Utilizing the Delphi Method for Selecting Smart Quality Key Factors in the Manufacturing Context

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Abstract **– The quality of products and services used in global marketplaces is critical. Manufacturing companies can compete in international marketplaces by leveraging quality effectively to outperform competition. Industry 4.0, a plan promoted by industrialized countries, has resulted in implementing "smart manufacturing," which places a premium on quality control. As a result of improved quality control enabled by new technology, the industrial sector has been changed. Nonetheless, smart quality implementation is still in its early stages, and more empirical study is needed to understand its benefits and drawbacks fully. A survey will be developed to assess how people perceive smart quality awareness and manufacturers' readiness to embrace Smart Quality. This study applied Delphi methodology to investigate the critical factors and particular indicators of implementing the Smart Quality model in manufacturing organizations. Experts from academics and business management analysed the Delphi approach and discovered eight factors and sixteen indicators. The findings will lead to a new method for assessing Smart Quality.**

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1. Introduction

Quality is a vital aspect of products and services used in global marketplaces. Organizations can compete in international markets by efficiently utilizing quality to outperform competitors. Integrating several cutting-edge technologies, such as machine learning, the Internet of Things, cyber security, 3D printing, mixed reality, autonomous robots, cloud computing, cognitive computing, quantum computing, augmented reality, cyber-physical spaces, nanotechnology, genetic engineering, artificial intelligence, and blockchain technology, has significantly impacted industrial systems in recent times [1]. Industry 4.0 has changed substantially modern enterprises' engineering, manufacturing techniques, procedures, and technologies [2]. This phenomenon, known as the Fourth Industrial Revolution is founded on advanced engineering and manufacturing technology. Extensive digitalization, advanced robotics, adaptive automation, modeling and simulation, artificial intelligence, additive and precision manufacturing, big data analytics, and material nanoengineering are all part of it [1], [3]. One issue to address is how traditional management systems and processes have accommodated changes in cycle time compression, product development stages, and staff efforts in order to meet customer expectations and requirements [4], [5].

The onset of the fourth industrial revolution has led to notable advancements in field of quality management (QM) due to modern technology that improves QM processes [6]. According to Silitonga *et al.* [6], by adding the concept of supply chain in quality management process, quality 4.0 expands on Industry 4.0. Smart quality is a framework that uses data analytics and digital technologies to optimize performance and streamline quality management operations.

It entails gathering, evaluating, and displaying quality-related data from a variety of sources, including sensors, industrial machinery, and quality assessments. As a result, this data is utilized to uncover patterns, trends, and anomalies, assisting organizations in improving their performance, reducing errors, and increasing efficiency.

Many countries are actively working to develop Industry 4.0 and intelligent manufacturing, which has emerged as a dominant trend in the global manufacturing industry. The fundamental goals and distinguishing characteristics of innovative manufacturing development are widely acknowledged as supporting environmentally sustainable practices and incorporating human-centric approaches [7]. Intelligent manufacturing is strengthened by an integrated automation system that is based on ICT (Information and Communication Technology). This system incorporates numerous technological tools, including big data, information-physical systems, cloud computing, the Internet of Things (IoT) and artificial intelligence [1], [8], [9].

Smart manufacturing is a cutting-edge and revolutionary solution to the industrial system. Smart manufacturing is a term researchers use to describe a sophisticated automation system used in manufacturing processes. It employs data-driven analytics and incorporates numerous sophisticated technology instruments inside a cyber-physical system [10]. Smart manufacturing is a holistic system that combines contemporary information and communication technology (ICT) and data analytics with intelligent technological improvements, all coupled with a decision-making system [11]. This technology enables the incorporation of sophisticated control and decision-making functionalities into industrial processes and shop floors, resulting in high autonomy and intelligence [12]. Integrating information technology and automation, as well as Internet of Things (IoT) technologies, allows for the smooth flow of production instructions, resources, components, processed parts, and finished goods in smart manufacturing [13].

