the Automotive Supply Chain Ecosystem and the necessity to produce high-quality products have driven companies toward implementing Total Quality Governance (TQM) systems. However, the diversity and complexity of TQM Capabilities, coupled with resource constraints, have made the identification and prioritization of critical success factors essential. This study aims to prioritize the critical TQM Capabilities supporting quality governance in the Automotive Supply Chain Ecosystem using the Fuzzy Analytic Hierarchy Process (Fuzzy AHP) method.. The research adopts a descriptive-applied approach, where key TQM Capabilities were first identified through a literature review and then evaluated by 27 automotive industry experts. Data were collected using a fuzzy pairwise comparison questionnaire, and the analysis was conducted using Fuzzy AHP method. The findings indicate that among the four main TQM Capabilities-leadership and management, processes and operations, strategic planning, and human resources-leadership and management, with a weight of 0.362, was identified as the highest priority, while top management commitment, with a weight of 0.109, was recognized as the most critical sub-component. Quality vision and strategy (0.098) and process management (0.080) ranked next in importance. The results of this study provide a practical framework for Automotive Supply Chain Ecosystem managers to focus on critical factors and adopt more effective TQM implementation strategies. The study provides a capability-based prioritization framework that can support decision-making in digitally transforming automotive ecosystems.

Keywords: *Total Quality Management, Digital Transformation, AI-enabled Quality Governance, Automotive Supply Chains , Engineering Management, Quality Governance, Industry 4.0, Supply Chain Collaboration*

INTRODUCTION

1.1. Background

The automotive industry is experiencing an unprecedented transformation driven by digital technologies, artificial intelligence (AI), Industry 4.0 architectures, connected production systems, and increasingly complex supply chain ecosystems. In such environments, quality management is no longer confined to internal production processes but has evolved into an inter-organizational capability involving suppliers, manufacturers, logistics partners, technology providers, and customers.

The growing adoption of data-driven analytics, digital twins, predictive quality systems, and real-time information sharing has fundamentally changed how organizations create, monitor, and improve quality performance across supply chains. Consequently, traditional quality management approaches must be re-examined from an engineering management perspective that integrates technology, organizational capabilities, and value creation mechanisms.

Artificial intelligence (AI)-enabled quality governance is considered as a contextual and enabling environment rather than a directly modeled decision variable in this study.

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1.2.Research Gap

This study addresses three key gaps in the existing literature. First, most studies on Total Quality Management (TQM) focus on internal organizational settings and do not adequately capture its role within digitally interconnected automotive supply chain ecosystems. Second, although digital transformation and Industry 4.0 are widely discussed in the literature, they are rarely incorporated into structured multi-criteria decision-making frameworks for capability prioritization under uncertainty. Instead, they are often treated conceptually without operational integration into analytical models. Third, existing studies primarily identify critical success factors of TQM but provide limited insight into structured prioritization under expert uncertainty in complex supply chain environments.

To address these gaps, this study applies a fuzzy multi-criteria decision-making approach to prioritize TQM capabilities in automotive supply chain ecosystems. In this study, digital transformation is considered as a contextual environment that influences expert judgment rather than a direct decision variable within the model.

1.3.Introduction

Digital transformation, including data-driven decision-making and industrial connectivity, is considered as an enabling context that influences how TQM capabilities are evaluated by experts. However, in this study, digital transformation is not modeled as an independent variable but rather as a contextual factor shaping managerial perception in automotive supply chain ecosystems.

Unlike previous studies that mainly focus on identifying or ranking TQM factors, this study contributes by embedding capability prioritization within a digitally transforming automotive supply chain context under uncertainty using fuzzy decision-making.

1.4. Research Objective

To address these gaps, this study develops a Fuzzy Analytic Hierarchy Process (Fuzzy AHP) framework to prioritize TQM capabilities that support quality governance within digitally transformed automotive supply chains.

The study seeks to answer the following research question:
RQ: Which TQM capabilities should receive the highest managerial priority to strengthen quality governance and value creation in digitally enabled automotive supply chain ecosystems?

This study contributes by (1) conceptualizing TQM as a capability-based quality governance system in automotive supply chain ecosystems, (2) prioritizing these capabilities under uncertainty using Fuzzy AHP, and (3) positioning digital transformation as a contextual enabler rather than a direct decision variable.

