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Quality in IR4.0 Environment: Digitalization Enhance Quality or Deteriorating Quality?

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Abstract
Purpose: This research is done to study how digitalization and ICT tools affect the quality performance within organization in manufacturing industries. The purpose of this investigation is to study the effects of digitalization and ICT tools on quality performance within organizations. Secondly, to study the mediating effects of digitalization and ICT tools in proposed conceptual model linked with quality performance as well. Simultaneously, quality performance within industries which apply digital smart manufacturing concepts were also studied together with Quality 4.0 concept.
Design/methodology/approach: A meta-analysis approach via review of 30 journals had been done to consolidate findings on digitalization and ICT tools in the context of Industry 4.0.
Findings: Digitalization and ICT tools are factors which influence the quality performance of an organization, taking into account having employees with digital minded awareness, skills and talents. In a nutshell, employees need to have digital minded knowledge and skills to embrace the rapid evolution in Industry 4.0.
Research limitations/implications: This research is using digitalization and ICT for studying the mediating effects on quality performance which is still at basic level of investigation. Therefore, more studies are needed by including the data on quality indicators such as KPIs, customer complaint indicators and etc from MNCs to prove that quality level of these companies are excellent with the application of digitalized tools.
Practical implications: In terms of Industrial Revolution 4.0, digitalization is able to improve quality provided digital minded skill and culture are highly cultivated among employees.
Originality/value: Quality is important and becoming more crucial as it is the base of a firm's competitiveness. Digital technology and quality performance are ties that become effervescent in the current business environment. It is believed that digitalization is able to become cornucopia of services in making quality performance better in Industry 4.0 environment.

Keywords: Industry 4.0, Digitalization, ICT Tools, Quality Performance

Introduction

The growth of digital technologies in an advanced manner has caused rapid industrial revolution in past decade. Industries have been seen to evolve dynamically over time leading towards a new digital revolutionary age known as the ''Fourth Industrial Revolution'' or Industry 4.0. Industry 4.0 concept was instituted by German Government as a collaborative effort between industrial and academic representatives to ensure better competitiveness of German

manufacturing sectors in future (Kadir & Broberg, 2020). It is a fact that Industry 4.0 became the start-up point for absolute digitalization of processes and production capitals which ranged from massive integration to a single system (Egor, 2020). With this dynamic Industrial revolution, quality has become an important indicator for products and processes. Just as how revolution is seen among technologies, quality models and practices are also subjected to revolutionary steps along with Industry 4.0 (Zonnenshain & Kenett, 2020).

Digitalization and Information Communication Technology (ICT) tools are significant in defining the quality and business competitiveness among various manufacturing industries. Industry 4.0 development routes a crucial impact on manufacturing systems, particularly on competitiveness levels and value chain integration (Mon & Giorgio, 2021).

Industry 4.0 has become popular among manufacturing sectors. The aim of Industry 4.0 is to improve production processes with meaningful amount of digitalization efforts being realized into core business enablers such as lot sizes, production monitoring by various stakeholders and predictive maintenance. Promoting Industry 4.0 has been part of the German Federal Government's effort with many industrial partners such as Bosch, ABB and SMS Group. The industrial partners invested in Industry 4.0 for reduction of operational costs and revenue increment plans (Nakagawa *et al*., 2021). Significance of Industry 4.0 is obvious based on the research done by Boston Consulting Group (2015), which showed that in Germany itself, contribution shall be 1% per year to GDP over 10 years, 390 000 jobs created and addition of €250 billion to manufacturing investment (1% till 1.5% of manufacturers' revenues) in another 5 to 10 years of time.

Transformation shall take place in manufacturing sectors whereby changes will be seen from single automated cells to fully integrated servers that have horizontal and vertical system integration incorporated for boosting flexibility, yield and quality. Applications of digital technologies in Industry 4.0 to empower best practices in quality management have led to a new term, known as ''Quality 4.0'' concept (Kupper *et al*., 2019). Quality 4.0 survey was done by Boston Consulting Group (2019) by having questionnaire answered by participants from various sectoral backgrounds. Quality 4.0 had been categorized under ''Extremely important'' and ''Very important'' in Value Chain amongst different sectors. Significance of Quality 4.0 was acknowledged at all value chain stages. Manufacturing and R & D had been identified as areas which would benefit the most from improved quality.

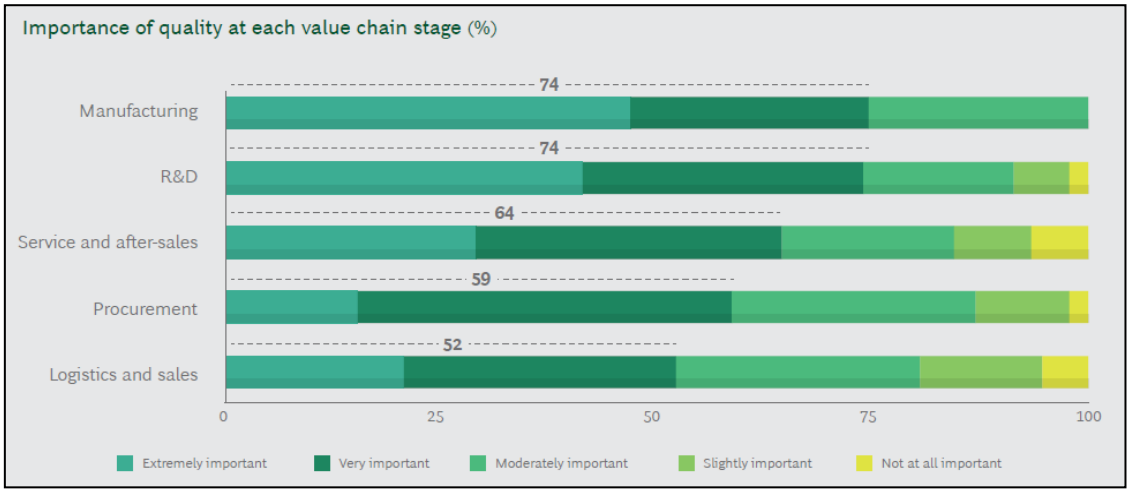

Figure 1: Survey Results on Participants' Rating on Quality 4.0 Importance from End to End in Value Chain

Source: Quality 4.0 Survey by BCG, ASQ & DGQ (2019)

It needs to be noted that Industry 4.0's technological core is formed from the coalescence of virtual world together with actual world (Birkel & Muller, 2019). Therefore, there is a need to embrace digital mindedness work culture along with the new journey of Quality 4.0 concept. This study investigates how digitalization together with ICT influence quality performances within industries via digital mindedness work culture.

