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Designing a Model for the Implementation and Deployment of Quality 4.0 Using an Integrated Approach: Delphi Technique and Structural Equation Modeling in a Research Industrial Organization

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ABSTRACT

This study aimed to develop a model for implementing and deploying Quality 4.0 in a research industrial organization using an integrated approach combining the Delphi technique and structural equation modeling. The research identified key factors influencing Quality 4.0 adoption, including leadership, employee cooperation, financial resources, technological infrastructure, big data control, and organizational agility. A panel of experts used the Delphi technique to achieve consensus on these factors, leading to the development of a conceptual model. The study employed confirmatory factor analysis and structural equation modeling to validate the relationships among these factors. The findings revealed that financial resources had the most significant impact, followed by technological infrastructure and leadership. The study concluded that implementing a Quality 4.0 system enhances organizational effectiveness, adaptability, and product quality. Recommendations include further investigation into leadership effectiveness and incorporating dynamic systemic approaches in future studies to improve Quality 4.0 integration. The research provides a practical framework for advancing Quality 4.0 initiatives in industries, with implications for improved performance and competitiveness.

1. Introduction

The evolving nature of military projects has introduced numerous complexities and challenges for research organizations. With technological advancements and an increasing need for national security, industries face heightened demands to ensure project quality and reliability. The stakes in the sector are high, making it crucial to maintain robust quality management systems that adapt to technological changes and evolving standards.

Traditional quality management approaches, which focus on optimizing processes and maintaining compliance, need to be revised. The advent of Industry 4.0, characterized by technologies like the

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Internet of Things (IoT), artificial intelligence (AI), big data analytics, and cyber-physical systems, has brought about the need for a more integrated approach—termed Quality 4.0. Quality 4.0 leverages digital tools and technologies to transform conventional quality practices, emphasizing real-time data-driven decision-making, process improvements, and increased automation.

However, implementing Quality 4.0 is more than just a technological endeavor. It involves a comprehensive organizational shift encompassing leadership, employee collaboration, technological infrastructure, and strategic alignment. This transformation requires organizations to adapt their quality management strategies to fit new technological capabilities while maintaining the integrity and precision that the sector demands.

Despite its potential, implementing Quality 4.0 in research organizations presents several challenges. The sector's conservative approach to change and complex hierarchical structures often hinders the adoption of innovative practices. However, the potential benefits of Quality 4.0, such as enhanced operational efficiency and improved project outcomes, should instill optimism. Moreover, given the critical nature of their projects, organizations are inclined towards minimizing risks and ensuring consistency, leading to a reluctance to embrace new digital tools without a strategic framework.

This study aims to develop a comprehensive model for implementing and deploying Quality 4.0 within a research organization, combining the Delphi technique and structural equation modeling (SEM). The Delphi technique, which gathers expert opinions to reach a consensus on complex issues, is ideal for identifying key drivers of Quality 4.0 in environments where existing knowledge is limited. On the other hand, SEM helps understand the relationships between these drivers, validating the proposed model's effectiveness.

This research aims to design a structured and strategic framework to guide the adoption of Quality 4.0 in research organizations. The model aims to enhance operational efficiency, minimize risks, and improve project outcomes by integrating advanced digital technologies with traditional quality management practices. The study identifies and validates critical factors influencing Quality 4.0 through a three-stage Delphi process involving a panel of experts who evaluate and consolidate the key drivers. Through this research, several key factors were identified as critical for implementing Quality 4.0, including leadership, employee cooperation, financial resources, technological infrastructure, big data control, and organizational agility. The findings indicate that financial resources have the most significant impact on Quality 4.0 adoption, highlighting the need for sufficient budgetary provisions for infrastructure and technology deployment. Leadership also emerged as a crucial factor, emphasizing the importance of managerial support, clear role delineation, and employee motivation in achieving quality objectives. However, it's important to note that employee cooperation is not just a factor, but a key element that makes the workforce feel valued and integral to the process.

In addition, the study emphasizes the importance of employee cooperation and the development of a strategic vision in driving the transition toward Quality 4.0. A strong organizational culture that values continuous improvement and innovation is essential for successfully implementing new technologies.

The study's findings provide valuable insights for research organizations seeking to align their quality management practices with modern technological advancements.

The proposed model serves as a practical framework for guiding research organizations in their journey toward adopting Quality 4.0. It underscores the need for a holistic approach that goes beyond mere technology integration. The model emphasizes the interconnectedness of technology, people, and processes, advocating for a collaborative and adaptive organizational environment. This holistic approach is not just a suggestion, but a necessity to fully grasp the depth and complexity of the task at hand.