SYSTEMATIC LITERATURE REVIEW

2.1 Literature Review Procedure

A systematic literature review was conducted to identify the most frequently discussed quality management capabilities in automotive, supply chain, engineering management, and digital transformation research.
The review process followed four stages:

1. Identification
2. Screening
3. Eligibility Assessment
4. Inclusion

Relevant studies published between 2015 and 2025 were collected from Scopus, Web of Science, ScienceDirect, SpringerLink, and Emerald databases.
Keywords included:

- Total Quality Management
- Digital Transformation
- AI-enabled Quality Governance
- Automotive Supply Chains
- Engineering Management
- Quality Governance

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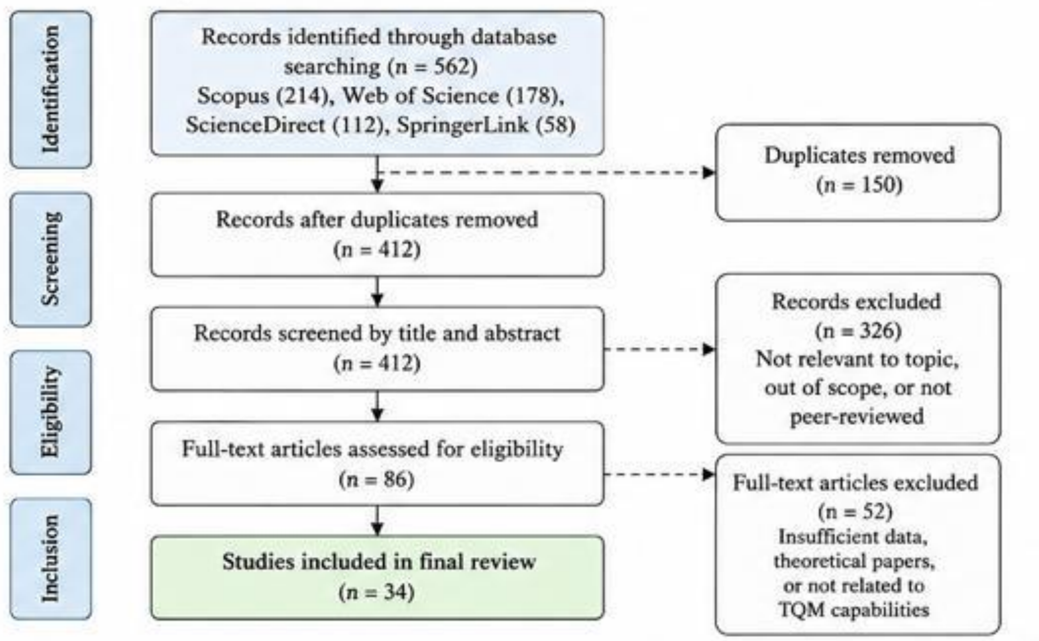
- Industry 4.0
- Supply Chain Collaboration

Figure 1. PRISMA-based Literature Review Process



2.2 Theoretical Foundations

The conceptual foundation of the study integrates four streams of literature:

Total Quality Management(TQM). TQM provides the organizational mechanisms required for continuous improvement and customer value creation.

Digital Transformation. Digital transformation enables organizations to leverage data, analytics, automation, and AI for operational improvement.

Supply Chain Governanc . Supply chain governance focuses on coordination mechanisms among multiple actors involved in value creation.

Engineering Management . Engineering management integrates technical systems and managerial decision-making to improve organizational performance.

Dynamic Capabilities Theory provides an additional theoretical lens for understanding quality governance in digitally transformed supply chains. The theory suggests that organizations achieve sustainable competitive advantage through their ability to integrate, build, and reconfigure internal and external capabilities in response to rapidly changing environments. In the context of digital quality governance, leadership commitment, process integration, strategic planning, and human resource development can be viewed as dynamic capabilities that enable organizations to leverage digital technologies and AI-enabled systems more effectively.

Furthermore, the Resource-Based View (RBV) argues that valuable, rare, inimitable, and organizationally embedded capabilities serve as key sources of competitive advantage. From this perspective, TQM capabilities represent strategic organizational resources that support quality governance and long-term value creation across automotive supply chain ecosystems. Together, these theoretical perspectives provide a foundation for explaining why certain TQM capabilities receive greater strategic importance in digitally transformed industrial environments.

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HYPOTHESES SECTION

Given the exploratory nature of this study, formal statistical hypothesis testing is not conducted. Instead, the study develops directional expectations based on prior literature to guide the prioritization process using the Fuzzy Analytic Hierarchy Process (FAHP).
H1. Leadership and Management capabilities are expected to receive the highest priority among TQM capability dimensions.
H2. Processes and Operations capabilities are expected to represent a major dimension of quality governance.
H3. Strategic Planning capabilities are expected to play a significant role in quality governance in automotive supply chains.
H4. Human Resource capabilities are expected to contribute as enabling capabilities in quality governance systems.
H5. The importance of TQM capabilities is expected to vary across digitally transformed automotive supply chain ecosystems.

