The Mediating Role of Knowledge and Awareness in Quality 4.0 Management Implementation: Evidence from the Egyptian Manufacturing Sector

submitted by

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Raya International Journal of Business Sciences

volume (4), issue (13), april 2025

https://www.rijcs.org/

Publisher

Raya Higher Institute of Management and Foreign Trade in New Damietta

الدور الوسيط للمعرفة والوعي في تنفيذ إدارة الجودة الرابعة: أدلة من قطاع التصنيع المصري

إعداد

د/ سارة السيد الشاذلي
مدرس بقسم إدارة الأعمال كلية التجارة جامعة حلوان

مجلة راية الدولية للعلوم التجارية
دورية علمية محكمة
المجلد (٤) ـ العدد (١٣) ـ أبريل ٢٠٢٥
https://www.rijcs.org/
الناشر
معهد راية العالي للإدارة والتجارة الخارجية بدمياط الجديدة
المنشأ بقرار وزير التعليم العالي رقم ٤٨٩٠ بتاريخ ٢٢ أكتوبر ٢٠١٨ بجمهورية مصر العربية

ABSTRACT

This study examines the mediating role of knowledge and awareness of Quality 4.0 on the relationship between Quality 4.0 readiness factors and the implementation of Quality 4.0 management practices within the Egyptian manufacturing sector, specifically targeting the automotive, food, and paper industries. A quantitative, cross-sectional, and correlational research design was employed, utilizing a structured questionnaire with a 5-point Likert scale to gather data from 123 middle-level managers. Stratified random sampling was implemented to ensure proportional representation across the selected industries, with data collection conducted between September 23, 2024, and January 18, 2025.The measurement model exhibited exceptional psychometric properties and demonstrating high internal consistency. Strong positive inter-correlations were observed among all constructs, suggesting significant interdependencies. Structural equation modeling (SEM) was subsequently employed to evaluate the hypothesized mediation model. The findings confirmed the significant mediating role of knowledge and awareness of Quality 4.0 in the relationship between readiness factors and implementation. This study contributes to the extant literature on Quality 4.0 adoption within the Egyptian manufacturing context, emphasizing the critical role of knowledge and awareness in facilitating effective implementation.

Keywords: Readiness factors, Quality 4.0, Knowledge and awareness

Introduction

The primary objectives of any organization include enhancing productivity, satisfying customer needs, and minimizing waste. As a result, organizations adopt quality systems and digital technologies to optimize their manufacturing processes and enhance overall organizational performance to achieve the previously mentioned objectives. Consequently, there arises the necessity for digital transformation, commonly referred to as Industry 4.0. By applying Industry 4.0 principles to the quality management system, it can be transformed into Quality 4.0. To comprehend the evolution of Quality 4.0, it is essential to elucidate the progression of Industry 4.0.

Rojko (2017) explained that integration of Information Technologies (IT) into manufacturing is a movement known as Industry 4.0 or the Fourth Industrial Revolution. Industry 4.0 is being actively promoted by the German government. This industrial evolution relies heavily on the implementation of core technologies, including Cyber-Physical Systems (CPS), the Internet of Things (IoT), cloud computing, and big data analytics.

Tamas and Illes (2016) clarified that Industrial manufacturing's shift away from purely manual operations towards the contemporary Industry 4.0 framework is commonly described as a sequence of four major technological advancements. The first such advancement, occurring in the 1800s, brought about mechanization and steam-based power generation. Following this, the second revolution, driven by electrification, enabled industrialization and the rise of large-scale manufacturing. Xu *et al.* (2018) stated that the third industrial revolution revolved around digitalization, marked by the introduction of microelectronics and automation and this revolution facilitates flexible production in manufacturing system. However, these manufacturing systems still lacked flexibility in terms of production quantity. Talaie *et al.*(2024) mentioned that fourth industrial revolution was triggered by the development of Information and Communications Technologies (ICT). Its technological foundation lies in the intelligent automation of cyber-physical systems with decentralized control and advanced connectivity, leveraging IoT functionalities. As a result, Carvalho *et al.*(2020) explained that traditional hierarchical automation systems in industrial production have undergone reorganization, evolving into self-organizing cyber-physical production systems that enable flexible mass customization and production quantity flexibility.