In conclusion, this research presents a comprehensive and structured framework for implementing Quality 4.0 in research organizations. The study provides a roadmap for adopting Quality 4.0 practices that enhance quality management in a technologically dynamic and mission-critical environment by combining the Delphi technique and structural equation modeling. The findings of this study contribute significantly to the existing body of knowledge on Quality 4.0 and offer valuable guidance for organizations globally. Implementing Quality 4.0 will enable industries to achieve greater operational effectiveness, reduce risks, and improve overall performance in their mission-critical projects.

2. Theoretical Foundations

The concept of Quality 4.0 has evolved with the advancement of information technology and the emergence of Industry 4.0. However, there has yet to be a universally recognized definition of Quality 4.0. Different experts and researchers have provided various definitions and perspectives [1].

Industry 4.0 encompasses the recent advancements in technological innovations within industrial production systems. This transformative system has emerged from seamlessly integrating various cutting-edge technologies such as the Internet of Things, cyber-physical systems, big data analytics, artificial intelligence, cloud computing, and others into industrial operations [2].

The current era of the Industrial Revolution, commonly known as Industry 4.0, has witnessed unprecedented advancements in technology and automation. These include the integration of cyber-physical systems that monitor and control physical processes, artificial intelligence that enables machines to learn from experience, big data analytics that extract valuable insights from large datasets, and the Internet of Things (IoT) that connects devices and systems over the internet. This integration has brought tremendous efficiency and productivity gains to various sectors. However, as we move forward, there is a growing recognition of the need to align these technological innovations with the principles of sustainability and resiliency [3].

Kupper and his colleagues present a comprehensive framework for implementing Quality 4.0 in research and manufacturing organizations. Their approach integrates technological advancements with organizational and cultural changes, emphasizing the importance of people, processes, and technology. They aim to examine the impact of Industry 4.0 on quality management and address the knowledge gap in this emerging field [4].

A study on the transition to Quality 4.0 in manufacturing companies in Tanzania found that most Tanzanian manufacturing industries still use Quality 3.0 or lower approaches to quality management. However, they are ready to adopt Quality 4.0 and recognize its benefits, such as customer satisfaction, product improvement, waste reduction, and decision support. The study also revealed challenges such as the need for high-speed internet, inadequate infrastructure, and financial resources required to adopt Quality 4.0 in Tanzanian manufacturing companies [5].

Other studies identified factors influencing the adoption of Quality 4.0, including organizational culture, leadership, compatibility of existing systems, senior management support, awareness, training, and technological competency [6].

In addition, Escobar and his colleagues also addressed the challenges and considerations related to implementing Quality 4.0 initiatives, particularly integrating artificial intelligence and big data into quality management practices in manufacturing.

- Paradigm shift - moving from traditional methods to data-driven approaches.
- Project selection - choosing suitable projects for Quality 4.0 implementation.
- Process redesign - modifying current processes to use artificial intelligence and big data.
- Relearning - the need for continuous learning and adaptation to new data and insights Escobar et al. [7].

The literature review and related research on Quality 4.0 has identified the factors that influence the establishment of Quality 4.0 in research industries, as shown in Table 1.

Table 1. Research Background on Quality 4.0: Factors Influencing the Establishment of Quality 4.0 in Research Industries.

Source	**Factors Influencing the Implementation and Establishment of Quality 4.0**	**Description**
Sony et al. [8] & Javaid et al. [9]	Organizational Culture	Organizational culture refers to employees' beliefs, convictions, and values towards embracing change and moving towards Quality 4.0 in industries.
Psarommatis et al. [10] & Zonnenshain et al. [11]	Leadership	Refers to the necessary skills of managers in motivating and guiding activities to achieve goals related to the establishment of Quality 4.0.
Dias et al. [12]	Training	Refers to the training of employees in the use of technologies related to Quality 4.0, including smart gloves, robots, autonomous vehicles, 3D printing, etc.
Escobar et al. [7]	Big Data Control	Big Data control refers to the monitoring, controlling, and awareness of large volumes of data related to quality management and accessing the necessary data at the