METHODOLOGY

4.1. Research Procedure

This research aims to prioritize the critical TQM Capabilities supporting quality governance in the Automotive Supply Chain Ecosystem using the Fuzzy Analytic Hierarchy Process (FAHP) method. The research process is defined in several sequential stages, including identifying key TQM Capabilities through literature studies, designing a conceptual model, collecting expert opinions, and data analysis. Initially, through an in-depth review of the literature and previous studies, components affecting the successful implementation of total quality management were extracted. Then, using the opinions of automotive industry experts, these components were reviewed and adapted to ensure their compatibility with the specific characteristics of the automotive industry. In the next stage, a pairwise comparison questionnaire was designed and distributed, and after data collection, the weight and final priority of each component were calculated using the Fuzzy AHP technique.

The Fuzzy AHP approach was selected because managerial evaluations regarding digital transformation, quality governance, and supply chain collaboration are inherently uncertain and subjective.

Fuzzy AHP was selected to capture uncertainty and vagueness in expert judgments under complex supply chain governance environments.

4.2 Population and Sample

The statistical population of this research includes experts and specialists in the Automotive Supply Chain Ecosystem who possess specialized knowledge and extensive experience in quality governance and quality management systems. The study involved a decision-making group of 27 experts who participated in the pairwise comparison process.

The selection criteria included a minimum of ten years of professional experience in the automotive sector, relevant academic qualifications, familiarity with TQM principles, and practical experience in implementing quality management systems. Purposive sampling was employed to ensure that all participants possessed the expertise required to evaluate and prioritize the identified TQM capabilities.

The selected experts represented various functional areas, including quality management, production, industrial engineering, operations management, and supply chain management. This diversity enhanced the reliability and comprehensiveness of the collected judgments.

4.3 Data Collection Methods and Tools

Data collection in this research was conducted through two methods: library and field research to ensure the necessary comprehensiveness and accuracy in identifying and evaluating TQM components. The library method included systematic review of credible scientific sources, Persian and English articles, specialized books, industrial reports, and scientific databases to identify and extract key TQM Capabilities. The field method also included designing and distributing a researcher-made questionnaire based on pairwise comparison techniques using Saaty's 9-point scale. This questionnaire provides the ability to compare components pairwise, and experts

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can evaluate the relative importance of each component through pairwise comparisons. The questionnaire structure is designed to consider uncertainties in human judgments through the use of fuzzy numbers.

4.4 Validity and Reliability

The validity of the questionnaire was evaluated through face validity and content validity. To determine face validity, the questionnaire was reviewed by a group of supervisory professors, advisors, and experienced experts in the automotive industry, and after receiving corrective comments, necessary changes were applied. Content validity was also ensured by matching the questionnaire questions with the theoretical literature of the subject and research objectives. For reliability assessment, Cronbach's alpha coefficient and the inconsistency rate index in the AHP method were used. The Cronbach's alpha value for the entire questionnaire was calculated as 0.847, indicating optimal tool reliability. Additionally, the inconsistency rate of all pairwise comparison matrices was less than 0.1, confirming the acceptable consistency of expert opinions.

4.5 Data Analysis Methods

For analyzing the data of this research, the Fuzzy Analytic Hierarchy Process (FAHP) method was used. The implementation stages of this method include forming fuzzy pairwise comparison matrices using expert opinions, calculating the geometric mean of opinions for each comparison, determining fuzzy values for each criterion, calculating the degree of possibility of each criterion's superiority over others, normalizing weights, and calculating the final weight of each component. In this research, SPSS version 26 software was used for analyzing demographic data and calculating Cronbach's alpha coefficient, and Excel software was used for data processing and calculations related to FAHP. This method provides more accurate results compared to traditional AHP methods and has the capability to process inherent uncertainties in expert opinions.

DATA ANALYSIS

This section focuses on the analysis of data collected from experts within the Automotive Supply Chain Ecosystem regarding the prioritization of critical TQM Capabilities supporting quality governance.The data analysis was conducted in several stages, including examining the demographic characteristics of respondents, identifying and determining the main and sub-components of TQM, calculating the final weights of components using the Fuzzy Analytic Hierarchy Process (Fuzzy AHP) method, evaluating the consistency of pairwise comparison matrices, and presenting the final ranking of components. The results of these analyses assist managers and decision-makers across the Automotive Supply Chain Ecosystem in accurately identifying TQM Capability priorities , enabling optimal allocation of limited resources and the adoption of effective implementation strategies. Additionally, these findings provide a foundation for establishing a comprehensive and practical framework for quality governance capability development across the Automotive Supply Chain Ecosystem.

5.1. Demographic Characteristics of Respondents

The demographic characteristics of the experts participating in this study include gender, age, work experience, and education level, as presented in Table 1. These characteristics demonstrate a suitable and diverse composition of experts, ensuring the collection of comprehensive and reliable opinions regarding Total Quality Governance in the Automotive Supply Chain Ecosystem.