Emblemsvag (2020) stated that through different industrial revolutions, the concept of quality, much like these industrial revolutions, experienced a notable evolution. The evolution of quality can be comprehended through various stages. The first quality evolution persisted from ancient times until the industrial revolution. Weckenmann *et al.* (2015) mentioned that with the advancement of industrialization, there was a rise in complexity of both products and processes. This led to the emergence of second quality paradigm known as quality assurance (QA). Sony *et al.*(2021) mentioned that key quality principles were developed, such as sampling inspection, the incorporation of statistical tools within the framework of scientific management, standardization, and the functionalization of the discipline. The purpose of these principles was to tackle the escalating complexities and guarantee the uniform quality of products. Dooley (2000) clarified that by the end of the 20th century, considerable attention was directed towards establishing quality control systems as enterprises acknowledged the significance of sustaining competitiveness on a global level. As a result, a third paradigm, comprehensive quality management, emerged. Total quality management (TQM) revolutionized the comprehension and implementation of quality standards by introducing concepts such as organizational learning and participatory management. Chiarini and Kumar (2021) mentioned that based on advent of the fourth industrial revolution, the expansion of industry poses a major hurdle for quality professionals seeking to adapt their methodologies accordingly. Sader *et al.* (2021) identified that numerous conceptual frameworks and models have been put forth, especially concerning the dimensions of Quality 4.0. However, the main challenge lies in facilitating organizations` transition from their current quality approaches to a contemporary quality paradigm that is in line with the demands of this current industrial revolution. In addition, research on Quality 4.0 remains in its nascent stages, particularly with the emergence of the new quality approach. A significant challenge is the transition of enterprises, especially in developing countries, from traditional methods to contemporary quality practices, necessitating a systematic approach to the implementation of Quality 4.0. To address the existing research gap from application perspective, this study aims to examine and validate the readiness factors identified by Maganga and Taifa (2023) through investigating quality professionals operating within the Egyptian manufacturing sector. The study seeks to establish a systematic framework for the implementation of Quality 4.0 in Egypt's manufacturing sector.

Therefore, the main objective of this study is to examine the readiness factors that affect knowledge and awareness of middle level managers to facilitate the implementation of Quality 4.0 in Egyptian manufacturing sector. This study utilizes Quality 4.0 because Egypt has started to embrace its potential due to the increasing use of artificial intelligence applications in the manufacturing industry. This will result in the following main research question: How does knowledge and awareness of Quality 4.0 facilitate the translation of readiness factors into Quality 4.0 management implementation?

Literature review

This definition is introduced by Aldag and Eker (2018), they referred to Quality 4.0 as the amalgamation of established quality management practices and techniques through emerging technologies such as machine learning, cloud technologies, Big-Data, connectivity devices, Internet of Things, and Artificial Intelligence.

This integration has given rise to a sophisticated collaborative environment, through this environment management activities are guided by enhanced connectivity across the entire value chain spanning from suppliers to end-customers.

Jacob (2017a) explained that Quality 4.0 represents the application of modern technologies to enhance traditional quality management techniques, aiming to achieve a higher level of excellence at the functional and operational levels. The researcher determined that manufacturers who implemented quality 4.0 technologies experienced significantly improved effectiveness and efficiency in quality management. This, in turn resulted in increased market share, heightened innovation, enhanced capabilities in addressing value chain challenges, and improved brand recognition.

According to Jacob (2017b), Business leaders pay attention to quality 4.0, or their business is estimated to have the risk of being marginalized and remaining on the side-lines of their respective industries.

According to Allcock (2018), emphasized distinction between Quality 4.0 and traditional quality lies in the transition from manual measurement, recording of results on quality charts, and manual adjustment of the manufacturing process, to a fully automated approach. In quality 4.0, sensors are used to measure parameters, software applications are employed to analyze and control the process.

Also, Schönreiter (2017) explained that Quality 4.0 refers to the seamless integration and synchronization of data pertaining to manufacturing processes and activities, along with quality management. In order to achieve this, quality 4.0 necessitates the connection to real-time analysis systems capable of monitoring, analyzing and controlling the entire value chain. This comprehensive approach allows for the implementation of timely countermeasures to prevent production downtime and product rejections.

According to Allcock (2018), Quality 3.0 encompasses the conventional activities of quality management, such as: analyzing manual metrics and addressing inefficiency issues that took place in the past days. On the other hand, quality 4.0 represents the evolution of quality tasks to anticipate future quality issues and proactively maintain performance, thus aiming for a higher level of excellence and stability. The primary advantage of quality 4.0 lies in its ability to guide the production process towards generating products of superior quality at a reduced cost, enhancing responsiveness, and achieving greater competitiveness.

Also, Bossert (2018) clarified that Quality 4.0 necessitates a higher level of professional competence in the field of quality management, diverging from the more IT centered approach of industry 4.0. As Industry 4.0 concentrates on leveraging technological advancements, such as: sensors, networks, Big-Data, and cyber physical systems in manufacturing. Quality 4.0 is a practice which relies on expertise and proficient quality managers who are capable of discerning the requisite data and determining its optimal utilization.

Finally, Antony et al. (2022) discussed that the contemporary manufacturing environment, driven by the proliferation of Quality 4.0, it concerned with knowledge and awareness of practitioners with quality 4.0. This evolution presented significant challenges for routine and repetitive tasks which are increasingly automated by intelligent, self-regulating systems. Consequently, Maganga and Taifa. (2023) mentioned that human-centric roles will demand advanced process integration, interdisciplinary expertise, and a shift away from traditional hierarchical management models. Therefore, the evolving landscape necessitates a broader and more sophisticated skillset, emphasizing complex problem-solving, emotional intelligence, foundational knowledge, and the practical application of Quality 4.0 tools.

It is essential to elucidate the situation in Egypt from the perspective of Quality 4.0. This analysis will be conducted by first assessing the degree to which quality management practices have been implemented in Egypt, along with the extent of Industry 4.0 adoption among Egyptian manufacturing companies. The subsequent studies and reports will provide insights into the current situation in Egypt.

