

DRIVERS AND CHALLENGES OF INDUSTRY 4.0 ADOPTION: AN EMPIRICAL STUDY ON METAL AND METAL PRODUCTS MANUFACTURING SMEs

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Abstract:

The global industrial sector is witnessing rapid advancements in digital manufacturing and the implementation of Industry 4.0 (I4.0). This transformation presents significant opportunities for manufacturing firms to innovate and enhance productivity. In this context, an empirical survey was conducted to assess the readiness and challenges of I4.0 adoption within Kingdom of Bahrain's manufacturing sector, which is considered a key component of the national economy. The study focused on Small and Medium-Sized (SME) metal and metal product manufacturing organizations, recognized as leaders in factory digitization within Kingdom of Bahrain. The country hosts 335 manufacturing organizations, out of which 65 are classified as Metal and Metal Product manufacturing (SMEs). The research method used in the study involved a quantitative questionnaire-based survey as the primary data collection tool, covering the following key aspects: (1) organization core activities and size, (2) management awareness of I4.0, (3) adoption of automated and digital technologies, (4) software and information communication technologies used, (5) extent of data sharing and analysis within departments, and (6) motivations and obstacles encountered in pursuing I4.0. The findings revealed that only 25% of respondents are fully aware of the I4.0 concept, while the majority have limited awareness. Conventional automation and primitive information technologies showed a high adoption rate of 70%, indicating a slow progression towards Cyber-Physical Systems (CPS) and the Internet of Things (IoT). The three main drivers identified were enhanced productivity, cost reduction, and quality improvement. On the other hand, the three primary barriers were the high financial investment required, difficulties in upgrading existing machinery, and uncertainty regarding the return on investment. The study's findings conclude that there is readiness to pursue I4.0 among the metal and metal product manufacturing SMEs; however, significant efforts will be required to keep pace with I4.0. Furthermore, these insights highlight the need for further research to overcome existing challenges and develop frameworks that support manufacturing organizations and policymakers in accelerating the implementation of I4.0

Key words: Industry 4.0 (I4.0), Internet of Things (IoT), Drivers, Challenges, Metal and Metal Products Manufacturing SMEs, Kingdom of Bahrain

INTRODUCTION

Globally, the manufacturing industry is currently provoked to speed up the transition phase toward the fourth wave of technological advancement. Since the inauguration and coining of the term Industry 4.0 (I4.0) at the Hannover Fair in 2001, literature has demonstrated that initiatives and readiness are falling short of expectations [1]. Two decades have elapsed, and most manufacturing SMEs are still categorized as either novice or beginner. Readiness analyses indicate that many manufacturing SMEs are still grasping the opportunities and benefits gained through factory digitalization. In addition, the latest advancements in information and communication technologies in manufacturing have made them readily available at lower costs. However, progress toward

intermediate and expert levels remains slow [2, 3, 4, 5]. The Kingdom of Bahrain has been paying great attention to the region's efforts in fostering smart cities. Accordingly, part of this endeavor is complemented by I4.0 integration [6, 7, 8]. Additionally, the manufacturing sector constitutes more than 36% of businesses in Kingdom of Bahrain and contributes 14% to the national GDP. Therefore, it is essential to investigate the sector's readiness for I4.0 adoption [7, 8].

However, extensive literature and comprehensive reviews of studies on I4.0 in frontier manufacturing countries have highlighted a common practice: assessing the driving forces and challenges before evaluating readiness and implementation strategies [9, 10]. Identifying the dominant challenges to I4.0 deployment will pave the way

for assessing I4.0 readiness and maturity levels. Readiness supersedes maturity assessment, as maturity is evaluated from actual implementation onward [11].

This study aims to assess the readiness of Kingdom of Bahrain's manufacturing sector for I4.0 adoption by evaluating awareness levels, technological adoption, and key challenges. Additionally, it seeks to identify the driving forces that facilitate I4.0 implementation while addressing the barriers that hinder progress. By bridging the literature gap on I4.0 studies in developing countries [12, 13, 14, 15], particularly in the Gulf region where research remains limited, this study provides valuable insights for policymakers and industry leaders.

To achieve this, the study explores the following research questions: What is the level of I4.0 awareness among Kingdom of Bahrain's Small and Medium-Sized metal and metal products manufacturing firms? To what extent have automated and digital technologies been adopted? What is the state of the relationship between data sharing and analysis? What are the key drivers influencing I4.0 adoption? What are the main challenges hindering its implementation?