Table 1. Demographic Characteristics of Respondents

Characteristic	Category	Frequency	Percentage
Gender	Male	20	74.1%
	Female	7	25.9%
	Total	27	100%
Age	25–35 years	2	7.4%
	36–45 years	17	63.0%
	Over 45 years	8	29.6%
	Total	27	100%
Work Experience	5–10 years	1	3.7%
	11–15 years	8	29.6%
	Over 15 years	18	66.7%
	Total	27	100%
Education	Bachelor’s	6	22.2%

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	Master's	19	70.4%
	PhD	2	7.4%
	Total	27	100%

The results from the table above indicate that the majority of respondents (74.1%) are male, while 25.9% are female, reflecting the workforce composition across the Automotive Supply Chain Ecosystem as well as the increasing presence of women in managerial and specialized roles within this sector. Regarding age, the highest frequency is observed in the 36–45 age group (63%), indicating the predominance of experienced individuals at the peak of their professional careers. In terms of work experience, it is noteworthy that 66.7% of experts have over 15 years of experience, ensuring the high credibility of the opinions provided. Regarding education, 70.4% of respondents hold a master's degree, and 7.4% hold a PhD, demonstrating the appropriate academic qualifications of the participating experts.

5.2. Identification and Determination of TQM Capabilities

The identification of key TQM Capabilities supporting quality governance in the Automotive Supply Chain Ecosystem was conducted through a comprehensive literature review and consultations with experienced experts, with the results presented in Table 2. This process was carried out in two main stages: first, key TQM Capabilities were extracted through a systematic review of the literature and previous studies, and then these components were reviewed, validated, and tailored by automotive industry experts. The final framework consists of four main capability dimensions , each with multiple sub-components, collectively covering a comprehensive range of factors influencing the successful implementation of TQM Capabilities across the Automotive Supply Chain Ecosystem.

Table 2. TQM Capability Structure for Digital Quality Governance

Main Component	Code	Sub-Component	Code
Leadership and Management	C_1	Top Management Commitment	C_{11}
		Quality Vision and Strategy	C_{12}
		Transformational Leadership	C_{13}
		Resource Allocation	C_{14}
Strategic Planning	C_2	Quality Planning	C_{21}
		Setting Quality Objectives	C_{22}
		System Review and Revision	C_{23}
		Risk Management	C_{24}
Processes and Operations	C_3	Process Management	C_{31}
		Quality Control	C_{32}
		Continuous Improvement	C_{33}
		Supplier Management	C_{34}
		Customer Management	C_{35}
Human Resources	C_4	Training and Development	C_{41}
		Employee Participation	C_{42}
		Teamwork	C_{43}
		Motivation and Incentives	C_{44}

The results from the table above indicate that the main TQM Capabilities in the Automotive Supply Chain Ecosystem include leadership and management, strategic planning, processes and operations, and human resources, with this classification based on credible scientific studies and practical experiences across the Automotive Supply Chain Ecosystem. The processes and operations component has the highest number of sub-components (five sub-components), highlighting the complexity and critical importance of operational processes across the Automotive Supply Chain Ecosystem. The leadership and management component includes four key sub-components, emphasizing the significant role of leadership in TQM success. This comprehensive structure covers all critical aspects of TQM, enabling a thorough analysis of factors influencing its successful implementation across the automotive Supply Chain Ecosystem.

5.3. Pairwise Comparison Matrix of Main TQM Capabilities

The formation of the pairwise comparison matrix for the main TQM Capabilities was conducted based on expert opinions using triangular fuzzy numbers, with the results presented in Table 3. This matrix forms the basis for weight calculations in the Fuzzy Analytic Hierarchy Process (Fuzzy AHP) method and contains pairwise comparisons of all main components. Each element in the matrix represents the degree of preference of one component over another based on the collective opinions of experts. The matrix was calculated using the geometric mean formula:

$$\tilde{a}_{ij} = \left(\sqrt[n]{\prod_{k=1}^{n} l_{ijk}}\ \sqrt[n]{\prod_{k=1}^{n} m_{ijk}}\ \sqrt[n]{\prod_{k=1}^{n} u_{ijk}}\right) \quad (1)$$

where (n) is the number of experts, and $(\text{و}\ l_{ijk})$, (m_{ijk}), (u_{ijk}) represent the lower, middle, and upper bounds of the triangular fuzzy numbers, respectively.