- The manufacturing sector in Egypt constitutes a vital segment of the economy, accounting for 16.2% of the nation's GDP and providing employment for 12.4% of the total labor force, as documented by El Dahshan (2020). However, this sector has encountered persistent difficulties in implementing and maintaining Quality 3.0 standards over the last twenty years. Similar to prevailing trends in other developing nations, a substantial portion of Egyptian manufacturing firms have historically adopted Quality 3.0 practices primarily as a compliance measure to meet governmental regulations, specifically those required for project acquisition. This compliance-driven approach has frequently resulted in compromised product quality and a subsequent decline in the competitive edge of these firms against international rivals.
- Acknowledging the critical role of quality in achieving sustainable industrial growth and enhancing competitive advantage, the Egyptian government, as highlighted by Khurana and Shaban (2019), implemented a broad reform program. This initiative focused on revitalizing the manufacturing sector and elevating the competitiveness of Egyptian products. A cornerstone of this strategy was the establishment of the National Quality Council (NQC) in 2012, designed to manage and develop the national quality infrastructure. Additionally, institutions such as the Industrial Modernization Center (IMC), the Foreign Trade Training Centre (FTTC), and the Egyptian Society for Quality (ESQ) were formed to offer training, technical assistance, and consultative services to Egyptian manufacturing enterprises. These organizations have been instrumental in providing extensive support for capacity building and sectoral development across diverse industrial domains.

- According to Khourshed, et al. (2023), Egypt's strategic vision includes a comprehensive digital transformation, aimed at improving citizen quality of life through the integration of advanced technologies and digitized public services. This initiative is also expected to diversify the national economy. Current discussions highlight the growing importance of smart city development, the Internet of Things (IoT), and related technological advancements. A key component of this transformation is the transition from traditional, paper-based government processes to digital transactions, which will enhance service efficiency and transparency for citizens.
- A collaborative initiative, formalized through a Memorandum of Understanding between the Industrial Modernization Center (IMC), Siemens Egypt, and the Information Technology Industry Development Agency (ITIDA), has been established. This partnership aims to develop and operationalize Egypt's first Industry 4.0 Innovation Center (IIC). The IIC's mandate is to facilitate the integration of Fourth Industrial Revolution technologies within smart factory environments. Furthermore, the center will provide crucial support for industrial innovation and the development of advanced manufacturing facilities, with a focus on disseminating knowledge and stimulating growth within the regional industrial ecosystem. *(https://mcit.gov.eg/en/Media_Center/Latest_News/News/63419)*

Following the definition and elucidation of the concept of Quality 4.0, as well as an assessment of the extent of its implementation in Egypt, previous studies will be reviewed to identify the research gap, research variables, and research hypotheses. Many studies explained quality 4.0 concept from different perspectives, few numbers of studies focused on readiness factors of Quality 4.0.the following table shows different studies in Quality 4.0 field.

Researcher	Title	Year	Results of the study
a- Studies about knowledge and awareness of Quality 4.0 and Quality 4.0 implementation			
Escobar et al.	Quality 4.0 – an evolution of Six Sigma DMAIC	2022	This investigation reveals that the Identify, Acsensorize, Discover, Learn, Predict, Redesign, and Relearn framework, when integrated with artificial intelligence, exhibits a substantial capacity for resolving intricate engineering challenges. This outcome offers critical insights into the strategic planning difficulties faced by quality-driven manufacturing leaders during the technological integration process and how it is needed specific level of knowledge and awareness.
Joshi et al.	An assessment framework to evaluate the critical success factors to Quality 4.0 transition in developing countries: a case experience of sustainable performance of Indian manufacturers	2024	The study underscores the considerable level of knowledge and awareness for Quality 4.0 within the Indian manufacturing companies, which is acquired through a variety of channels including training, experience, learning and research in order to implement Quality 4.0.
Roy Ghatak and Garza-Reyes	Investigating the barriers to Quality 4.0 adoption in the Indian manufacturing sector: insights and implications for industry and policymaking.	2024	The research findings emphasize the absence of Quality 4.0 standards and the insufficiency of Big Data Analytics (BDA) tools as significant barriers and also, lack of knowledge and awareness about Quality 4.0 to integrate Quality 4.0 within the Indian manufacturing sector.
Wawak et al.	Quality 4.0 in higher education: reinventing academic-industry-government collaboration during disruptive times	2023	The successful fusion of innovative technologies, Quality 4.0 paradigms, and Triple Helix partnerships within academic settings relies heavily on the ongoing educational advancement of instructors. To effectively incorporate these technological shifts and integrate

Researcher	Title	Year	Results of the study
			Quality 4.0 principles into their teaching methodologies, educators must prioritize the development of their digital proficiency
b- Studies about Readiness factors of Quality 4.0 and Quality 4.0 implementation			
Bui et al.	Supply chain quality management 4.0: conceptual and maturity frameworks	2022	The present study culminates in the proposition of a conceptual model for Supply Chain Quality Management 4.0, designed to leverage the inherent capabilities of its constituent constructs for optimized governance and implementation efficacy. Furthermore, this research delineates a unique developmental pathway within the Supply Chain Quality Management 4.0 maturity framework, predicated on the strategic application of these constructs.
Maganga and Taifa	The readiness of manufacturing industries to transit to Quality 4.0	2023	The findings of this study suggest that Tanzanian manufacturing industries demonstrate a foundational understanding of Quality 4.0 (Q4.0) characteristics and its associated benefits, suggesting an inherent capacity for its adoption. While the prevailing quality management paradigm within these industries remains rooted in Quality 3.0 (Q3.0) methodologies, a nascent trend towards Q4.0 integration is evident through the selective incorporation of advanced technological solutions.
Mittal et al.	Essential organizational variables for the implementation of Quality 4.0: empirical evidence from	2023	The findings of this study demonstrate the paramount significance of the identified organizational readiness factors in ensuring the successful