Although it is a known fact that digital technologies and ICT have been increasingly important factors for improvement in operational excellence, the correlation of digital mindedness with quality performance remains ambiguous. Considering the new concept of Quality 4.0, digital and ICT tools alone will not assure the success and sustainability of an industry without considering the culture of digital mindedness in work. More studies need to be done for understanding the above concept as there is a need for every employee to expand their digital skills and knowledge for a holistic quality improvement throughout the organization.

Literature Review Digitalization in Industry 4.0

Digitalization refers to a digital transformation process that involves utilization of digital technologies to create the ''Smart Factory Manufacturing'' concept. The changes induced by digital transformation through usage of advanced digital technologies create a new digital age with assorted culture, processes, framework and blueprints (Albukhitan, 2020).

Industrial leaders agree that digital manufacturing technologies have potential for transforming each and every aspect of value chain in manufacturing system (Hartmann *et al*., 2015). Evolution of Digital Manufacturing (DM) was seen to exist from from Computer Integrated Manufacturing (CIM) in 1980s. Pre-existence of Industry 4.0 is observed in manufacturing environment where technological integration is done in a single system instead of individual isolation (Silva *et al*., 2020). According to the research done by Rubmann (2015), the ''Nine Pillars of Technological Advancement''. These pillars are highly crucial drivers for increasing industrial productivity yield.

Main pillars of Industry 4.0 + Quality Control = Quality Control 4.0	
These new technologies that form the main pillars of industry 4.0: →	Quality control
• Big Data and Analytics • Autonomous Robots • Simulation • Horizontal and Vertical System Integration • The Industrial Internet of Things • Cybersecurity • The Cloud → • Additive Manufacturing • Augmented Reality	• Quality requirements • Requirements • Conformity • Capability • Traceability • Nonconformity • Defect analyse • …

Figure 2: Main Pillars of Industry 4.0

Source: New Needed Quality Management Skills for Quality Managers 4.0 (2021)

The adoption and collaboration with technologies above will create new models, blueprints and frameworks for smart manufacturing (Kalarani, 2021).
When Industry 4.0 merges with Quality 4.0, a ''smart model'' is created eventually. Quality 4.0 links new technologies with traditional quality methods for achieving optimized operational performance, excellence and innovation (Santos *et al*., 2021).
According to Santos (2021), by 2025, 80% of people across the world will have a digital existence across 800 companies surveyed. In a nutshell, Industry 4.0 leads to a new digital age in the current millennium.

Digitalization and Quality of Life

In this modern world, digitalization has created huge transformations in advanced digital technologies leading towards upgraded lifestyle. Undeniably, digitalization is said to have an unambiguous influence on many socio-economic processes. According to a study done by Kryzhanovskij (2021), digitalization and quality of life were correlated to one another. In this study, two popular indicators were chosen as reflectors in the quality of life from objective and subjective standpoints. Ranking of Happiness (RH) were used to study the correlation between subjective well-being and objective conditions for human development (HDI). Human development index (HDI) was used as an indicator to measure quality of life and World Digital Competitiveness Ranking (WDCR) was utilized to measure digitalization.
Correlation analysis showed that the coefficient of determination, R2 = 75% indicated a rather strong positive correlation between world digital competitiveness ranking (WDCR) and HDI.

WDCR	HDI	
	Reduced	Increased
Increased	Group B (4): CZE, ITA, SVN, *CYP*	Group A (25): AUS, AUT, BEL, CAN, CHE, DEU, DNK, ESP, FIN, FRA, GBR, IRL, ISL, ISR, LUX, NLD, NOR, NZL, SGP, SWE, USA, *EST*, *HKG*, *JPN*, *KOR*
Reduced	Group C (27): *BRA*, *CHL*, *MEX*, *SAU*, *SVK*, ARG, BGR, COL, GRC, HRV, HUN, IDN, IND, JOR, KAZ, LVA, MNG, PER, PHL, POL, ROU, RUS, THA, TUR, UKR, VEN, ZAF.	Group D (5): *ARE*, CHN, LTU, MYS, PRT.

Note: Country codes are based on the standard ISO 3166 [52]; countries are included in different groups in Tables 1 and 2 in italics.

Figure 3: Classification of Countries by the level of HDI and WDCR
Source: How to Make Digitalization Better Serve An Increasing Quality of Life? (2021)
Note: Country codes are based on the Standard ISO 3166

Sample size of 61 countries had been selected with RH, HDI & WDCR indices. Correlation analysis between HDI (indicator for measuring quality of life) and WDCR (indicator for measuring digitalization) was done in a two-dimensional matrix (WDCR/ HDI) divided into four quadrants by medians. Based on the interpretation made from table above, it can be observed that 27 (44.26%) countries out of total sampling size (61) exhibited reduction in HDI when WDCR was reduced. Additionally, 25 countries (40.98%) had an increase in HDI indicator when WDCR was also increased. Therefore, it can be concluded that WDCR was directly proportional to HDI. Meaning that when there is an improvement in digitalization, quality of life is also upgraded and this has been proven from the study above.