Table 3. Fuzzy Pairwise Comparison Matrix of Main TQM Capabilities

Component	C_1	C_2	C_3	C_4
C_1	(1, 1, 1)	(1.31, 1.58, 1.87)	(1.42, 1.62, 1.89)	(1.65, 1.89, 2.14)
C_2	(0.53, 0.63, 0.76)	(1, 1, 1)	(1.14, 1.32, 1.56)	(1.43, 1.75, 2.08)
C_3	(0.53, 0.62, 0.70)	(0.64, 0.76, 0.88)	(1, 1, 1)	(1.28, 1.54, 1.83)
C_4	(0.47, 0.53, 0.61)	(0.48, 0.57, 0.70)	(0.55, 0.65, 0.78)	(1, 1, 1)

The results of the above table indicate that the leadership and management component (C_1) has a preference over other components, as evidenced by values greater than one in the first row of the matrix. Additionally, comparisons between strategic planning (C_2) and processes and operations (C_3) show that strategic planning has a higher priority. Human resources (C_4) received the lowest weights in the comparisons, indicating a relatively lower priority compared to other components in the experts' opinions.

5.4. Calculation of Final Weights of Main TQM Capabilities

The final weights of the main TQM Capabilities were calculated using Fuzzy Analytic Hierarchy Process method, with the results presented in Table 4. This calculation involves multiple stages, including computing row sums, normalization, and determining the degree of preference of each component over others. The final weights were calculated using the following formula:

$$W_i = \frac{\sum_{j=1}^{n} \tilde{S}_i}{\sum_{i=1}^{n} \sum_{j=1}^{n} \tilde{S}_i} \quad (2)$$

where $(\tilde{S}_i)$ is the fuzzy sum of the i row of the pairwise comparison matrix.

Table 4. Final Weights and Ranking of Main TQM Capabilities

Main Component	Fuzzy Weight	Crisp Weight	Rank
Leadership and Management	(0.270, 0.362, 0.452)	0.362	1
Processes and Operations	(0.196, 0.289, 0.387)	0.289	2
Strategic Planning	(0.168, 0.249, 0.335)	0.249	3
Human Resources	(0.091, 0.132, 0.178)	0.132	4

The results of the above table indicate that the leadership and management component, with a crisp weight of 0.362, ranks first in priority, highlighting the critical importance of management and leadership in the successful implementation of TQM in the Automotive Supply Chain Ecosystem. This finding aligns with the literature and global experiences, emphasizing that without strong support, serious commitment, and effective leadership from top management, successful TQM implementation is not feasible. The processes and operations component, with a weight of 0.289, ranks second, underscoring the importance of designing, controlling, and continuously improving operational processes in the Automotive Supply Chain Ecosystem.

5.5. Calculation of Weights for Leadership and Management Sub-Components

The calculation of weights for the sub-components of leadership and management, identified as the most critical main TQM Capabilities, is presented in Table 5. The leadership sub-components include four key factors, each playing a significant role in effective leadership for TQM implementation. The weight calculation process for these sub-components follows the same Fuzzy AHP method as used for the main components.

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Table 5. Pairwise Comparison Matrix of Leadership and Management Sub-Components

Sub-Component	C_{11}	C_{12}	C_{13}	C_{14}
C_{11}	(1, 1, 1)	(1.09, 1.28, 1.51)	(1.32, 1.56, 1.84)	(1.57, 1.83, 2.13)
C_{12}	(0.66, 0.78, 0.92)	(1, 1, 1)	(1.14, 1.31, 1.52)	(1.29, 1.51, 1.77)
C_{13}	(0.54, 0.64, 0.76)	(0.66, 0.76, 0.88)	(1, 1, 1)	(1.08, 1.25, 1.46)
C_{14}	(0.47, 0.55, 0.64)	(0.56, 0.66, 0.77)	(0.68, 0.80, 0.93)	(1, 1, 1)

Table 6. Final Weights of Leadership and Management Sub-Components

Sub-Component	Fuzzy Weight	Crisp Weight	Rank
Top Management Commitment	(0.189, 0.302, 0.426)	0.302	1
Quality Vision and Strategy	(0.167, 0.272, 0.389)	0.272	2
Transformational Leadership	(0.141, 0.228, 0.325)	0.228	3
Resource Allocation	(0.119, 0.190, 0.269)	0.190	4

The results of the above table indicate that among the leadership and management sub-components, top management commitment, with a crisp weight of 0.302, holds the highest priority, underscoring the critical importance of genuine and practical commitment from senior managers to TQM implementation. Quality vision and strategy, with a weight of 0.272, ranks second, highlighting the necessity of a clear vision and well-defined quality strategy. Transformational leadership, with a weight of 0.228, ranks third, emphasizing the importance of leaders in fostering the cultural and organizational transformation necessary for TQM adoption.