Researcher	Title	Year	Results of the study
	the Indian furniture industry		implementation of Quality 4.0. Automation and cloud computing are highly influential factors.
Oliveira et al.	Quality 4.0: results from a systematic literature review	2024	The researchers studied documents which primarily offer theoretical discussions on the concept and definition of Quality 4.0. Through content analysis, five distinct categories have been identified: Industry 4.0, the emergence of a novel perspective on quality, factors motivating quality 4.0 application, determining the readiness factors for implementing a Quality 4.0 approach, and the implementation of digital quality management systems.
Tewary and Jadon	Building a competent workforce in implementing Quality 4.0: a systematic literature review and proposed agenda for future research	2023	The review conducted by the researchers reveals significant findings, which encompass the progression of literature in the domain of Quality 4.0, as well as the systematic analysis of prior literature reviews that concentrate on training and development. Furthermore, the researchers detected various obstacles pertaining to training that hinder the implementation of Quality 4.0.
c- Studies about Readiness factors of Quality 4.0 and knowledge and awareness of Quality 4.0			
Antony et al.	Quality 4.0 conceptualization and theoretical understanding: a global exploratory qualitative study	2022	This study aims to provide organizations with a comprehensive understanding of the concept of Quality 4.0 in the industry. It explores the various benefits and motivating factors that drive the implementation of Quality 4.0, as well as the Critical Success Factors associated with its deployment.

Researcher	Title	Year	Results of the study
			Furthermore, the study examines the challenges that organizations may face during the implementation process, factors related to organizational readiness, and the crucial role of leadership and knowledge in facilitating a successful Quality 4.0 deployment.
Maganga and Taifa	The readiness of manufacturing industries to transit to Quality 4.0	2023	The findings of this study suggest that Tanzanian manufacturing industries demonstrate a foundational understanding of Quality 4.0 (Q4.0) characteristics and its associated benefits, suggesting an inherent capacity for its adoption. While the prevailing quality management paradigm within these industries remains rooted in Quality 3.0 (Q3.0) methodologies, a nascent trend towards Q4.0 integration is evident through the selective incorporation of advanced technological solutions.
Virmani et al.	Assessing solutions to overcome Quality 4.0 barriers: a decision-making framework	2023	The research findings demonstrate that the primary obstacles are "Failure to utilize advanced analytics for the identification of Quality 4.0 initiatives" and "Failure to integrate data from diverse sources throughout the organization. The study recommends more training and learning to enhance knowledge level.

Table 1: previous studies about quality 4.0 concept

Research gap is identified based on previously explained concepts in literature review, there is a scarcity of research articles that participate to the limited contribution on relationship among Quality 4.0 readiness, Knowledge and awareness of Quality 4.0 and Quality 4.0 implementation. Based on the aforementioned explanation, a research model has been formulated to identify research variables, which is presented as follows.

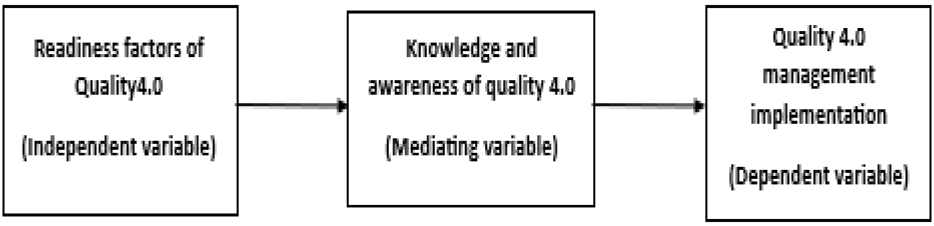

Figure 1: Conceptual framework identifying the mediating role of knowledge and awareness of Quality 4.0 between readiness factors for Quality 4.0 and Quality 4.0 management implementation

<table>
<tr><td>Readiness factors of Quality4.0</td><td rowspan="6">Knowledge and awareness of Quality 4.0 is mentioned by: Sony et al. (2021), Antony et al. (2022), Maganga and Taifa. (2023)</td><td rowspan="6">Quality 4.0 management implementation
Taifa (2021), Antony et al. (2022), Maganga and Taifa. (2023), Sureshchandar (2023)</td></tr>
<tr><td>Data driven is mentioned by: Maganga and Taifa. (2023) , Mittal et al. (2023), Sureshchandar (2023)</td></tr>
<tr><td>Competence is mentioned by: Mittal et al. (2023), Sureshchandar. (2023)</td></tr>
<tr><td>Advanced analytics is mentioned by: Maganga and Taifa. (2023), Mittal et al. (2023), Sureshchandar (2023)</td></tr>
<tr><td>Customer is mentioned by: Wechsler & Schweitzer (2019), Osakwe (2020), Maganga and Taifa. (2023), Sureshchandar (2023)</td></tr>
<tr><td>Supplier is mentioned by: Antony et al. (2022), Sony et al. (2021), Maganga and Taifa. (2023)</td></tr>
</table>

Table 2:References for conceptual framework variables

Based on the previously discussed research conceptual framework and the identified variables, research hypotheses have been formulated to identify the relationships among these variables.