Table 1: Meta-Analysis Summary

No	Author	Year	Industry	Country	IV	DV
1	Silva, Shinohara, Nielsen, Lima & Angelis	2020	Manufacturing	General	1) Digital Simulation 2) Autonomous Robots 3) Cloud Computing 4) Internet of Things (IoT) 5) Big Data & Analytics 6) Cybersecurity 7) Additive Manufacturing (AM)	Digital Manufacturing
2	Horvat, Kroll & Jager	2019	Manufacturing	Germany	1) Main explanatory factors 2) Additional factors	Efficiency & Performance Indicators
3	Raweewan & Kojima	2020	Manufacturing	Thailand	1) Japanese style LEAN manufacturing culture 2) Digital engineering	Development of cognitive and non- cognitive skills in LEAN manufacturing
4	Albukhitan	2020	Manufacturing	Saudi Arabia	1) Digital transformation of valuable players for manufacturing 2) Digital transformation strategy 3) Digital transformation strategy development	Nature of manufacturing sector
5	Pop	2020	Automotive	Romania	1) Failure collection card process 2) In process control 3) Sorting 4) The 2/4/6 eyes concept 5) The Control Plan 6) The traceability	After effects of certain processes' optimization via implementation of digitalization including reduction of costs
6	Saxena	2019	Government sector	India	TQM variable (enablers)	OGD initiative
7	Gruzman	2020	Foundry	Russia	Digital Technologies	1) Charge material development 2) Initial molding material development 3) Smelting 4) Mixing 5) Tapping to ladles 6) Sand molds manufacture 7) Pouring smelt into molds 8) Knocking out from mold 9) Cutting, cleaning & heat treatment of castings 10) Quality inspection of castings

8	Egor	2020	Construction & Petrochemical	Austria & China	Digital Transformation	Impact on process management
9	Hanel, Schnellhardt, Wenkler, Nestler, Brosius, Corinth, Fay & Ihlenfeldt	2020	Aerospace	Germany	Calculation models in a digital process twin	Cutting force
10	Neto, Deschamps, Silva & Lima	2020	Manufacturing	Europe and America	1) Drivers (Factors and forces that induce companies to initiate and fully implement digital twin related projects. 2) Enablers (Factors that make digital twins possible to achieve) 3) Barriers to Implementation (Factors and forces that cause friction or slow-down digital twin related projects	Implementation of digital twin initiatives
11	Tolkachev, Bykov, Morkovkin, Borisov & Gavrilin	2020	Manufacturing	Russia	1) Analysis on the digitalization of economy of leading countries of the worlds. 2) Identification of current trends and promisng of digital transformation of the domestic economy.	Development of generalized digitalization index of manufacturing enterprises
12	Shinkevich, Vertakova & Galimulina	2020	Manufacturing	Russia	1) Energy efficiency 2) Environmental protection of manufacturing	Synergistic Effect of Digitalization
13	Gillani, Chatha, Jajja & Farooq	2020	Manufacturing	General	1) Technological context - Digital solutions 2) Organizational context 3) Environmental context	Implementation of digital manufacturing technologies (DMTs)
14	Siedler, Langlotz & Aurich	2020	Manufacturing	Germany	1) Key Performance Indicators (KPIs) 2) Supporting elements	Selection of suitable digital technology

15	Papacharalampopoulos, Stavropoulos & Petrides	2020	Manufacturing	Greece	1) Methodologies derived from process physics	Creation of process level digital twin in manufacturing
16	Piedade, Bapista & Chaves	2020	Metal Mold	Portugal	1) Welding current 2) Preheating temperature of the mold 3) Pressure and flow rate of the propellant gas 4) Pressure of the shielding gas 5) Cycle time 6) Humidity & ambient temperature	Integration of Industrial 4.0 paradigm into existing manufacturing process
17	Sullivan, Desai, Sole, Rossi, Ramundo & Terzi	2020	Maritime 4.0	General	1) System design and construction 2) Vessel design 3) Vessel construction	Integration of advanced Manufacturing for vessel development
18	Buyukozkan, Havle & Feyzioglu	2020	Aviation	Turkey	Proposal of digital service quality (DSQ) model	Validation on airline industry based on models proposed
19	Bag, Gupta & Kumar	2020	Manufacturing	General	1) Extent of the effect of I4.0 adoption 2) Moderating role of I4.0 delivery system	1) 10R advanced manufacturing capabilities and sustainable development 2) Relationship between degree of I4.0 implementation and 10R advanced manufacturing capabilities
20	Li, Wang, Zhu & Liu	2020	Manufacturing	General	Manufacturing Task (MT) and Manufacturing Resource (MR) algorithm	MT semantic normalisation modelling and MR optimisation recommendation for DTS
21	Xia, Sacco, Kirkpatrick, Saidy, Nguyen & Kircaliali	2020	Smart manufacturing	General	Digital transformation methods	Automation of smart manufacturing systems

22	Liu, Le Roux, Körner, Tabaste, Lacan & Bigot	2020	Metal Additive Manufacturing	General	1) Design parameters 2) Process parameters 3) Process signatures 4) Post processing 5) Product quality	Metal AM systems
23	Liu, Leng, Yan, Zhang, Wei, Yu, Zhao & Chen	2020	Smart manufacturing	China	1) Configuration design 2) Motion planning 3) Control development 4) Optimization decoupling	Flow type smart manufacturing systems in Industry 4.0
24	Li, Dai & Cui	2020	Manufacturing firms	China	1) Mediating effect of digital supply chain platforms 2) Moderating effects of environemental dynamism	Influence on Industry 4.0
25	Kamble, Gunasekaran, Ghadge & Raut	2020	Auto component manufacturing in small medium, micro enterprises (SMMEs)	India	Performance dimensions: 1) Cost 2) Quality 3) Flexibility 4) Time 5) Integration 6) Optimized productivity 7) Real time diagnosis & prognosis 8) Social 9) Computing 10) Ecological sustainability	Evaluation on planned investments in smart manufacturing systems (SM)
26	Kristoffersen, Blomsma, Mikalef & Li	2020	Manufacturing	General	Circular strategies: 1) Restore, reduce & avoid 2) Recirculation of parts and products 3) Recirculate materials	Smart circular economy (CE) framework
27	Birch-Jensen, Gremyr, Martin & Melf	2020	Manufacturing, Life science firm and government body	Sweeden	Roles of QM practitioners	Digitalisation initiatives

28	Sjodin, Parida, Leksell & Petrovic	2018	Automotive manufacturers	Sweeden, Brazil & Germany	1) Process challenges 2) People challenges 3) Technology challenges	1) Introduce Agile process 2) Cultivate digital people 3) Configure modular technology
29	Holmstrom, Holweg, Lawson, Pil & Wagner	2019	Operations and Supply Chain Management (OSCM)	General	Transformation pathways 1) Independence 2) Re-distribution Interactivity	Impacts on Processes over the product life cyle: 1) Design 2) Manufacturing 4) Delivery and use
30	Silva, Shinohara, Lima, Angelis & Machado	2019	Manufacturing	General	1) Digital Factory 2) Digital Manufacturing	Definition in Industry 4.0 Paradigm