5.6. Consistency Analysis of Pairwise Comparison Matrices

The consistency analysis of pairwise comparison matrices is a critical step in the Analytic Hierarchy Process (AHP) method, with results presented in Table 7. This analysis aims to ensure the logical coherence and reliability of expert opinions. If the inconsistency rate exceeds 0.1, a review of the provided responses is necessary. The inconsistency rate is calculated using the following formula:

$$\boldsymbol{CR} = \frac{\boldsymbol{CI}}{\boldsymbol{RI}} = \frac{\boldsymbol{\lambda}_{\max} - \boldsymbol{n}}{(\boldsymbol{n}-\mathbf{1}) \times \boldsymbol{RI}} \quad \textbf{(3)}$$

where ($\boldsymbol{\lambda}_{\max}$) is the maximum eigenvalue of the matrix, ($\boldsymbol{n}$) is the matrix size, (RI) is the random index, (CR) is the consistency ratio, and (CI) is the consistency index.

Table 7. Consistency Analysis Results of Pairwise Comparison Matrices

Matrix	($\boldsymbol{\lambda}_{\max}$)	CI	RI	CR	Consistency Status
Main Components	4.086	0.029	0.90	0.032	Acceptable
Leadership Sub-Components	4.092	0.031	0.90	0.034	Acceptable
Processes Sub-Components	5.104	0.026	1.12	0.023	Acceptable
Strategic Planning Sub-Components	4.078	0.026	0.90	0.029	Acceptable
Human Resources Sub-Components	4.064	0.021	0.90	0.024	Acceptable

The results from the above table indicate that all pairwise comparison matrices have inconsistency rates below 0.1, confirming acceptable consistency and high reliability of the experts' opinions. The lowest inconsistency rate is observed for the human resources sub-components (0.024), while the highest is for the leadership sub-components (0.034), all of which fall within the acceptable range. These results demonstrate that the experts provided their opinions with high precision and logical consistency.

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5.7. Final Weights and Ranking of All TQM Capabilities

The final weights and ranking of al TQM Capabilities , derived from combining the weights of main and sub-components, are presented in Table 8. This calculation was performed by multiplying the weights of the main components by the weights of their respective sub-components to determine the comprehensive final weight of each TQM Capability within the Automotive Supply Chain Ecosystem. These final results provide a complete prioritization of all factors influencing the successful implementation of quality governance capabilities, enabling managers to make informed decisions regarding resource allocation and focus on the most critical factors.

Table 8. Final Weights and Ranking of All TQM Capabilities

Rank	Component	Main Component	Local Weight	Final Weight
1	Top Management Commitment	Leadership and Management	0.302	0.109
2	Quality Vision and Strategy	Leadership and Management	0.272	0.098
3	Transformational Leadership	Leadership and Management	0.228	0.083
4	Process Management	Processes and Operations	0.277	0.080
5	Quality Control	Processes and Operations	0.256	0.074
6	Resource Allocation	Leadership and Management	0.190	0.069
7	Continuous Improvement	Processes and Operations	0.229	0.066
8	Quality Planning	Strategic Planning	0.262	0.065
9	Setting Quality Objectives	Strategic Planning	0.239	0.059
10	Supplier Management	Processes and Operations	0.195	0.056
11	System Review and Revision	Strategic Planning	0.213	0.053
12	Risk Management	Strategic Planning	0.191	0.048
13	Customer Management	Processes and Operations	0.157	0.045
14	Training and Development	Human Resources	0.337	0.044
15	Employee Participation	Human Resources	0.289	0.038
16	Motivation and Incentives	Human Resources	0.238	0.031
17	Teamwork	Human Resources	0.187	0.025

The results from the above table indicate that top management commitment, with a final weight of 0.109, holds the highest priority among all TQM Capabilities , underscoring the critical importance of genuine and practical commitment from senior management for successful TQM implementation. Quality vision and strategy and process management rank second and third, respectively, emphasizing the importance of a clear vision and effective process management. Notably, the top seven components include four from the leadership and management dimension and three from the processes and operations dimension, highlighting the critical importance of these two dimensions in TQM success.

5.8. Analysis of TQM Capabilities Prioritization

Figure 3 presents a bar chart of the final weights of the main TQM Capabilities . This chart clearly shows that leadership and management, with a weight of 0.362, holds the highest importance, with a significant gap compared to other components, emphasizing the unparalleled role of leadership in TQM success. Processes and operations, with a weight of 0.289, rank second, followed by strategic planning with a weight of 0.249 in third place, and human resources with a weight of 0.132 in fourth place. This weight distribution indicates that while leadership is the primary priority, other components also hold significant importance and cannot be overlooked. The notable difference between the weight of leadership and management and other components suggests that across the Automotive Supply Chain Ecosystem, the role of leadership is more critical than other evaluated factors.