Research investigates the variables linked with Quality 4.0 or smart quality. Antonino *et al.* [14] found three criteria that influence the accomplishment of Quality 4.0: The industrial system configuration, technology of cyber-physical systems, and the standardization of cyber-physical quality procedures are all explored. Carvalho and Lima [15] identified eight characteristics that strongly influence the performance of Quality 4.0: commitment from management, employee involvement, customer and supplier participation, benchmarking methodology, information and analysis, process management, and formal strategy development are all critical components of successful business operations. Another study by Maganga and Taifa [16] examined the critical components of achieving Quality 4.0. Some key factors that contribute to the success of an organization include support from top management, leadership support, strategic vision, awareness, knowledge, training and skills development, adoption of advanced technology, government structure, organizational culture, supplier and customer orientation, collaboration, reliable infrastructure, supporting technology implementation, big data utilization, presence of a talented and skilled labor, and sufficient financial supports.

Industry strives to mechanize digital procedures and synchronize and integrate those mechanized procedures with other systems and operations to utilize smart quality fully. Staff and management may spend more time on innovation and creativity and less time implementing changes when the system is improved. A firm's top management's unwavering support will enable and promote actions and attitudes that result in superior outcomes for the company. To achieve excellence and preserve their competitive edge, businesses also need to put into practice a strategy plan that emphasizes ongoing development and the application of cutting-edge technology. Various essential abilities are required for quality practitioners in the context of new revolutions. Adequate preparation will be critical, as various talents at multiple levels will be required. The aim of this research is to create a framework/model that will enable manufacturing enterprises to switch from conventional quality methodologies such as total quality management (TQM), quality control and assurance, to smart quality. A contemporary approach to quality control called "smart quality" is in line with the advancements of the fourth industrial revolution.

2. Research Methodology

The traditional Delphi method starts with an unstructured questionnaire that needs a lot of time to finish and usually has a low response rate [17], [18]. The Delphi approach justifies the merger. It shows how it might be used to assess leadership performance in real-time restructuring projects involving system decision-makers [19]. Figure 1 depicts the incremental steps in four stages.

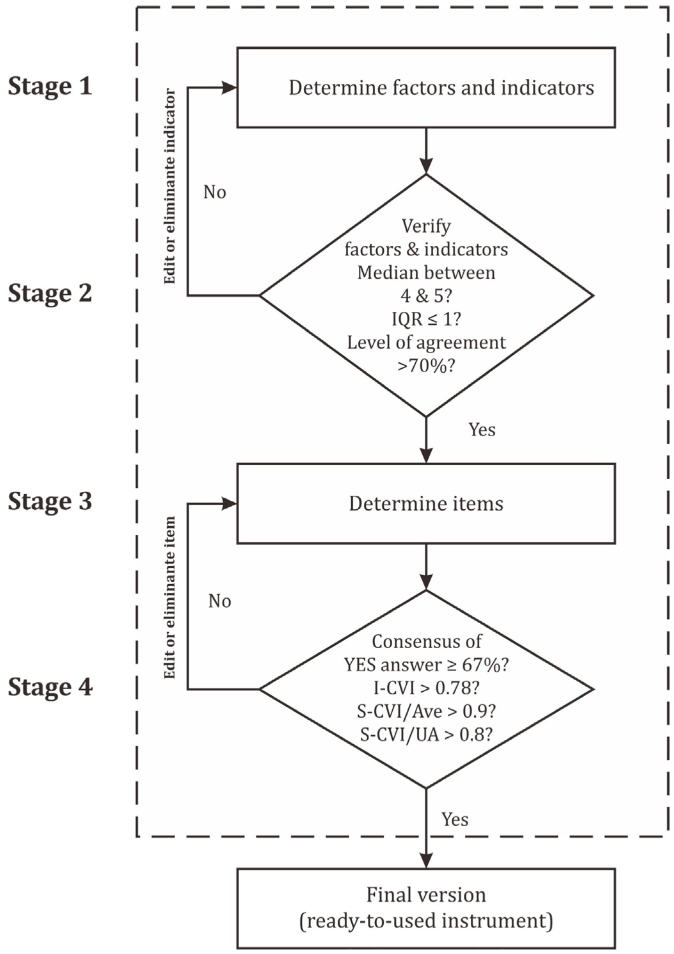

Figure 1. Research method

The first stage focuses on getting consensus among the panelists on the proposed relationship, which is the foundation for building the model. The panelists were asked to agree if the factors and indicators aligned with current theories. According to a Likert scale with a range of 1 to 5, the approval scores were determined: 1= considerable disagreement, 2= disagreement, 3= neutrality, 4= agreement, and 5= great agreements.