This paper is organized as follows: Section 1 presents a brief review of the literature on I4.0 enablers and discusses the driving forces and challenges to I4.0 adoption. Section 2 highlights the methodology used to assess the readiness of manufacturing organizations in Kingdom of Bahrain, along with the identification of drivers and core challenges hindering advancement toward I4.0. Section 3 outlines the results, Section 4 discusses the findings, and Section 5 provides the conclusion.

LITERATURE REVIEW

The 21st century industrial paradigm is branded as I4.0 (I4.0) or the fourth industrial revolution. The term came into existence in Hannover Messe in the year 2011, coined by the German government as an important initiative for its high-tech strategy [16, 17]. The first industrial revolution dated back to the late part of the 18th century (1760-1840) and was considered the first phase of machine integration in the production process. The machines in this era were of introductory nature, as they used steam power and waterpower. Thereafter, the progression in technology associated with electricity contributed to the existence of mass production assembly lines, in the late 19th century (1871-1914). However, the greatest technological advancement was noticed when computers were introduced as part of machine functionality and in manufacturing processes, in the late 20th century (1996) [14, 18].

I4.0 has been given numerous definitions, and according to Branco et al. they all revolve around an environment that is characterized as highly digitized manufacturing processes where information flows among machines in a controlled environment so that human intervention is reduced to a minimum [12]. While Lu, sheds the light on fact of it being the integration of complex physical machinery and devices with networked sensors and software, used to predict, control and plan for better business and

societal outcomes [13].

Moreover, I4.0 has been labelled, in the manufacturing sector, as digital factory, intelligent factory, or smart factory, all aiming towards an end digital integration. Extending the ongoing automation advancement of traditional manufacturing and industrial technologies, to incorporate Cyber-Physical Systems (CPS) and Internet of Things (IoT) within the manufacturing processes and operations throughout the product supply chain and lifecycle [19, 20, 21, 22].

According to Mahdiraji et al. Cyber-Physical Systems is referred to "as a network of cyber space-based systems with computing and communicating abilities and physical components such as sensors and drivers placed in a single cycle. Sensors send the information to the cloud computing points and analysis applications, and after being processed by data analyzing algorithms, drivers receive the information and lead to decision-making or action". While Internet of Things is considered the interoperability of the network which enables the machines, devices, sensors, and people connects and communicate with each other via the Internet [11, 21] To build I4.0 in the manufacturing world requires the formation of a certain setting that ensures delivering an automated and digitized horizontal and vertical integration throughout the company, production planning, process, control, and field level [10]. As a result, the characteristics of I4.0 were clustered into key enablers and presented as a coherent part of the assessment and implementation process. In the literature and consultancy reports, these enablers were referred to as criteria, dimensions, factors, pillars, or technologies, and they were mainly used to measure/distinguish the level of readiness [22, 23].

Saniuk et al., conducted an extensive literature review identified 8 key technological components associated with Industry 4.0, including the Internet of Things (IoT), smart factories, the Internet of Services (IoS), smart products, machine-to-machine communication (M2M), Big Data, and Cloud Computing. These technologies were organized under broader pillars such as Smart Solutions, Smart Innovations, Smart Supply Chain, and Smart Factory, with Smart Solutions comprising Smart Products and Smart Services [25]. In parallel, the Boston Consulting Group (BCG) proposed 9 core pillars of Industry 4.0 widely adopted in academic literature: Big Data and Analytics, Augmented Reality, Additive Manufacturing (3D Printing), Cloud Computing, Cybersecurity, Autonomous Robots, Simulation, Horizontal and Vertical System Integration, and IoT [24]. This categorization is consistent with the framework of Saucedo-Martínez et al. who grouped the foundational enablers of Industry 4.0 into 9 backbone blocks. Furthermore, Stentoft et al. introduced 3 additional technologies Artificial Intelligence (AI), Mobile Technologies, and Radio Frequency Identification (RFID) with Real-Time Location Systems (RTLS) which are often considered as embedded subsets within the original nine blocks [10].

Meanwhile, Ghobakhloo et al. clustered I4.0 technologies into first tier and second-tier technologies [23]. First-tier

technologies are off-the-shelf technological products, such as 3D printers, that SMEs can purchase and implement on a standalone basis. Industrial Internet of Things (IIoT) and CPS, as the second-tier I4.0 technologies, are the byproduct of implementing and integrating several first-tier technologies such as data acquisition systems or machine learning.

In a similar effort, Lee et al. proposed a unified 5C architecture for Cyber-Physical Systems (CPS) as a foundational structure for the implementation of Industry 4.0 in manufacturing environments. The architecture consists of 5 sequential levels: Smart Connection, Data-to-Information Conversion, Cyber, Cognition, and Configuration. This framework serves as a practical guideline to enhance resilience, efficiency, and intelligence across all manufacturing layers from components and machines to entire production systems [25].