- **Null Hypothesis (H0):** Knowledge and awareness for Quality 4.0 does not mediate the relationship between readiness factors of Quality 4.0 and Quality4.0 management implementation.
- **Alternative Hypothesis (H1):** Knowledge and awareness for Quality 4.0 mediates the relationship between readiness factors of Quality 4.0 and Quality4.0 management implementation.

Which is subdivided into:

(H1.1): Knowledge and awareness for Quality 4.0 mediates the relationship between data driven and Quality4.0 management implementation.

(H1.2): Knowledge and awareness for Quality 4.0 mediates the relationship between competence and Quality4.0 management implementation.

(H1.3): Knowledge and awareness for Quality 4.0 mediates the relationship between advanced analytics and Quality4.0 management implementation.

(H1.4): Knowledge and awareness for Quality 4.0 mediates the relationship between customer and Quality4.0 management implementation.

(H1.5): Knowledge and awareness for Quality 4.0 mediates the relationship between supplier and Quality4.0 management implementation.

Research methodology

This research employs a quantitative, correlational, and cross-sectional design to examine the mediating role of knowledge and awareness of Quality 4.0 in the relationship between Quality 4.0 readiness factors and Quality 4.0 management implementation. Data will be collected via a structured questionnaire, incorporating established and validated measurement scales, from a representative sample of participants within three key Egyptian manufacturing sectors: automotive, food, and paper. The cross-sectional nature of this study allows for the analysis of variable relationships at a single time point, specifically between September 23, 2024, and January 18, 2025, providing a contemporary snapshot of the relevant dynamics. Structural equation modeling (SEM), utilizing SmartPLS software, will be the primary analytical technique. This approach is well-suited for testing the hypothesized mediation model, enabling the simultaneous evaluation of direct and indirect effects. Model fit will be assessed by using established indices, such as: Root Mean Square Error of Approximation (RMSEA).

Sample

This study employed a stratified random sampling technique to ensure representation from key industries within the Egyptian manufacturing sector. The population was stratified based on industry type, specifically: automotive, food and paper manufacturing. These industries were selected due to their significant contribution to the Egyptian economy as it is identified in the following table.

Automotive industry	**Food industry**	**Paper industry**
-Automotive industry represents 14% from national GDP. - Employing 70,000 workers -No. of producers/assemblers: 26 - Annual capacity: 470,000 vehicles - No. of feeder industries factories: 338 -Annual production: US# 655 million - No. of brands: 62 —Sales: 90,000 vehicles (annually) - No. of registered cars: 6 million 20% buses 30% trucks 50% passenger	-Egypt's food industry sector accounted for 14% of Egypt's total exports. - Food industry contributes to 24.5% of the country's GDP. -Food sector exports rose by 20% in 2021. - Food companies doubling from 4,000 to 17,000 and investments of around EGP 500 billion. -Food sector provides 23.3% of Egypt's employment through approximately 7 million job opportunities. *(https://sis.gov.eg/Story/194720/Egypt%E2%80%99s-food-industry-plays-vital-role-in-economy%2C-accounts-for-14%25-of-exports--El-Khatib?lang=en-us#:~:text=Egypt's%20food%20industry%20is%20a,Hassan%20El%20Khatib%20on%20Monday.)*	-Paper sector's exports in 2022 rose by eight percent to 1.063 billion dollars. -Egypt`s ranked 45th out of 226countries globally. -It's estimated that the paper and cardboard industry in Egypt employs approximately 55,000 workers. - Egypt`s share in the global paper industry

Automotive industry	Food industry	Paper industry
(https://www.statista.com/topics/13063/automotive-industry-in-egypt/)		exports represents approximately 0.28%. - Paper industry annual production capacity is around 250,000 tons. *(https://www.sis.gov.eg/Story/176270/Egypt-printing%2C-packaging-%26-paper-exports-up-8%25-in-2022?lang=en-us)*

Table 3: Sample data.