According to Mao *et al*. [18], the statistical analysis will determine the level of comprehension, interquartile range (IQR), and median based on the following criteria:

a) The responses from the top two measures should agree by more than 70%.
b) The IQR should be one or less.
c) Between the top measures should lie the median

Getting validation for the suggested indicators is the purpose of the second stage. To find out if the suggested indicators produced a conformance rating between 1 and 5 and matched the pertinent factors, the panelists were asked a series of questions (Table 1 defines the scoring system). As in the first round, the statistical analysis will assess the degree of agreement with the requirements, the median, and the interquartile range (IQR).

Agreeing on the compiled items is the goal of stage 3. Based on panelist comments and references from previous studies, each indicator is turned into a statement or an article. Each item needs to be stated clearly. Future empirical research participants who are stakeholders expect all items to be easily understood. At this point, the panelists will be asked to assess an item's level of acceptability for a particular stakeholder group. A positive or negative binary scale is used to convey the responses. The panelists' unanimity in agreeing to inform the chosen stakeholders about an issue is represented by the affirmative response "YES," whereas the negative response "NO" suggested otherwise. When there is more agreement than 67% (0.67) among the panelists, a response is deemed the consensus [20]. In these conditions, the issue is considered appropriate for a particular stakeholder group of 36 individuals if more than 67% (0.67) of the panelists responded in the affirmative. Items that receive a majority "YES" vote are kept; otherwise, they are removed. During the final round, the panelists were required to determine if a certain item was appropriate for a given stakeholder group.

Table 1. Suitable scale [17]

No	Scale reference	Definition
1	Most unsuitable	No connection/no relevance. It should not be considered a factor at all.
2	Unsuitable	Relevant insignificantly to the latent variable. It barely makes a difference.
3	Moderate suitable	Potentially pertinent to the latent variable (Possibly pertinent to the latent variable).
4	Suitable	Pertinent to the latent variable.
5	Very suitable	The latent variable is where it is most applicable. It directly affects the latent variable.

3. Results and Discussion

This section will present the data processing and discuss the results from stage 1 to stage 4 based on the research methodology.

3.1. Stage 1: Determine Factors and Indicators

Latent variables that required measurable indicators were the factors that were being examined. As such, identifying indications was the next step in the conversation. Prior research was used for the concepts [6]. Table 2 lists the twenty-one indicators that have been selected. The panelists' approval and unanimity were also necessary before going on to the next round.

Table 2. List of proposed indicators

Factor	References
Leadership	[21]
Strategy	[2], [3], [21]
Organizational culture	[22]
Skilled and competent workers	[2], [22]
Adoption of smart quality	[2], [21]
Infrastructure	[23],[24], [25]
Financial	[26]
Performance	[2], [21]

3.2. Stage 2: Verify Factors and Indicators

A panel of experts must reach a consensus in order to use the Delphi technique [27]. The panelists' replies were analyzed to arrive at a consensus. Invitations to participate as panelists have been sent to six professionals. Grime and Wright [28] recommend consulting five to twenty specialists with a variety of backgrounds and pertinent field experience. Every one of the six experts said they would be willing to take part in the research. These were the executives and management from industry and academia. The experts' demographic features are displayed in Table 3.

Table 3. The experts' profile

	Level	Number of experts
Industry	C-level	1
	Management	2
Academia	Managerial	2
	Lecturer	1

The panelists were questioned about the suitability of the proposed indicators in bolstering the pertinent factors. Experts provided a rating ranging from 1 to 5 based on Table 1. Based on a prior study by Mao *et al.* [18], statistical analysis was conducted for this investigation.