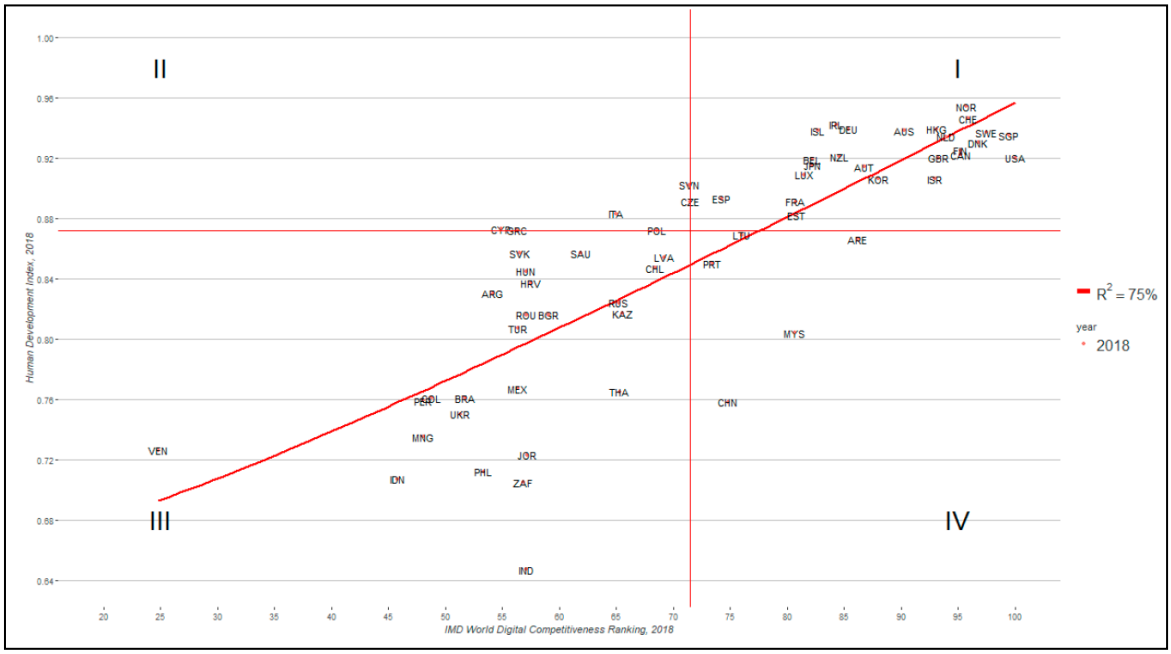

Figure 4: Linear correlation between HDI and WDCR at the two-dimensional matrix. *Source: How to Make Digitalization Better Serve An Increasing Quality of Life? (2021)* Note: Country codes are based on the Standard ISO 3166

In the study done by Kryzhanovskij (2021), it can be concluded that close relationship between digitalization and quality of life exist is observed, and shall be considered as a sufficient factor in further panel data models which explain the national quality of life. Furthermore, more potential had been discovered with the use of visualization tools that allow graphical location mapping to be done across countries in the context of digitalization and quality of life.

Information Communication Technology (ICT)

ICT refers to Information Communication Technology, an extensional term which emphasizes on unified communications with integrated telecommunications. According to the studies done by Kim (2020), ICT has two main contributions, namely in terms of innovations and reduction in product pricing plus creation of new opportunities and solutions. The global diffusion of ICT has rapidly increased in past decade (Millan *et al*., 2019). ICT has become a crucial driver for improving profits, yield, and employment (Zhu *et al*., 2021).

According to the studies done by Shi (2018), roles of ICT in enhancing sustainable product lifecycle shall be as below:

1)Simplified model introduction for assembly precision information (API) of complex products. This model on Assembly Precision Analysis (APA) is crucial for entire lifecycle of complex products in terms of design, production and assembly, thus reducing workload of API.
2)According to Johansson (2019), contribution of ICT was emphasized on sustainable e maintenance. E maintenance was focusing on digitalization related to ICT. In E maintenance, the ICT adoption is in such a manner where costs are reduced and resources can be saved via real time diagnosis besides supporting on environment. E maintenance has enabled predictive maintenance as well besides preventive maintenance in equipment within manufacturing sector.
3)The third contribution of ICT was presented by Bottani (2019), which studied on quantitative evaluation role from ICT in supporting data collection and valorization of spent coffee grounds. A logistic model supported by ICT had been created to convert spent coffee grounds into combustible pellets which are environmentally friendly. The application of ICT tools was in the form of transportation management system for optimizing collection and transportation of spent coffee grounds.

Undeniably it is proven that ICT tools can be ideal technologies for cost saving and planning on activities (Galati *et al*., 2019).

ICT and Quality of Life

ICT tools had not only become crucial factors for the quality of life, however major role is also played for the quality of business sustainability. The investigation on digital inclusion and ICT whether Quality of Life is affected from worldwide perspective had been done by Alhassan & Adam (2020). Analysis was done across 121 countries by referring to Readiness Index Report in 2018, Partial Least Squares-Structural Equation Modelling (PLS-SEM) had been used for data analysis and observations had been listed as below:

1) Quality of Life is highly influenced by digital inclusion at global level.
2) Individuals become happy and improvement is seen in their quality of life when they are provided with ICT access which ease most of their daily activity tasks.
3) The positive association between digital inclusion and ICT application is well supported.

Quality in IR4.0

Industry 4.0 has become a reality and is seen to thrive majority changes among industries by connecting digitalization with ICTs. New quality management skills are needed for embracing the digitalized Industry 4.0 and quality performance of industries highly depend on such skills. This is the reason why the current industries need managers with Quality 4.0 mindset who are able to establish digital mindedness work culture across all the employees (Zonnenshain & Kenett, 2020). According to Dan Jacob (2017), Quality 4.0 relates new digital technologies with traditional quality methods for achieving optimized performance in industries.