Furthermore, the most prominent readiness assessment models created to define the readiness level of manufacturing organization to evolve into the fourth industrial revolution, were based on the degree of these 9 enablers adoption conducted a comprehensive literature review on 30 different I4.0 readiness models, contributed by industry and academia [26]. The findings indicated that these models were based on 6 common dimensions, Technology, Process, People, Strategy, Leadership, and Innovation, out of which 70 sub-dimensions were associated the technology dimension and 17 sub-dimensions with the process dimension. From another perspective, Schumacher et al. developed a maturity model based on organizational aspects rather than technology focus. The maturity model assessment was based on 9 dimensions, Products, Customers, Operations and Technology, Strategy, Leadership, Governance, Culture, and People [27]. In addition, Cinar et al., cross examined 16 maturity models and 8 frameworks/architecture models, along with the existing Technology Forecasting Applications, with the intention of developing a readiness framework integrated with technology forecasting to evaluate the growth and completion duration of I4.0 [28]. Their proposed framework consisted of a maturity model with four assessment dimensions: Factory 4.0, Logistics 4.0, Operator 4.0, and Management 4.0, which were further cascaded into 246 subdimensions.

Axmann and Harmoko, on the other hand, conducted a comparison on the existing readiness assessment tools, IMPULS (VDMA), PwC, and Uni-Warwick, and created their own tool based on the weakness and strength comparison results [29]. The developed tool consisted of 12 categories: Data Sharing, Data Storage, Data Quality, Data Processing, Product Design and Development, Smart Material Planning, Smart Production, Smart Maintenance, Smart Logistic, IT Security, Machines Readiness and Communication Between Machines. Those categories were grouped into three parts: Data, Software, and Hardware. Based on the above, the 9 enablers presented by Saucedo-Martínez et al. will be adopted in this research study to determine the readiness level of the manufacturing firms in Kingdom of Bahrain. Furthermore, the 3

additional technologies, presented by Stentoft et al. will be imbedded within the associated enabler components to address their findings [9, 21]. While, assessing the enablers will be complemented by a selective set that were found to be common between the sub-dimensions, presented by Ghobakhloo et al., Hizam-Hanafiah et al., Cinar et al. and the data, software, and communication sub-criteria, presented by Axmann and Harmoko [22, 26, 28, 29]. To ensure that the relevant factors concerning the benefits and barriers of I4.0 adoption are adequately addressed, it is essential to examine existing research on its driving forces and challenges. Understanding these elements will help in identifying key enablers and obstacles that influence the readiness and implementation of I4.0 in Kingdom of Bahrain's manufacturing sector. Examining the primary driving forces that facilitate I4.0 adoption alongside the major challenges that hinder its implementation provides a comprehensive perspective on the opportunities and limitations associated with this technological transformation.

In literature it is noticed that there are several research studies investigating the relationship between I4.0 gained advantages and the overall organization performance. According to Li et al. their study results found that digital technologies positively influence economic and environmental performance [30]. In addition, further studies were able to confirm that the operational advantages of new I4.0 technologies and production processes contribute positively to their adoption [31].

Ratnasingam et al. conducted a study to evaluate the factors driving the transiting towards Industry 4.0, that included a total of 29 motivators: increased output, on-time delivery, reduced down-time, shortened manufacturing cycle-time, reduced unit cost, higher investment, higher Return-on-Investment (ROI), reduced workforce, higher productivity, limited skilled workers, lack of Information Communication Technologies (ICT), lack of production-networking data, consistent quality, product diversity, improved quality, smaller batch-size, standardized components, reduced waste, less pollutants, improved ergonomics, improved safety and health factors, improved workers welfare, higher manufacturing standard, International Standard Organization (ISO) 9001 compliant, ISO 14001 compliant, ISO 18001 compliant, low-wage workers, no clear policy directions on automation and I4.0, and lack of incentives [32]. The results of the analysis revealed that only the factors of lower unit cost, standardized components, higher manufacturing standards, higher output, and increased productivity were important factors in the use of auto-mated technologies.

In addition, Ghobakhloo et al. pointed out that there are several other advantages in literature for the adoption of this concept, which included: shorter time-to-market for the new products, improved customer responsiveness [22]. While Vath and Szabó, found that the major force behind I4.0 adoption, is to have better ability to measure performance in real-time, which eventually leads to improved decision-making process [33].