The automotive, food, and paper industries have been selected for analysis, with a leading company identified in each sector. In the automotive industry, the leading company is determined based on its substantial market share, which constitutes 15.9% of the Egyptian automotive market. In the food industry, the leading company specializes in the production of dairy products and commands a dominant share of 57% of the market. Finally, in the paper industry, the leading company is identified based on its highest revenue, which is projected to reach EGP 2.67 billion in 2024.*(https://www.statista.com/search/?q=leading+companies+in+Egypt&Search=&p=1)*

Construction of questionnaire

The data collection instrument for this study was a structured questionnaire designed to assess the constructs of Quality 4.0 readiness factors, knowledge and awareness of Quality 4.0, and Quality 4.0 management implementation. The questionnaire was developed and finalized based on a comprehensive review of the existing literature and preliminary field observations within the Egyptian industrial sector. Each item in the questionnaire was measured using a 5-point Likert scale, ranging from 1 (Strongly Disagree) to 5 (Strongly Agree). This scale was chosen to enable participants to express varying degrees of agreement or disagreement, thereby providing nuanced data for subsequent analysis. To ensure content validity, the questionnaire was reviewed by a panel of experts in quality management and Industry 4.0. The questionnaire was administered to a stratified random sample of participants from three key Egyptian manufacturing sectors: automotive, food, and paper industries. This stratified approach, as described in the sampling section, ensured proportional representation from each industry, enhancing the generalizability of the findings to the broader Egyptian manufacturing context. The data collection period spanned from September 23, 2024, to January 18, 2025. The participant group consisted of middle-level managers, encompassing roles such as quality managers, quality practitioners, operations managers, marketing managers, IT managers, and purchasing managers. Questionnaires were provided in both Arabic and English languages. The total number of questionnaires that were distributed among three leading companies with their factories which located in different geographical industrial zones was 225 questionnaires. Of these, 123 questionnaires were collected and fully completed, representing approximately 55%.

Discussion of results

a-Demographic analysis

The following tables relate to demographic factors, they are explained according to manufacturing system, gender and experience factors for respondents in three leading companies in automotive, food and paper industries.

	Frequency	Percent	Valid Percent	Cumulative Percent
Make to order	60	48.8	48.8	48.8
Make to stock	21	17.1	17.1	65.9
Make to assemble	42	34.1	34.1	100.0
Total	123	100.0	100.0	

Table 4: Manufacturing system

This table presents the distribution of manufacturing systems used by the respondents in this study. The most frequent manufacturing system used is "Make to Order" (MTO), with 60 respondents (48.8%) indicating its use. While "Make to Assemble" (MTA) is the second most common system, with 42 respondents (34.1%). And "Make to Stock" (MTS) is the least common system among the respondents, with only 21 respondents (17.1%) at a total sample size of 123 respondents.

	Frequency	Percent	Valid Percent	Cumulative Percent
5 years to 10 years	62	50.4	50.4	50.4
10 years to 20 years	61	49.6	49.6	100.0
Total	123	100.0	100.0	

Table 5: Experience

This table shows the distribution of the respondents' years of experience, categorized into two ranges: 5 to 10 years and 10 to 20 years. The respondents are almost evenly split between the two experience categories.

- 62 respondents (50.4%) have 5 to 10 years of experience.
- 61 respondents (49.6%) have 10 to 20 years of experience.

The "Valid Percent" is the same as the "Percent," indicating that all 123 respondents provided valid answers for this variable.

	Frequency	Percent	Valid Percent	Cumulative Percent
Male	102	82.9	82.9	82.9
Female	21	17.1	17.1	100.0
Total	123	100.0	100.0	

Table 6: Gender

This table displays the gender distribution of the respondents in this study. The sample is heavily skewed towards male respondents.

- 102 respondents (82.9%) are males.
- 21 respondents (17.1%) are females.

This shows a significant disparity between male and female respondents suggests a potential gender imbalance within middle level managers at the automotive, food, and paper manufacturing industries in Egypt.

b-Testing validity and reliability

This part shows validity and reliability for mentioned factors through measuring:

1- *Internal consistency reliability (CR). CR and Cronbach's alpha and rho_A*

	Cronbach's alpha	**Composite reliability (rho_a)**	**Composite reliability (rho_c)**	**Average variance extracted (AVE)**
Advanced analytics	0.966	0.970	0.983	0.967
competence	0.935	0.941	0.959	0.886
customer	0.953	0.961	0.977	0.955
Data driven	0.960	0.961	0.971	0.893
knowledge and awareness of quality4.0	0.941	0.943	0.962	0.895
Quality4.0 management implementation	0.930	0.937	0.966	0.935
supplier	0.936	0.936	0.960	0.888

Table 7:Validity and reliability

This table presents the reliability and validity statistics for research constructs, which are: advanced analytics, competence, customer, data driven, knowledge and awareness of Quality4.0, Quality4.0 management implementation, and supplier. These statistics are crucial for assessing the quality of research measurement model, especially when using techniques like structural equation modeling (SEM).

- All Cronbach's alpha, rho_a, and rho_c values are very high (above 0.90 in most cases).This indicates excellent internal consistency and reliability for all constructs.
- This means that the items within each construct are consistently measuring the same underlying concept.
- All AVE values are above 0.88, which is well above the recommended threshold of 0.50.
- This demonstrates strong convergent validity.

Therefore, it is concluded that this table demonstrates that the research measurement model exhibits excellent reliability and convergent validity.