Source	Factors Influencing the Implementation and Establishment of Quality 4.0	Description
		right time. Big Data control is one of the critical factors in the establishment of Quality 4.0.
Van der Poll et al. [13]	Vision and Strategy	Vision and strategy refer to identifying and determining short-term and long-term goals, strategies, and necessary actions for moving toward and establishing Quality 4.0.
Alzahrani et al. [14]	Financial Resources	Financial resources refer to financial support and allocating a sufficient budget for utilizing the required technologies in establishing Quality 4.0.
Alzahrani et al. [14] & Emblemsvåg et al. [15]	Employee Cooperation	Refers to the participation and collaboration of employees in industries to share information, knowledge, and experiences to move towards and establish Quality 4.0.
Alzahrani et al. [14]	Employee Competence and Skills	Refers to the competence and skill levels of employees in steel industries concerning the use of tools and technologies related to Quality 4.0.
Cao et al. [16]	Technological Infrastructure	Refers to the use of required technologies in establishing Quality 4.0, such as the Internet of Things (IoT), robots, 3D printing, etc.
Sader et al. [1]	Rewards	Refers to using an appropriate reward system to motivate employees in industries to support and cooperate in establishing Quality 4.0.

3. Research Methodology

This study adopts a developmental-applied research approach to create a practical model for implementing Quality 4.0 within the industry. A descriptive survey design was employed to achieve this, which is particularly suitable for capturing expert insights and validating the relationships among critical variables. The research began with an extensive literature review to identify the key drivers influencing the establishment of Quality 4.0, drawing insights from previous studies on Industry 4.0 and quality management frameworks. These initial findings were refined and validated using the Delphi technique, a structured method that helps achieve expert consensus in situations with limited integrated knowledge.

A panel of 12 senior professors and managers from the relevant organization was formed. These experts were selected purposefully and judgmentally based on their extensive experience in quality management and research. Their expertise and knowledge in these fields made them ideal candidates for evaluating the factors influencing the successful implementation of Quality 4.0. Over three rounds, the Delphi technique enabled these experts to evaluate the importance of various factors on a five-point

Likert scale, with options ranging from "Very Important" to "Very Unimportant," And propose additional factors. In the first round, 10 main factors were identified, and two new factors were suggested. The second and third rounds refined these factors, with no new factors proposed in the final round, indicating that a consensus had been reached among the experts.

Based on the results from the Delphi process, a comprehensive questionnaire was designed with 40 items covering 12 main components, each with three questions, and four additional items focusing on the core variable of Quality 4.0 implementation. This questionnaire was distributed to a quantitative sample of 155 employees and experts within the organization. These participants, who were selected using a convenience sampling approach, played a crucial role in providing diverse perspectives and insights on the factors influencing Quality 4.0 implementation. Their responses, along with the expert evaluations, contributed to the comprehensive understanding of the topic. A final sample size of 110 participants was determined using Cochran's formula. To ensure the reliability and validity of the questionnaire, construct validity was assessed using confirmatory factor analysis, and reliability was measured through Cronbach's alpha, both of which confirmed the instrument's suitability.

The study employed structural equation modeling (SEM) using AMOS software to analyze the collected data. SEM was chosen due to its ability to handle complex relationships between multiple variables and to validate theoretical models. The analysis focused on identifying the direct and indirect effects of the 12 factors on the successful implementation of Quality 4.0, using second-order factor analysis to capture hierarchical relationships among the components. Multiple fit indices, including the chi-square to degrees of freedom ratio, Root Mean Square Error of Approximation (RMSEA), Adjusted Goodness of Fit Index (AGFI), and Comparative Fit Index (CFI), were used to validate the model's robustness. The chi-square to degrees of freedom ratio was found to be 1.372, indicating an excellent fit, with other indices such as RMSEA (0.035), AGFI (0.951), and CFI (0.965) further supporting the model's validity.

The research methodology provides a systematic approach to developing a model for implementing Quality 4.0 in research organizations. By integrating the Delphi technique and SEM, the study effectively captures expert consensus and rigorously tests the relationships among critical factors. This approach refines the understanding of the drivers influencing Quality 4.0. It offers practical insights for industries aiming to enhance their quality management systems by integrating modern technological advancements. The detailed methodological design of this study ensures both the theoretical rigor and practical applicability of the proposed model, making it a valuable resource for organizations looking to transition towards Quality 4.0 frameworks.

4. Data Analysis and Research Findings

The study utilized the Delphi technique in three iterative stages, ensuring a thorough research process. In the first stage, a questionnaire was presented to experts, incorporating components from the research background. They were asked to rate the components using a five-point Likert scale, with options ranging from 'Very Important' to 'Very Unimportant' (scored 5 to 1). The experts also had the opportunity to suggest any additional components they deemed significant. Each round involved the distribution and collection of questionnaires in person among the experts and professors.