This is said, many organizations still hesitate or delay

perusing I4.0, as they do not adequately understand how their operations and organization could change. Ramchander, conducted a systematic literature review on the eight leading consultation agencies I4.0 phenomenon survey's findings: covering Europe, America, Asia, Middle East, and Africa [34]. Based on the literature review analysis, he pointed out that the greatest challenges revolve around lack of understanding and resistance to change, lack of skills, and cyber security breaches.

In addition, Kamble et al., conducted a widespread literature review and interviews with experts from industry and academia, to identify the barriers to I4.0 adoption and measure the relationship between them [35]. By applying the fuzzy MICMAC (Matriced' Impacts Croise's Multi-plication Applique'e a' un Classement) analysis, they were able to determine the most significant barriers for I4.0 adoption. According to relationships analysis between the 12 adoption barriers and concluded that the I4.0 adoption uncertainties lie in the high investment levels and the unclear cost-benefits for the I4.0 application areas, the workforce lacks the adequate skills required to cope up with the upcoming automation, and there is a lack of clarity in the standards for the implementation of I4.0.

Moreover, Raj et al. conducted a comparative study and identified 15 key barriers to Industry 4.0 adoption in manufacturing across developed and developing economies. The most prominent barrier was the lack of a digital strategy alongside resource scarcity. Other key barriers included high investment requirements, unclear economic benefits, challenges in value-chain integration, cybersecurity risks, low maturity of technologies, inequality, job disruption, lack of standards and infrastructure, shortage of digital skills, poor data quality, weak internal digital culture, resistance to change, and ineffective change management [36].

Furthermore, Kumar et al. conducted survey-based empirical research and identified 16 barriers to I4.0 adoption along with investigating the relationship between them, using three statistical techniques: Principal Component Analysis (PCA), Fuzzy Analytical Hierarchical Process (Fuzzy AHP), and K-means clustering. Accordingly, the findings revealed that the most prominent adoption barriers of I4.0 practices were lack of transparent cost-benefit analysis, IT infrastructure, missing standards, lack of properly skilled manpower, fitness of present machines/equipment in the new regime, and concern to data security [37].

Finally, Elhousseiny and Crispim, conducted a literature review where a total of 18 factors were cross examined between the developed and the developing countries [38]. The review concluded that the main obstacles were lack of technological know-how and organizational reluctance to change.

As Kingdom of Bahrain is in line with the industrial world movement towards I4.0, it will eventually face similar drivers and barriers. Therefore, it is important, from an empirical research perspective, to assess the current local manufacturing industry readiness, with regards to I4.0 awareness, technologies utilization, data analysis level.

Then proceed with investigating the anticipated influential drivers and barriers, to support further research in developing frameworks for manufacturing organizations and policymakers to expedite I4.0. implementation.

RESEARCH METHODOLOGY

The research method used in the study was conducted using a quantitative questionnaire-based survey, as a data collection tool. The questionnaire was developed based on the findings discussed in section 2 and validated by a group of executives from the Industry and Energy Committee in Kingdom of Bahrain Chamber of Commerce and Industry (BCCI), whom have been involved in promoting automated technologies and are familiar with I4.0.

The survey consisted of 10 quantitative, closed-ended questions based on a 5-point Likert scale, with each question designed to address the five research questions and capture data on the following areas: (1) the organization core activities and size (2) the management's awareness of I4.0 (3) the automated and digital technologies adopted by the organization; (4) the software and information and communication technologies used by the organization; (5) the extent of data sharing and analysis across different departments within the organization; and (6) the motivations and obstacles anticipated/encountered in pursuing I4.0.

As to the population of this study, it was confined to Metal and Metal Products manufacturing SMEs, as they are part of the leading Metal and Metal Products manufacturers in pursuing factory digitization transformation in Kingdom of Bahrain. According to the 2nd National Business Agenda for the Kingdom of Bahrain and (BCCI) there is a total of 335 Metal and Metal Products manufacturing organizations, out of which 65 representing the metal and metal product manufacturing SMEs [39].

With the support of the (BCCI), the survey population data was obtained. The BCCI facilitated the distribution of the questionnaire via emails to the 65 manufacturing companies. Additionally, personal visits were made to all 65 companies to encourage participation and enhance the response rate. As a result, 20 organizations positively responded and filled out the questionnaire, yielding a response rate of 31%, ensuring a representative dataset. Among the respondents, 10 were categorized as medium-sized organizations, while the remaining 10 were categorized as small-sized organizations.

RESULTS

The survey results and analysis are presented in five parts: (1) I4.0 awareness level, (2) automation and information technologies utilization level, (3) data share and analysis level, (4) influential drivers, (5) anticipated barriers.