Digital Mindedness in the Context of Quality IR 4.0

When it comes to digital transformations across the Globe, different countries have various terms for referring towards the pillars of industrial policy. For instance, digital transformation is regarded as ‘’Industry 4.0’’ in Europe, ‘’Made in China 2025’’ in China, ‘’Smart Cities’’ in Asia and ‘’Society 5.0’’ in Japan. The digital transformations will cause prominent changes in our lives leading towards Quality 4.0 (Santos *et al*., 2021).

Research was done by Santos (2021) across workers who were from quality departments in one of the industries within Portugal. The main aim of research was to analyse the extent to which digital mindedness is perceived by workers in the context of Quality 4.0. Embarking the journey along with digitalized era requires huge skills, knowledge, speed and digital minded working culture among professionals. The survey design was more on quantitative research.

Most of the respondents were workers who were actively involved in Quality Management System such as quality audits, 5S implementation, PDCA, etc. Results of the survey revealed that the main activities related to quality were mostly quality audits, 5S, PDCA, continuous process improvements and ISO9001.

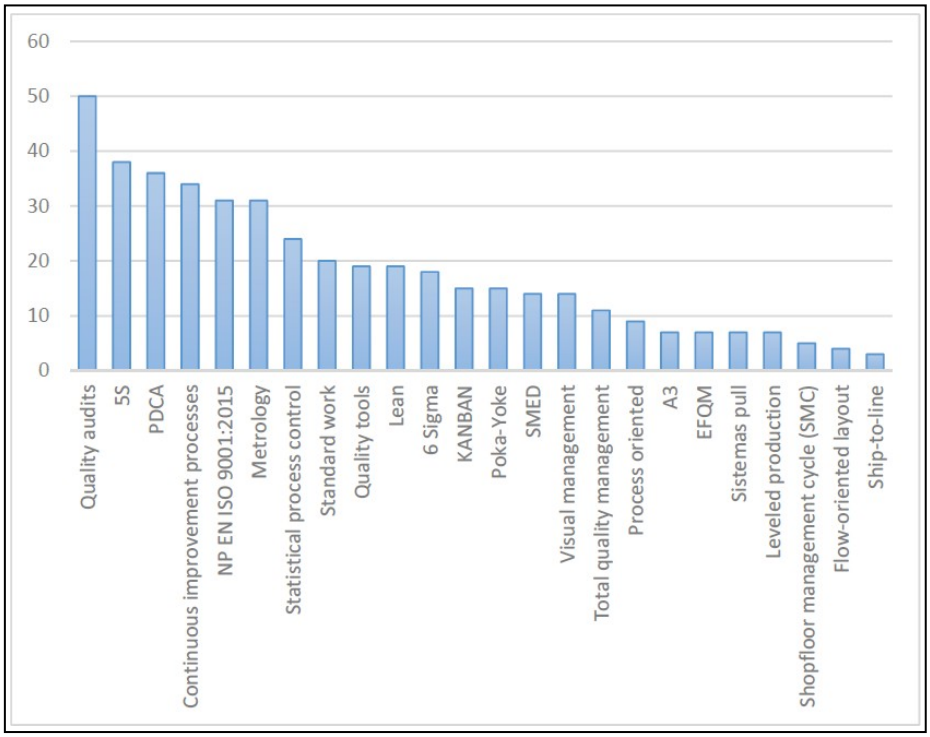

Figure 5: Results of Surveillance Among Companies on the Main Activities Related to Quality
Source: New Needed Quality Management Skills for Quality Managers 4.0 (2021)

In the current Industrial 4.0 digital age, quality is also becoming equally important based on the survey done by Santos (2021). Undeniably, quality involvement in Industry 4.0 with digital mindedness has important benefits. By having Quality 4.0 practiced in management application, Emergent Quality Management (EQM) manufacturers are able to decrease their total quality cost between 22% till 50% (Miller, 2020). This means that workers in an organization should have tremendous skills with knowledge of digital technologies together with digital mindedness work culture. In this way, quality performance of an organization shall improve well.

The integration of digital technologies together with Total Quality Management (TQM) lead towards Quality 4.0. In short, Quality 4.0 is said to be the digitalization of Total Quality

Management (Carvalho *et al*., 2021).
Studies were done by Carvalho (2021) to correlate Quality Management practices with 7 Technological Tools which can be utilized to improve quality.

I4.0 Tools and Technologies	Quality Management Practices							
	Management Commitment	Customer Involvement	Supplier Involvement	Employee involvement	Benchmarking techniques	Process Management	Information and Analysis	Formal strategic planning
Data science and statistics	X					X	X	X
Enabling technologies (IoT, IIoT, Integrated systems, VR, AR, cloud computing	X	X	X	X	X	X	X	X
Big Data	X	X	X			X	X	
Blockchain	X			X		X		X
AI	X			X			X	
ML	X						X	X
Neural Networks and Deep Learning	X					X	X	

Figure 6: Quality Management Practices and Industry 4.0 Technologies Relationship Source: *Quality 4.0: An Overview (2021)*

Among the technological tools studied were Data Science and Statistics, Enabling Technologies (IoTs, Cloud, AR, etc), Big Data, Blockchains, Artificial Intelligence, Machine Learning (ML), Neural Networks and Deep Learning. This led towards development of Figure 6. The different applications of digital technologies (I4.0 Tools and Technologies) together with quality management practices were seen to improve overall quality as per aimed. With the improvement in quality, entire manufacturing management becomes effective. Several benefits of effective manufacturing management have been illustrated in diagram below.

Figure 7: Quality Management Practices and Industry 4.0 Technologies Relationship Source: *Quality 4.0: An Overview (2021)*

Studies were also done by Ammar (2021) with the aim of improving operational management system performances via usage of Industry 4.0 technologies. Manufacturing management is a form of management style which ensures that certain KPIs (Key Performance Indicators) are reached to meet goals. For instance, indicators related to an organization may include utilization performance, First Pass Yield (FPY), confirmed failures, quality related issues etc. Applications of these different technologies play major influential roles in making sure that proper management practices are executed by prioritizing quality. The roles have been discussed and shown in figure below.