Ten main components were identified in the first round, and two additional components were suggested. In the second round, experts re-evaluated the components and rated the new components. No new components were suggested. Experts again rated the questionnaire in the third round, and no new components were proposed. Results from the second and third rounds indicated that the experts had agreed on these components. The final results of the third round of the Delphi technique are presented in Table 2.

Table 2. Report of Selected Components and Statistical Analysis Results of the Third Round of the Delphi Technique.

Effective factors	Average	Median	Standard Deviation	Minimum	Maximum
Leadership	3.62	3.42	0.94	1	5
Employee Cooperation	3.94	3.60	0.74	2	5
Vision	4.33	4.15	0.68	3	5
Big Data Control	3.92	3.70	0.71	2	5
Technology Infrastructure	4.10	4.02	0.87	2	5
Competence and Skills of Employees	4.54	4.15	0.45	1	5
Rewards	4.31	4.12	0.54	3	5
Organizational Agility	4.58	4.34	0.79	1	5
Organizational Culture	4.90	4.21	0.88	2	5
Financial Resources	4.67	3.90	0.47	2	5
Training	4.44	3.85	0.98	1	5
Management Systems Based on Program Development	3.88	3.28	0.82	1	5

According to Table 2, all factors were approved by the panel members. The factors had a mean and median score of 3 or higher, showing their high importance from the experts' perspective. Therefore, 12 factors were included in the analysis. Since all factors were approved and there was no interest in adding more, the Delphi technique was concluded after three rounds. The results of the statistical analysis of the experts' responses to each factor are provided.

Table 3 presents the results of the first stage, where Kendall's coefficient of concordance was a significant 0.454 at the 0.01 level. This significant result validates the research model, which is depicted in Figure 1, based on the outcomes of the data analysis.

Table 3. Kendall's Coefficient of Concordance for the Second Round of the Delphi Technique.

Number of samples	12
Kendall coefficient	0.454
K^2	348.251
Degree of freedom	11
P-Value	0.001