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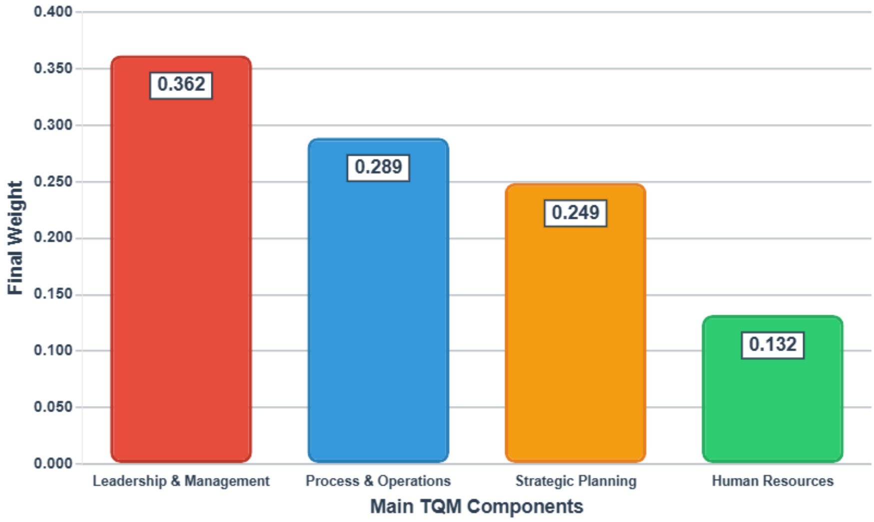

Figure 3. Bar Chart of Final Weights of Main TQM Capabilities in the Automotive Supply Chain Ecosystem

Figure 4 presents a comprehensive bar chart of the prioritization of all TQM sub-components based on their final weights, calculated by multiplying the weights of the main components by those of their respective sub-components. The results show that top management commitment, with a final weight of 0.109, clearly surpasses other components, highlighting its critical importance in quality governance success. Following it, quality vision and strategy, transformational leadership, and process management rank next, indicating the combined importance of leadership and process-related factors in successful quality governance implementation . The weight distribution in this chart shows that while there are differences among components, none are of negligible importance, and all play a significant role in the overall success of TQM.

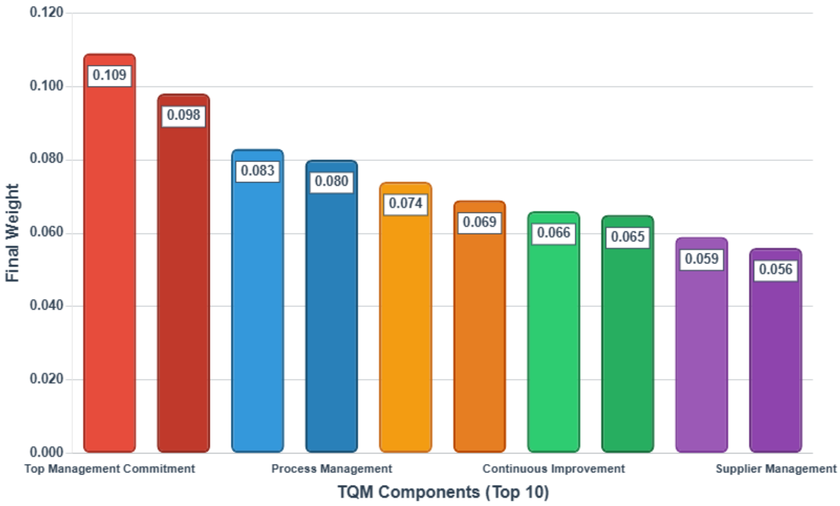

Figure 4. Bar Chart of Final Prioritization of All TQM Capabilities in the Automotive Supply Chain Ecosystem

The results of this analysis indicate that successful implementation of TQM Capabilities supporting quality governance across the Automotive Supply Chain Ecosystem requires a comprehensive and multidimensional approach, in which top management commitment, a clear vision, effective process management, and attention to human factors all play key roles. These findings align with global experiences in quality governance implementation and emphasize that organizations across the Automotive Supply Chain Ecosystem must simultaneously focus on strengthening leadership capabilities, improving processes, developing appropriate strategic planning, and enhancing human resources to successfully implement TQM and realize its benefits.

5.9. Interpretation of Prioritization Results

The proposed propositions were evaluated based on the final weights obtained through the Fuzzy Analytic Hierarchy Process (FAHP). Since the objective of the study was to prioritize TQM capabilities rather than test causal relationships, the analysis is based on comparative ranking and weight interpretation rather than statistical hypothesis testing.