Sr. No.	Technologies	Description
1.	Manufacturing process management	Manufacturing process management (MPM) is the process of managing manufacturing processes. It bridges the gap between product development and operations. With Industry 4.0 technologies, the bridge is more smoothed. Both sectors can have real-time updates on a product. The IoT binds properties to processes, structures and people in manufacturing.
2.	Quality management	Quality management is a very crucial part of the manufacturing processes. Companies' reputation largely depends on this sector. If the product lacks its standards or is not up to the mark, it drastically affects the company. With IoT, the ability to analyze and monitor the process and product quality at key points in the manufacturing processes and identify when sub-standard products are introduced or product attributes deviate from requirements promises substantial cost savings.
3.	Supervision	Supervision at every step is required in the manufacturing processes. IoT has made supervision comparatively easier. The supervisor does not need the go-to machine to the machine to check the status. Everything is available with a click.
4.	Real-Time OEE	OEE stands for Overall Equipment Effectiveness. Real-Time OEE means IoT, and Industry 4.0 enabled OEE. It has numerous advantages like real-time analytics, improved reports and dashboards, real-time smart alerts, improved transparency; secure data transfer, higher production efficiency and less waste.
5.	Production Analysis	Latest advances in the Internet of Things provide smart manufacturing opportunities in production planning, execution, and control, with real-time traceability, visibility, and interoperability. Smart services help in getting the data more accurately. Data accuracy is vital for good analysis
6.	Assembly & Conveyor Monitoring	A smart monitoring device for assembly and conveyor is possible with the use of Industry 4.0 applications. In traditional systems, there are various challenges faced by the industries. Technologies like remote monitoring, RTIS, sensors combined with other IoT technologies can drive a more effective monitoring system.
7.	Machine Diagnostics	Machine Diagnostics can be performed with more precision. If any part in the machine is malfunctioning or is about to malfunction can be located at a very early stage. There are various IoT enabled software's which have made this possible.
8.	Track and Trace	Accurate traceability and geology of all parts and assemblies manufactured on the shop floor can be retained. If master manufacturing workflow is linked with WIP tracking, Poka-Yoke can be designed to ensure strict adherence without missing sequences.
9.	Process Energy Monitoring	With smart energy management solutions, energy consumed by machines can be tracked and handled regularly. The energy used by each piece of equipment can be tracked by embedded sensors, meters and other IoT devices. For a chain of properties, the energy usage parameters may also be obtained to assess an entire facility's total consumption.
10.	Workflow Apps	The use of state-of-the-art manufacturing apps which keep employees accountable, effective and mobile attributes their success to many companies. Production apps are extremely fine-tuned for key tracking and record-keeping, ranging from universal CRM applications to real-time equipment monitoring. Like a well-oiled machine, these applications make day-to-day tasks flow smoothly, spending less time and fostering protection and organization more importantly, e.g. 5S Audit, MRPeasy, Manufacturing 360 and many more.

Figure 8: Major role of Industry 4.0 technologies in proper management during manufacturing. *Source: Improving Material Quality Management and Manufacturing Organizations System through Industry 4.0 technologies (2021)*

In reference to the studies done above, Industry 4.0 technologies play a crucial role in making sure that effectiveness of manufacturing management is met to ensure overall quality performance within an organization. Having digital minded concept is also equally important in an organization via applications of digital technologies and ICT tools.

Methods

In this research, meta-analysis had been done to consolidate findings on digitalization and ICT tools in the context of Industry 4.0. Digital smart manufacturing concept is becoming seemingly important along with ICT such as Internet of Things which is on the rise. For example, one of the Nine Technological Pillars application can be seen in Big Data utilization. Aligned with Industry 4.0 needs, Big Data architecture has its relevant implementation that will validate all the tasks which have been undertaken so far. An example of Multinational Company (MNC) which is aligned with Industry 4.0 concepts is Bosch Car Multimedia in Braga (Portugal) (Santos *et al*., 2017). Data is stored in Hadoop Distributed File System (HDFS) at staging area of Warehouse and this enables access of information towards real time data anytime digitally in a more integrated manner. Similarly, another MNC company which uses Artificial (AI) Intelligence is Boise, Idaho based Micron. Usage of AI has generated more promising quality of

memory chip products leading towards increase in productivity yield. Based on meta-analytical approach, it can be deduced that digitalization and ICT tools play an influential role towards quality performance within manufacturing industries.

Findings

The world is becoming more dynamic with rapidly changing things. Skills are highly needed to embrace these changes and embark towards a new challenging journey along together with Industry 4.0 digitalization. If an organization intends to be competitive in terms of quality and innovation, then it is crucial to ensure that top management support quality professionals. Quality 4.0 professionals should have the knowledge of new technologies, which is Cyber Physical Production Systems (CPS) that combine with best quality management practices. Therefore, instilling digital mindedness work culture among employees in current industries is highly essential for an organization to preserve its quality indicators and improve its overall performance.

Boston Consulting Group (2019) conducted a survey on the status of adoption and challenges faced to implement Quality 4.0 among industries. Approximately, two thirds of surveyed participants believed that digital technologies will become crucial for quality governance, performance management and training within quality function. In terms of challenges faced, ranking had been done on the challenging factors. Shortage of digital skills and talent was ranked at the top most barrier for Quality 4.0 implementation. This shortage led to fiery competition for digital specialists within internal and external portion of the company. The need to have a professional who is highly skilled in providing digital technical solutions is scarce. This is the reason why certain companies are still struggling to get Quality 4.0 fully implemented. The demand for digital technologist is highly important in creating digital mindedness culture among employees in the current industrial era. The entire ‘’Smart Factory’’ concept is to have a highly digitalized working environment for long term business sustainability besides manufacturing of robust products that full-fill customer’s demand in terms of quality, time and delivery.