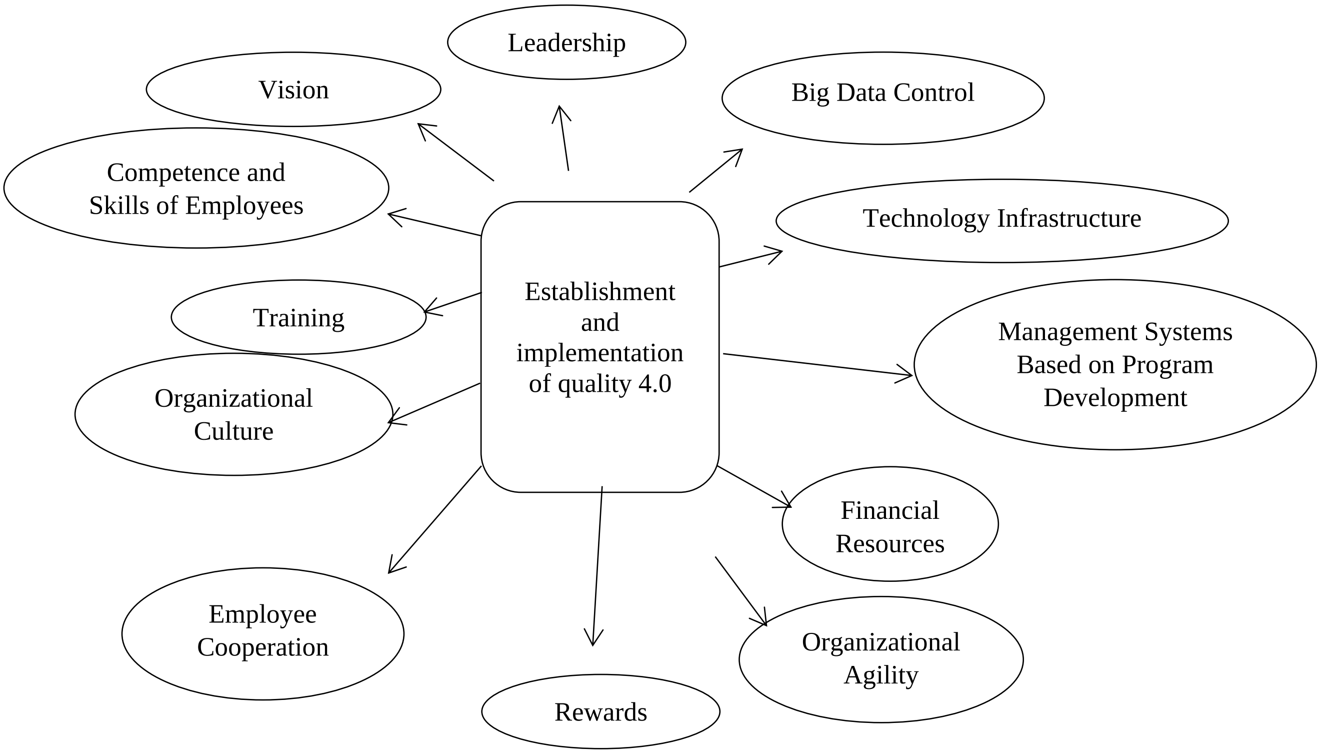

Fig. 1. Conceptual Model of the Research.

We assessed the validity of the questionnaire by conducting a construct validity test and evaluated its reliability using Cronbach's alpha with SPSS version 26. The results of the measurement model (confirmatory factor analysis) and Cronbach's alpha values for the questionnaire were confirmed, and the results are reported in Table 4.

Table 4. Validity and Reliability Values.

Effective factors	**Objects**	**Factor load coefficients**	**Cronbach's alpha values**
Leadership	1-3	0.82	0.87
Employee Cooperation	4-6	0.82	0.74
Vision	7-9	0.55	0.91
Big Data Control	10-12	0.79	0.83

Technology Infrastructure	13-15	0.55	0.79
Competence and Skills of Employees	16-18	0.54	0.82
Rewards	19-21	0.64	0.96
Organizational Agility	22-24	0.71	0.93
Organizational Culture	25-27	0.66	0.90
Financial Resources	28-30	0.88	0.86
Training	31-33	0.57	0.77
Management Systems Based on Program Development	34-36	0.61	0.80

A structural model was used with AMOS software to assess the impact of each variable. After inputting the data for each question and variable and performing second-order factor analysis, the direct effects of the variables were assessed. The following results were obtained in Figure 2 and Table 5.

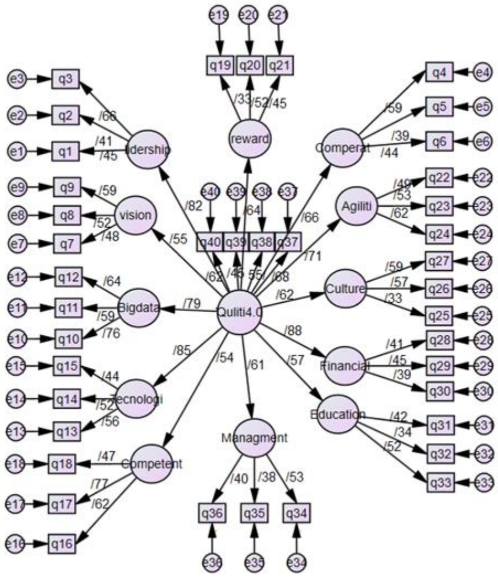

Fig. 2. Final (Structural) Research Model.

Table 5. Importance of Quality 4.0 Implementation Factors and Path Analysis of the Structural Model.

Local Variables	Direction of Relationship	Manifest Variable	R^2	Critical Ratio C.R	Factor Load	Percent Confidence	Significance Level	Label
Leadership	<---	Quality 4.0	0.733	11.874	0.82	0.99	***	Meaningful
Employee Cooperation	<---	Quality 4.0	0.909	10.801	0.66	0.99	***	Meaningful
Vision	<---	Quality 4.0	0.850	10.433	0.55	0.99	***	Meaningful

Local Variables	Direction of Relationship	Manifest Variable	R^2	Critical Ratio C.R	Factor Load	Percent Confidence	Significance Level	Label
Big Data Control	<---	Quality 4.0	0.764	11.639	0.79	0.99	***	Meaningful
Technology Infrastructure	<---	Quality 4.0	0.702	8.883	0.55	0.99	***	Meaningful
Competence and Skills of Employees	<---	Quality 4.0	0.781	9.939	0.54	0.99	***	Meaningful
Rewards	<---	Quality 4.0	0.792	10.582	0.64	0.99	***	Meaningful
Organizational Agility	<---	Quality 4.0	0.687	10.955	0.71	0.99	***	Meaningful
Organizational Culture	<---	Quality 4.0	0.692	7.838	0.62	0.99	***	Meaningful
Financial Resources	<---	Quality 4.0	0.631	12.704	0.88	0.99	***	Meaningful
Training	<---	Quality 4.0	0.631	10.247	0.57	0.99	***	Meaningful
Management Systems Based on Program Development	<---	Quality 4.0	0.668	10.515	0.61	0.99	***	Meaningful

Based on the critical ratio values, a value outside the range -1.96 to 1.96 indicates significance with 95% probability for the latent variables. Additionally, if the value exceeds 2.58, significance is accepted with 99% probability. Since the values in the table are greater than 2.58, the latent variables are significant at a 99% probability. Furthermore, the variable indices are considered significant with a p-value of 0.000 (less than 0.05).