3.3. Stage 3: Determine the Items

The next step in the procedure was to gather the items that were derived from each indicator. There were sixteen items in all (Table 4). In addition, the panelists' agreement was required to confirm the suitability of the items. SPSS was used to analyze the stage 2 data, and Table 5 shows the results, including the median, IQR, and degree of agreement.

Table 4. List of factors and items

Factors	Items	Code
Leadership	How eager the leaders to put smart quality (SQ) into practice?	IL1
Strategy	Is the company prepared to implement a SQ-aligned modern quality approach?	IS1
	Does your company have a roadmap for putting SQ into practice?	IS2
	What role does SQ play in the organization's vision and strategy?	IS3
Organizational Culture	How is the quality culture in your organization?	IOC1
Skilled & Competent Workers	Is your company building the quality knowledge and abilities necessary to implement the modern quality philosophy in line with the fourth industrial technology?	ISC1
	Within the organization, how are skills and knowledge shared?	ISC2
Adoption of Smart Quality	Did you know that satisfying customer needs is the main goal of quality improvement?	IASQ1
	As you may know, cutting losses, waste, quality expenses, and inefficiencies across the whole manufacturing cycle is what continuous improvement entails.	IASQ2
	Do you know what technology the Industry 4.0 revolution's new quality techniques are based on?	IASQ3
Infrastructure	Does your organization use cyber security in its IT applications?	II1
	Is data transparency being achieved by your organization via the use of technology and data integration in quality management?	II2
	Does your business use technology that can handle large amounts of data (big data)?	II3
Financial	Is your company utilizing funds to implement the high-quality technology that is driving the industry 4.0 revolution?	IF1
Performance	How does your company focus on meeting customer needs?	IP1
	Do the products have integrations with other systems (such supply chain, purchasing, sales, etc.)?	IP2

Table 5. The median, IQR, and level of agreement of items

Factors	Code	Indicators	Median	IQR	Level of Agreement
Leadership	IL1	Leadership	5	0	1
Strategy	IS1	Top management support	5	0	1
	IS2	Formal strategic planning	4	0	0.83
	IS3	Benchmarking techniques	4	0.75	0.67
Organizational culture	IOC1	Organizational culture	4	0.75	0.83
Skilled and competent worker	ISC1	Information and analysis	4	0.75	0.83
	ISC2	Competent and skilled workers	4	0	1
Adoption of Smart quality	IASQ1	Management commitment	5	0.75	1
	IASQ2	Process management	4	0	0.83
	IASQ3	Collaboration	4	0	0.83
Infrastructure	II1	Cyber security	4.5	1	1
	II2	Cognitive technology availability	4.5	1	0.83
	II3	Reliable infrastructure	5	0.75	0.83
Financial	IF1	Financial setup	4	0.75	0.83
Performance	IP1	Customer Involvement	4	0.75	0.67
	IP2	Employee involvement	4	0	0.67

3.4. Stage 4: Verify the Items

In this phase, the panelists were assigned the responsibility of assessing an item's suitability regarding a particular stakeholder group. Responses were measured on a binary scale of "YES" or "NO". The answer "YES" signifies the panelists' agreement to direct an item to the specified stakeholders, whereas the response "NO" indicates the opposite. The response is considered the consensus when the panelists' agreement exceeds 67% (0.67) [20]. Under these circumstances, it is presumed that the item is appropriate for a specific stakeholder group of 36 individuals if over 67% (0.67) of the panelists answered affirmatively. Items are preserved if there is a prevailing "YES" vote; otherwise, they will be eliminated.

The remaining inquiries will generate a prototype survey tailored to specific stakeholder demographics.

The content validity index (CVI) was analyzed continuously throughout the process. It is a crucial aspect of scale construction as it assesses how much a questionnaire includes a representative selection of items that accurately measure the intended construct [29]. To guarantee that the questionnaire contains an appropriate assortment of things for the evaluated concept, Rodriques *et al.* [30] furnished guidance on computing content validity while Polit *et al.* [31] specified the crucial threshold within the acceptance range. Table 6 provides an overview of both descriptions. The procedure proceeded by assessing the content validity index, beginning with each item's I-CVI and UA computations, as indicated in Table 7.