Figure 9: A Shortage of Digital Skills – Top Barrier for Quality 4.0 Implementation
Source: Quality 4.0 Survey by BCG, ASQ & DGQ (2019)

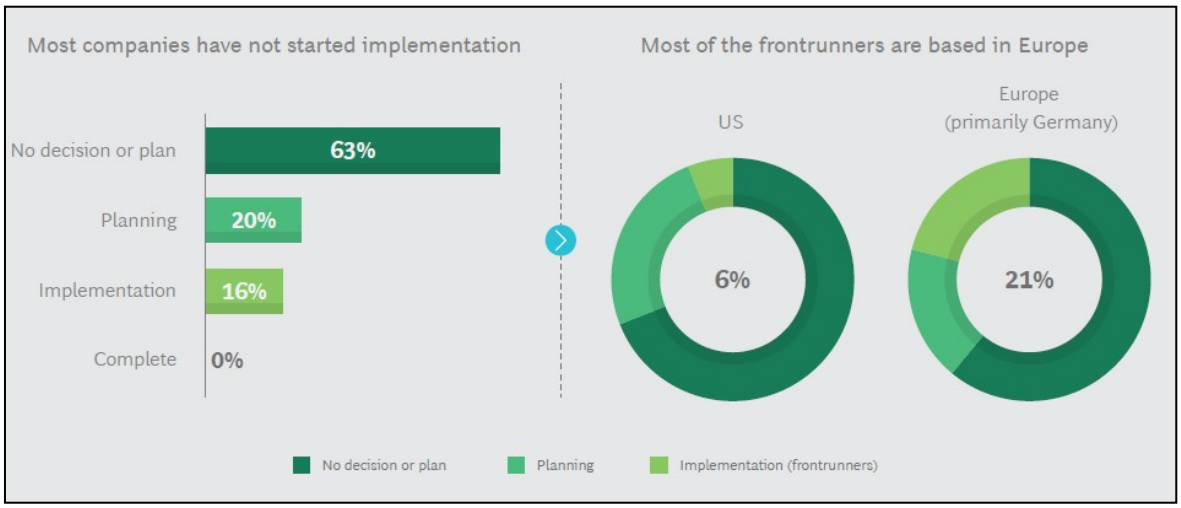

Figure 10: Overview on the Percentage of Companies which have Implemented Quality 4.0
Source: Quality 4.0 Survey by BCG, ASQ & DGQ (2019)

Therefore, it can be deduced that digitalization and ICT tools are factors which influence the quality performance of an organization, taking into account of having employees with digital minded awareness, skills and talents.
The concept of integrating Industry 4.0 into quality which leads to Quality 4.0 is much more than a technology. In a nutshell, it is a whole new way of managing quality by having digital and ICT tools which consistently improve the performance of an organization, delivering high quality products and services to customers.

Hypothesis Development Proposed Conceptual Model

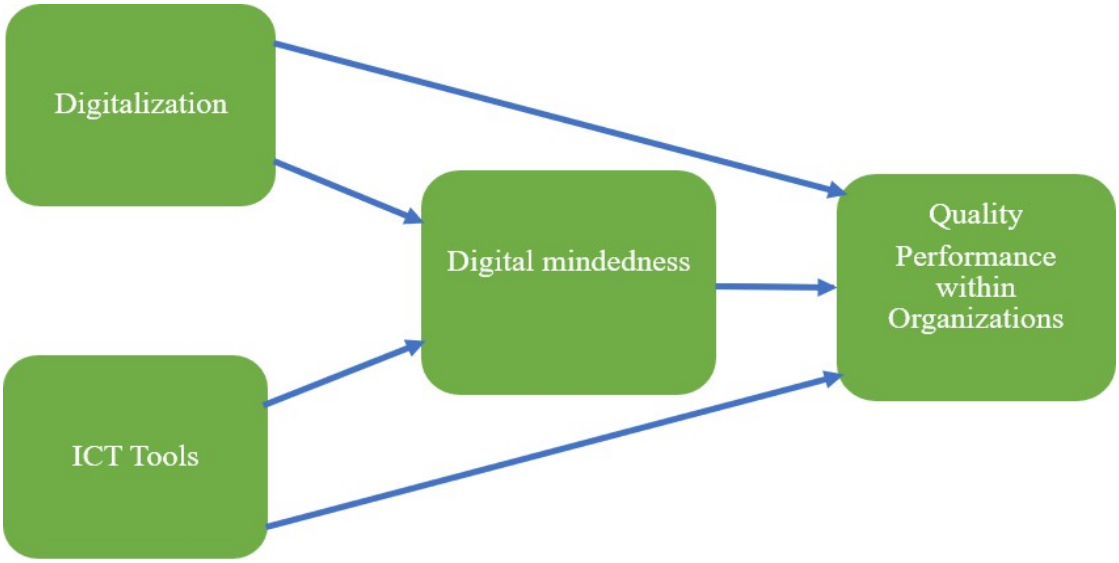

Figure 11: Proposed Conceptual Model

Theme 1: Digitalization and ICT tools affect Quality Performance within Organizations.
Theme 2: Quality Performance within Organizations depends on mediating effects of Digitalization and ICT tools.

Discussion

Industry 4.0 indicates that technologies are rapidly revolutionizing from day to day. Based on the research done, quality performance regardless whether it comes to quality within industries or quality of life, it is basically influenced by 2 major factors such as digitalization and ICT tools. The term digitalization and ICT are inseparable as both are interconnected with one another. Many things in current era are being exposed to creativity and innovation. Digitalization is the core for creativity, enabling the current generation of employees to think 'out of the box' without just being confined to manual work concepts. People should also be effective in enhancing their communication skills and ability to work as a team for Problem Solving on issues. Quality which has become an essential integrated part of customer orientation has to be placed at top most priority under digital transformation (Dutta *et al*., 2021). In order to embark the new journey of digitalization together with Industry 4.0 concept, it is important to have knowledge and skills with digital minded work culture. Along with this, quality becomes a very crucial indicator to measure the performance within organizations. Therefore, Quality 4.0 comes into the picture where emphasis is given to Quality concept merged together with Industry 4.0 concept. In Industry 4.0 concept, manual work which had been executed by people previously has been replaced with Autonomous Robots and advanced automated manufacturing machines. For instance, in Surface Mount Technology (SMT) manufacturing process, solder paste printing process which had been manually done by people are replaced with solder paste printing machines and similar concept goes for placement where component mounting is no longer done by humans instead replaced by placement machines with autonomous arms. In this way, cycle time is reduced and productivity yield is maximised. This results into a higher quality of products minimising the occurrence of defect rate and increasing relative utilization. This is supported with the studies done by Hamid (2022) to reveal the key factors of Industrial Revolution 4.0 concept among Multinational Companies (MNCs) in Malaysia. MNCs such as Intel and Toyo were studied by considering five key factors and their respective smart manufacturing practices. Among the key factors studied were Autonomous Production Lines, Smart Manufacturing Practices, Data Challenge, Process flexibility and Security. The results revealed that having certain level of technical and digital skills are important to assess and acquire Big Data in organizations which apply digital technologies in their manufacturing practice. This means that implementing digital technologies alone will not assure 100% efficiency in terms of quality performance. However, subordinates who work in such organizations also need to have the knowledge of handling, analysing and close looping actions according to their data analytical skills. Quality adoption is not about having Zero Defects in Shopfloor of manufacturing environment, but it is also based on the skills of handling Big Data and documentation in an automated manner instead of manual mode. This led to the development of quality adoption maturity matrix by Dutta (2021). The main objective of having maturity matrix is to establish the characteristics exhibited by an organisation based on its competency level at every functional area.