Based on the results in Table 6, the chi-square to degrees of freedom ratio is a statistic used to evaluate how well a model fits the population data. According to this statistic, if the ratio is less than 3, it confirms that the model fits the population data perfectly, supporting the null hypothesis. In this case, the calculated relative chi-square for the latent variables is 1.372, confirming the null hypothesis and showing a perfect fit of the model to the population data. The goodness-of-fit indices also indicate that the model has an acceptable fit. Therefore, based on these indices, it can be concluded that the model fit is confirmed.

Table 6. Model Fit Indices for Variable Measurement

Model Fit Criteria	Indicator	Amounts	Acceptable Domain	Result

Relative chi-square	ℵ ^{2}/df	1.372	<3	Very Good
Root Mean Square Error of Approximation	RMSEA	0.035	<0.08	Very Good
Parsimony Goodness of Fit Index	PGFI	0.664	>0.05	Accept
Adjusted Goodness of Fit Index	AGFI	0.951	>0.08	Very Good
Goodness of Fit Index	GFI	0.972	>0.08	Very Good
Normed Fit Index	NFI	0.986	>0.09	Very Good
Tucker-Lewis Index	TLI	0.990	>0.09	Very Good
Incremental Fit Index	IFI	0.950	>0.09	Very Good
Comparative Fit Index	CFI	0.965	>0.09	Very Good

5. Conclusion and Recommendations

5.1 Conclusion

This research aimed to identify the factors influencing the establishment of Quality 4.0 and to investigate the relationships and impact among them. The study found that factors such as financial resources, leadership, technological infrastructure, big data control, organizational agility, employee cooperation, rewards, organizational culture, management systems focused on program development, training, vision, and employee competence and skills significantly affect the establishment of Quality 4.0.

The research revealed that financial resources have the highest impact on the implementation and establishment of Quality 4.0 in the research organization. Adequate budgetary provisions for infrastructure and technology are essential for subsequent planning stages in any organization. Technological infrastructure is also crucial, as the availability of necessary infrastructure is required for the utilization and implementation of new technologies. Leadership is critical, with managerial support, employee motivation, and clear role delineation being essential for establishing Quality 4.0. However, the study also highlights the crucial role of employee cooperation. Increasing employee cooperation in the journey towards Quality 4.0 is essential and necessary. This, along with the establishment of a vision and strategies, influences organizational culture and employee beliefs and values, which in turn affect the management of financial resources and employee training. Furthermore, the study indicates that increased employee cooperation, skills, and competence are influential in the adoption of Quality 4.0 in research industries.

The study also highlights the relationship between technological infrastructure, big data control, and rewards. Additionally, organizational agility and culture are essential factors in establishing Quality 4.0. The ability of an organization to adapt to changes and collaborate on strategic objectives, as well as internal unity and cohesion, are crucial for the successful establishment of Quality 4.0.

Incorporating appropriate technologies in conjunction with Quality 4.0 allows for the improvement of managing product demand data, production processes, material requirements, and inventory, resulting in enhanced product quality. Additionally, by establishing essential infrastructure, the country's research industries can gain a competitive advantage over similar industries, leading to improved performance, profitability, and the ability to provide suitable rewards to employees in this sector. Creating optimal conditions for big data management and offering appropriate rewards to employees can pave the way for establishing a Quality 4.0 system within the country's research industries. However, it is essential to acknowledge that, like many other studies, this research also has certain limitations in executing its processes. One of these limitations is the failure to examine various cycles among the drivers, a standard structural limitation encountered in structural equation modeling techniques.

5.2 Recommendations

Future research should identify the factors influencing effective leadership, given its significant role in establishing Quality 4.0, and develop an appropriate communication map. Additionally, it is suggested that future studies incorporate the time factor when researching specific case studies to apply a dynamic systemic approach, allowing for more significant interaction among dimensions.

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