2- Discrimination validity by using Fornell–Larcker criterion

	advanced analytic	competence	customer	Data driven	knowledge and awareness of Quality4.0	Quality4 .0 management implementation	supplier
Advanced analytics	0.983						
competence	0.864	0.941					
customer	0.849	0.895	0.977				
Data driven	0.923	0.974	0.854	0.945			
knowledge and awareness of quality4	0.958	0.898	0.903	0.942	0.946		
Quality4.0 management implementation	0.914	0.970	0.890	0.983	0.969	0.967	
supplier	0.908	0.894	0.818	0.938	0.866	0.876	0.942

Table 8: Discrimination validity

The values in the table are the square root of the AVE, which is used to assess discriminant validity. Discriminant validity ensures that each construct is distinct from the others. According to this table, all diagonal values are high (above 0.90), indicating strong discriminant validity. This means that each construct is distinct and not overlapping significantly with the others. According to correlation coefficient values that range from -1 to +1, this explained as:

- Values close to +1 indicate a strong positive relationship.
- Values close to -1 indicate a strong negative relationship.
- Values close to 0 indicate a weak or no relationship.

Therefore, when all values in this table are positive and high, this indicates a strong positive relationship between all the variables.

c-Measuring model path coefficient

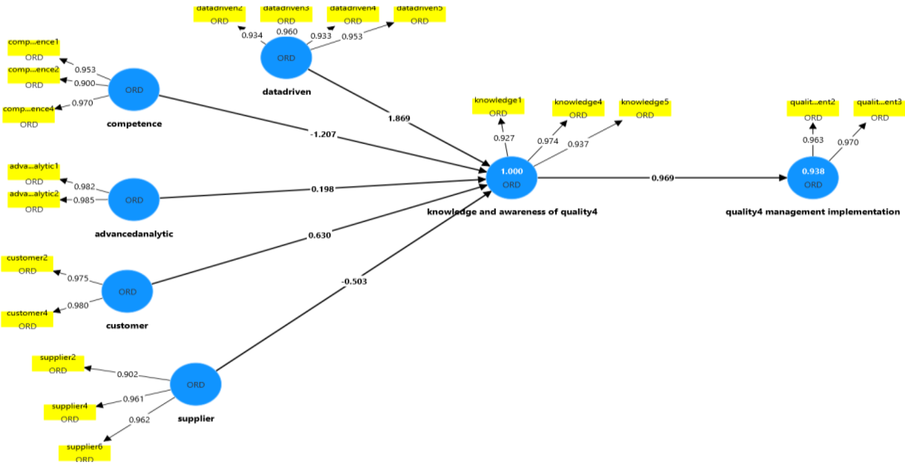

Figure 2: Path analysis of research model

	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values
Advanced analytic -> knowledge and awareness of Quality4.0	0.198	0.198	0.008	24.591	0.000
Advanced analytic -> Quality4.0 management implementation	0.192	0.192	0.008	24.883	0.000
competence -> knowledge and awareness of Quality4.0	-1.207	-1.207	0.029	42.069	0.000
competence -> Quality4 .0 management implementation	-1.169	-1.169	0.026	45.301	0.000
customer -> knowledge and awareness of Quality4.0	0.630	0.630	0.012	54.571	0.000
customer -> Quality4.0 management implementation	0.610	0.610	0.010	60.128	0.000
Data driven -> knowledge and awareness of Quality4.0	1.869	1.870	0.029	64.501	0.000

	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values
Data driven -> Quality4.0 management implementation	1.811	1.812	0.027	67.303	0.000
knowledge and awareness of Quality4.0 -> Quality4.0 management implementation	0.969	0.969	0.002	460.045	0.000
supplier -> knowledge and awareness of Quality4.0	-0.503	-0.504	0.009	53.025	0.000
supplier -> Quality4 .0 management implementation	-0.488	-0.488	0.009	51.596	0.000

Table 9: Path analysis coefficient

This table presents the results of a path analysis or Structural Equation Model (SEM), showing the statistical significance of the relationships between research variables. The key to interpreting this table is the *p-value*. A p-value less than a predetermined significance level (commonly 0.05) indicates that the relationship is statistically significant. This means that the relationship is unlikely to be due to chance.

Based on above table analysis, *all* of research path coefficients have a p-value of 0.000 (which effectively means $p < 0.001$). This indicates that *all* of the relationships in research model are statistically significant at a very high level.

By combining the information from the path coefficients and the p-values, it is concluded that:

- **Advanced analytic -> knowledge and awareness of Quality4.0 (0.198, $p < 0.001$):** A positive and statistically significant relationship, and acceptance of alternative hypotheses. A focus on advanced analytics leads to increased knowledge and awareness of Quality4.0.
- **Advanced analytic -> Quality4.0 management implementation (0.192, $p < 0.001$):** A positive and statistically significant relationship, and acceptance of

alternative hypotheses. A focus on advanced analytics leads to improved Quality4.0 management implementation.

- **competence -> knowledge and awareness of Quality4.0 (-1.207, p < 0.001):** A *negative* and statistically significant relationship, and acceptance of alternative hypotheses. Higher competence is associated with *lower* knowledge and awareness of Quality4.0.
- **competence -> Quality4.0 management implementation (-1.169, p < 0.001):** A *negative* and statistically significant relationship, and acceptance of alternative hypotheses. Higher competence is associated with *lower* Quality4.0 management implementation.
- **customer -> knowledge and awareness of Quality4.0 (0.630, p < 0.001):** A positive and statistically significant relationship, and acceptance of alternative hypotheses. A stronger customer focus leads to increased knowledge and awareness of Quality4.0.
- **customer -> Quality4.0 management implementation (0.610, p < 0.001):** A positive and statistically significant relationship, and acceptance of alternative hypotheses. A stronger customer focus leads to improved Quality4.0 management implementation.
- **Data driven -> knowledge and awareness of Quality4.0 (1.869, p < 0.001):** A very strong positive and statistically significant relationship, and acceptance of alternative hypotheses. A data-driven approach leads to a substantial increase in knowledge and awareness of Quality4.0.
- **Data driven -> Quality4.0 management implementation (1.811, p < 0.001):** A very strong positive and statistically significant relationship, and acceptance of

alternative hypotheses. A data-driven approach leads to substantial improvements in Quality4.0 management implementation.