The maturity criteria for quality adoption were developed based on data-driven process improvement by Buer (2018). In this matrix, Quality Digitalization Maturity were categorized into five levels based on four stages of PDCA (Plan-Do-Check-Act).

Level 1: Represented traditional paper-based situations, with manual data handling.

Level 2: Spread sheet-based to provide basic analytics which supported need-based decisions.

Level 3: Project management, RFID based tracking, APQP, FMEA, SPC, tolerance analysis. Digitalized data handling.

Level 4: Integration of Quality Systems with business systems such as PLM, ERP, MES and data analytics. Automated data handling observed.

Level 5: Highest level of maturity with Close Loop Manufacturing (CLM) and Close Loop Quality (CLQ) data. Digital twin methodology can be practiced which enables Horizontal and Vertical System Integration.

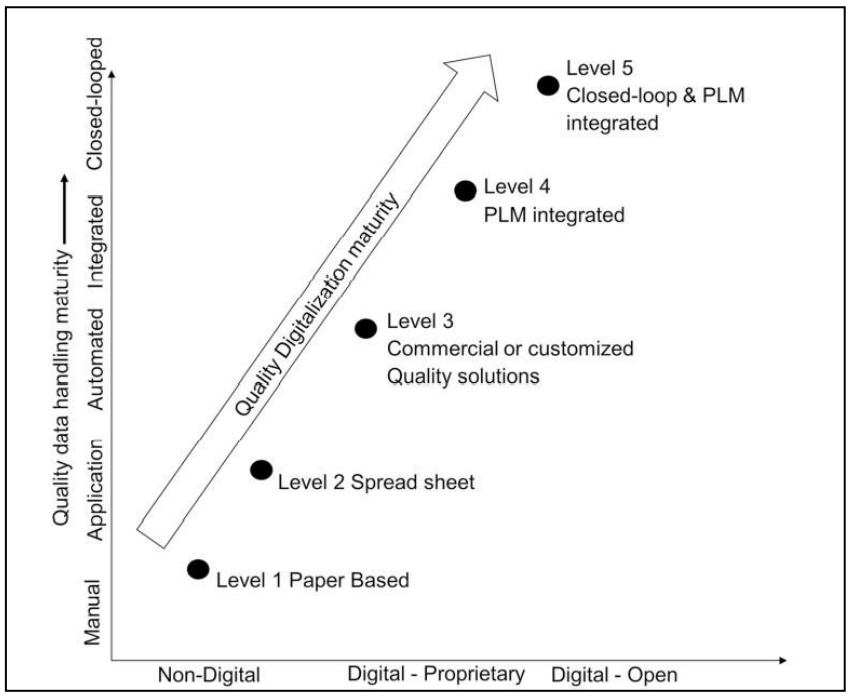

Figure 12: Quality Adoption Maturity Matrix based on Data Handling and Data Formats
Source: Digitalization Priorities of Quality Control Processes for SMEs: A Conceptual Study in Perspective of Industry 4.0 Adoption

However, people will need the knowledge and skills to be more focused in terms of integrating, controlling and managing machines' work tasks. The need is there for employees to analyse large amount of data by utilizing the newest and smartest technologies. New educational approaches and competences are needed to accommodate such high technological requirements. A shortage of digital skills and knowledge is one of the top barriers in fully implementing Quality 4.0. Therefore, this creates Quality 4.0 concept which eventually leads towards Total Quality Management (TQM). Quality 4.0 appears to be an ideal opportunity to realign towards business's corporate strategy (Santos *et al*., 2021).
This research is using digitalization and ICT for studying the mediating effects on quality performance which is still at basic level of investigation. Therefore, more studies are needed by including the data on quality indicators such as KPIs, customer complaint indicators and etc from MNCs to prove that quality level of these companies are excellent with the application of digitalized tools. The challenge is to get MNCs' support in providing their companies' data as evidences, which are highly confidential and protected by Cybersecurity protocols.

Conclusion
The purpose of this study is to achieve two main objectives. First, to study the effects of digitalization and ICT tools on quality performance within organizations. Secondly, to study the mediating effects of digitalization and ICT tools in our model (see. Fig. 11) in terms of quality performance. Therefore, a conceptual model (see. Fig. 11) has been developed as informed by structuration theory. Our finding from this study is to make valuable contribution in the category of quality performance within organizations where studies in Malaysia remain

scarce. Studies done by Hamid (2022) indicate that Industry 4.0 is enabled by certain key factors. However, in order to get manufacturing environment to be fully digitalized, digital skills should also be prioritized. Without having sufficient knowledge to handle data and interpret them, decision making process would be a great challenge. Therefore, digital mindedness and skills play a very important role in ensuring that the overall quality performance is achieved in an organization. Based on the studies done by Boston Consulting Group (2019), it was observed that shortage of digital skill is the top barrier to Quality 4.0 implementation (see. Fig. 9). In this research we rely on structuration theory to empirically study the interplay between digitalization and ICT tools and how they affect quality performance within organizations. In terms of Industrial Revolution 4.0, digitalization is able to improve quality provided digital minded skill and culture are highly cultivated among employees. This means that Digitalization and ICT tools have gained much interest to researchers to execute their related studies as these variables are part of Industry 4.0 which would transform the entire world in future.

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