H1 proposed that Leadership and Management capabilities exert the strongest influence on quality governance effectiveness. The results strongly support this hypothesis, as Leadership and Management achieved the highest global weight (0.362) among all main capability dimensions.
H2 proposed that Processes and Operations capabilities significantly contribute to quality governance performance. This hypothesis is supported, as Processes and Operations ranked second with a weight of 0.289, indicating a substantial contribution to quality governance effectiveness.
H3 proposed that Strategic Planning capabilities positively support digital quality governance. The results support this hypothesis, with Strategic Planning obtaining a weight of 0.249 and ranking third among the evaluated capability dimensions.
H4 proposed that Human Resource capabilities positively influence quality governance effectiveness. The findings support this hypothesis, as Human Resources achieved a positive weight of 0.132 and remained an important contributor to overall quality governance performance.
H5 proposed that the relative importance of TQM capabilities differs significantly within digitally transformed automotive supply chains. The prioritization results clearly support this hypothesis, as substantial differences were observed among the capability dimensions and sub-capabilities. Leadership and Management demonstrated considerably greater importance than Human Resources, while Top Management Commitment emerged as the highest-priority sub-capability.

Overall, the hypothesis evaluation confirms that all proposed capability dimensions contribute to quality governance effectiveness,although their relative importance varies considerably across the Automotive Supply Chain Ecosystem.

DISCUSSION

The results of this study indicate that leadership-related capabilities represent the most critical dimension of quality governance in automotive supply chain ecosystems. In particular, top management commitment and quality vision and strategy emerge as the most influential sub-capabilities, highlighting the central role of leadership in ensuring the effectiveness of Total Quality Management (TQM).

A key finding is that digital transformation and Industry 4.0 technologies do not independently determine quality governance outcomes. Instead, they function as contextual enablers whose effectiveness depends on the strength of organizational capabilities, particularly leadership and process management. This suggests that technological advancement alone is insufficient to ensure quality excellence without strong governance structures.

The findings further indicate that capability prioritization in complex supply chains is driven more by organizational governance structures than by technological factors. Leadership and process integration act as foundational mechanisms that determine how effectively digital tools can be utilized in quality management systems.

Overall, the results extend the TQM literature by demonstrating that organizational capabilities remain the primary drivers of quality governance performance even in digitally transformed environments. Digital technologies enhance rather than replace these capabilities.

Interestingly, the relatively low ranking of Human Resource capabilities contrasts with classical TQM theory (e.g., Deming’s emphasis on people), suggesting that in automotive supply chain ecosystems, governance and leadership structures may outweigh workforce-centric quality perspectives.

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MANAGERIAL IMPLICATIONS

The findings provide several important implications for managers operating in digitally transformed automotive supply chains. First, organizations should prioritize leadership development and executive commitment before investing heavily in digital technologies and AI-based quality systems. The results indicate that leadership capabilities constitute the primary foundation for effective quality governance.

Second, managers should allocate resources toward strengthening process integration and continuous improvement mechanisms across supply chain partners. Digital technologies can enhance quality performance only when supported by standardized processes and effective governance structures.

Third, organizations should establish integrated quality governance frameworks that facilitate collaboration among suppliers, manufacturers, and logistics partners. Such governance mechanisms can improve transparency, information sharing, and ecosystem-wide value creation.

Finally, human capability development should remain a strategic priority. Although Human Resources received the lowest relative weight, employee participation, training, and teamwork remain essential enablers for the successful implementation of digital transformation initiatives.

RESEARCH LIMITATION

This study has several limitations. First, the analysis relies on expert judgments collected from a specific automotive supply chain context, which may limit the generalizability of the findings to other industries or geographical settings. Second, the Fuzzy AHP methodology focuses on prioritization and does not explicitly examine causal relationships among TQM capabilities. Third, the evaluation is based on expert perceptions rather than objective organizational performance indicators. Future studies may address these limitations by employing larger international samples, longitudinal datasets, and complementary analytical approaches. In addition, future research may investigate the interactions among TQM capabilities and explore how digital technologies and AI-enabled quality systems influence organizational performance outcomes across different industrial contexts.Another limitation is that digital transformation is not operationalized as a measurable construct but treated as a contextual factor influencing expert judgments.

CONCLUSION

This study developed a fuzzy multi-criteria decision-making framework to prioritize Total Quality Management (TQM) capabilities in automotive supply chain ecosystems. The results show that leadership and management capabilities are the most critical dimension, followed by processes and operations, strategic planning, and human resources.

A key contribution of this study is the interpretation of digital transformation as a contextual factor rather than a direct explanatory variable. This perspective highlights that organizational capabilities remain the dominant drivers of quality governance even in digitally enabled supply chain environments.

The findings provide a structured decision-making framework for managers to allocate resources more effectively in complex automotive supply chain ecosystems. The results also suggest that technological investments should be aligned with organizational capability development to achieve sustainable quality performance.

Future research may incorporate measurable indicators of digital maturity and hybrid multi-criteria decision-making methods to enhance the explanatory power of the model.

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