Table 6. Content validity and the significant value

Content Validity	Symbol	Calculation	Significant Value
Content validity for each item	I-CVI	The proportion of experts who said "YES" to all experts	≥ 0.78
Overall scale validity (Average)	S-CVI/Ave	The sum of the I-CVIs is divided by the total number of items	≥ 0.90
Overall scale validity (Universal agreement)	S-CVI/UA	If all panelists responded YES to an item, it is given a value of 1; otherwise, it is given a value of 0 (Universal Agreement/UA). The S-CVI/UA is derived via dividing the entire number of items by sum of UAs	Overall scale validity (Universal agreement)

Table 7. Calculation of I-CVI and UA for each item

Code	Experts 1	2	3	4	5	6	Expert in Agreement	I-CVI	UA	S-CVI/Ave	S-CVI/UA
IL1	1	1	1	1	1	1	6	1	1	0.979	0.875
IS1	1	1	1	1	1	1	6	1	1		
IS2	1	1	1	1	1	1	6	1	1		
IS3	1	1	1	1	1	1	6	1	1		
IOC1	1	1	1	1	1	1	6	1	1		
ISC1	1	1	1	1	1	1	6	1	1		
ISC2	1	1	1	1	1	1	6	1	1		
IASQ1	1	1	1	1	1	1	6	1	1		
IASQ2	1	1	1	1	1	1	6	1	1		
IASQ3	1	1	1	1	1	1	6	1	1		
II1	1	1	1	1	1	1	6	1	1		
II2	1	1	1	1	1	1	6	1	1		
II3	1	1	1	1	1	1	6	1	1		
IF1	1	1	1	1	1	1	6	1	1		
IP1	1	1	1	0	1	1	5	0.833	0		
IP2	1	1	1	0	1	1	5	0.833	0		

The ratios of S-CVI/UA and S-CVI/Ave were computed. The entries in the list had I-CVI values ranging from 0.80 to 1.00, which exceeded the recommended cut-off point of 0.78. This suggests that every item's content was of the exceptional quality. The S-CVI/UA and S-CVI/Ave values are 0.875 and 0.979, respectively, above the suggested thresholds of 0.8 and 0.9. Subsequently, the entire scale demonstrated outstanding content validity. Each of the three variables is represented by a different indicator: leadership, organizational culture, and financial factors. This statistic is generated by assessing the efficacy of leadership, the state of corporate culture, and the financial structure within the organization. The three indicators of strategic considerations are the extent of top management support, formal strategic planning, and the application of benchmarking tools throughout the firm. Two indicators were used to assess the skilled and competent worker component: the quality of information and analysis and the presence of competent and professional people.

Three essential variables influence the adoption of intelligent quality elements: management commitment, process management, and collaboration. The infrastructure factor includes three indicators: cyber security, cognitive technology accessibility, and the dependability of the used infrastructure. Two performance measures are used: customer engagement and employee engagement. The things were arranged to be distributed among the recipients. As a result, it is critical to formulate the questions understandably and adequately so that all responders interpret them similarly. A prototype instrument was created that included a wide range of pertinent questions for every stakeholder group. There was broad consensus on every topic, with agreement rates topping 67%. As so, the revised Delphi survey has been finished.

4. Conclusion

This study developed a tool for evaluating the manufacturing company. Eight factors were discovered: the primary focus areas include leadership, strategy, organizational culture, qualified and competent staff, intelligent quality implementation, infrastructure, financial management, and performance. The eight criteria were fundamental constructs that required measurable evidence to confirm their validity. Furthermore, a total of 16 specific indicators have been identified.

Using a combination of focus group discussion, expert consensus, and research a deductive method was employed to discover attributes, indicators, and items.

The panelists, experts in corporate management and higher education/academics, shared their thoughts. The application of the modified Delphi technique led to the agreement. The questions presented to the panelists were straightforward but relatively well-organized inquiries based on established and reliable preceding research. Expert panel consensus was established on every item, and the scale as a whole and its separate parts were determined to have exceptional content validity.

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