- **knowledge and awareness of Quality4.0 -> Quality4.0 management implementation (0.969, p < 0.001):** A positive and statistically significant relationship, and acceptance of alternative hypotheses. Increased knowledge and awareness of Quality4.0lead to better Quality4.0 management implementation.
- **supplier -> knowledge and awareness of quality4 (-0.503, p < 0.001):** A *negative* and statistically significant relationship, and acceptance of alternative hypotheses. Greater supplier involvement is associated with *lower* knowledge and awareness of Quality4.0.
- **supplier -> quality4 management implementation (-0.488, p < 0.001):** A *negative* and statistically significant relationship, and acceptance of alternative hypotheses. Greater supplier involvement is associated with *lower* Quality4.0 management implementation.

d- Model fit

	Saturated model	Estimated model
SRMR	0.073	0.076

Table10: Measuring model fit

This table presents model fit indices for research structural equation modeling (SEM) analysis, comparing a "saturated model" (a perfect fit) to research "estimated model". The SRMR for research estimated model is 0.076, which is below the 0.08 threshold, indicating acceptable fit.

Main Findings

- **Advanced Analytics:** A greater focus on advanced analytics has a positive overall impact on both knowledge and awareness of Quality4.0 and, subsequently, on Quality4.0 management implementation.
- **Competence:** Surprisingly, higher levels of competence have a *negative* overall impact on both knowledge and awareness of Quality4.0 and Quality4.0 management implementation.
- **Customer Focus:** A stronger customer focus has a positive overall impact on both knowledge and awareness of Quality4.0 and Quality4.0 management implementation.
- **Data-Driven Approach:** A greater emphasis on data-driven decision-making has a very strong positive overall impact on both knowledge and awareness of Quality4.0and Quality4.0management implementation.
- **Supplier Involvement:** Unexpectedly, greater supplier involvement has a *negative* overall impact on both knowledge and awareness of Quality4.0 and Quality4.0management implementation.
- **Mediation:** Knowledge and awareness of Quality4.0 plays a crucial role in mediating the relationships between the independent variables and Quality4.0 management implementation. Its strong positive effect on implementation highlights its importance.

Based on the above findings, an action plan will be established

Action	Objective	Activities	Timeline	Responsible party
1- **Analyze Supplier**	Understand the negative relationship between supplier	a-Map the organization's supply chain and identify key suppliers.	3-6 months	Procurement Department and Quality

Action	Objective	Activities	Timeline	Responsible party
Relationship Impact	involvement and knowledge/awareness of Quality4.0 principles	b-Conduct surveys or interviews with employees to understand how supplier relationships influence their perceptions of internal Quality 4.0 knowledge. c-Review the organization's Quality 4.0 management practices related to supplier selection, evaluation, and collaboration.		Management Team
2-Strengthen Quality4.0 Training & Awareness	Increase understanding and awareness of Quality4.0 principles across the organization.	a-Develop comprehensive Quality4.0 training programs for all employees, tailored to different roles and responsibilities. b-Communicate the importance of Quality4.0 through various channels (e.g., newsletters, intranet, town hall meetings). c-Recognize and reward employees who demonstrate a commitment to Quality4.0. d-Establish a Quality4.0 champions network to promote Quality 4.0 within different departments.	Ongoing	HR Department and Quality Management Team

Table 11: Action plan

Managerial implications

The findings of this research carry substantial implications for both scholars and practitioners.

-For scholars: The strong inter-correlations among constructs suggest a need for refined theoretical models that explicitly account for these interdependencies. Also, Future research should explore the underlying mechanisms driving these relationships, potentially through the development of more integrated conceptual frameworks. Scholars should consider employing network analysis or systems theory to better understand the complex interplay between Quality 4.0 readiness factors and implementation outcomes.

-For practitioners: The significant mediating role of knowledge and awareness underscores its importance for successful Quality 4.0 implementation. Therefore, Organizations should prioritize investments in training, education, and knowledge management initiatives to enhance employee understanding of Quality 4.0 concepts and technologies. This will be achieved through establishing internal centers of excellence or partner with academic institutions to provide specialized training programs.

Avenues for further research

-Assessing the Maturity of Quality 4.0 Adoption: Development and Validation of a Diagnostic Tool.

-Human-Centered Quality 4.0: Investigating the Role of Employee Engagement and Empowerment.

-Quality 4.0 in the Construction Industry: Optimizing Building Performance through Data-Driven Approaches.

-Quality 4.0 and Small and Medium-Sized Enterprises (SMEs): Developing Tailored Implementation Strategies.

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