I4.0 awareness level

Figure 1 illustrates the current awareness level of I4.0, within the Metal and Metal Products manufacturing SMEs sector.

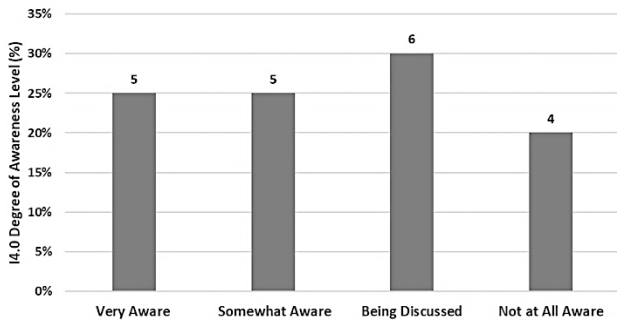


Fig. 1 I4.0 awareness level

The findings indicate that 25% of the respondents are aware of I4.0, and 25% possess partial awareness, while the remaining 50% are not aware of it. Furthermore, 30% acknowledge the importance of investigating the advancements in industrial automation and digital transformation towards I4.0.

Automated and information technologies utilization level

Table 1 shows the utilization level of the sub-enabling Automated Technologies within the 9 enablers, considered in this study.

Table 1 Automated technologies utilization level

No.	Automated Technologies	No. of Organizations	Utilization Level (%)
1	Computer Numerical Control (CNC) machine	13	65%
2	Programmable Logic Controllers (PLC)	11	55%
3	Smart Mobile Devices; such as tables and phones	8	40%
4	Auto ID technologies; such as bar code readers, and Radio Frequency Identification (RFID)	7	35%
5	Wireless machine sensors and actuators	7	35%
6	Autonomous production workstation	6	30%
7	Global Positioning Systems (GPS)	4	20%
8	Autonomous robots	4	20%
9	Product operational performance monitoring sensors	1	20%
10	3D Printing machines	0	5%
11	Autonomous Automated Guided Vehicles (AGVs)	0	0%
12	Augmented/Virtual reality devices such as smart glasses and head-mounted display	0	0%
13	Voice controls	0	0%
14	Gesture controls	0	0%
15	Robot remote maintenance	0	0%

It is important to note that these percentages represent the adoption rate of each technology individually, rather than a cumulative total, and therefore do not sum to 100%. The Computer Numerical Control (CNC) machine was found to be the most utilized form of automated technology, with 65% of participants adopting it, followed by Programmable Logic Controllers (PLC) at 55%. On the other hand, the utilization of more sophisticated automated technologies like additive manufacturing and augmented reality varied, from 30% to nil.

The above results reveal that the present application of automation in the Metal and Metal Products manufacturing SMEs is focused primarily on conventional automation and, which are considered the preliminary stages of the digital factory concept.

Table 2 shows the utilization level of the sub-enabling Information Communication Technologies within the 9 enablers.

Table 2 Information Communication Technologies utilization level

No.	Information Technologies	No. of Organizations	Utilization Level
1	Computer Aided Design/Engineering (CAD/CAE) software	19	95%
2	Production planning & scheduling software, such as Enterprise Resource Planning (ERP)	13	65%
3	Warehouse management system; such as Supply Chain Management and (SCM) and Smart Storage Systems	6	30%
4	Operation control software; such as Supervisory Control and Data Acquisition (SCADA)	6	30%
5	Cloud Computing	6	30%
6	Data Security Management System	6	30%
7	Simulation software	5	25%
8	Statistical Process Control (SPC) software	4	20%
9	Customer Relationship Management (CRM) System	4	20%
10	Maintenance Management System; such as Computerized Maintenance Management System (CMMS)	3	15%
11	Wireless Sensor Networks	2	10%
12	Artificial Intelligence platforms	2	10%

It is important to note that these percentages represent the adoption rate of each technology individually, rather than a cumulative total, and therefore do not sum to 100%. The Computer Aided Design/Engineering (CAD/CAE) software was found to be the most utilized form of automated technology, with 95% of participants adopting it, followed by Production Planning and Scheduling software, such as Enterprise Resource Planning (ERP),

at 65%. On the other hand, the utilization of more sophisticated information communication technologies varied, from 30% to 10%.

Data share and analysis level

Figure 2 presents findings from these organizations, offering a comprehensive perspective on the relationship between data sharing and analysis. The results compare the level of data analysis with the level of data sharing across business units within organizations where data-sharing and data analysis levels exceed 50%.

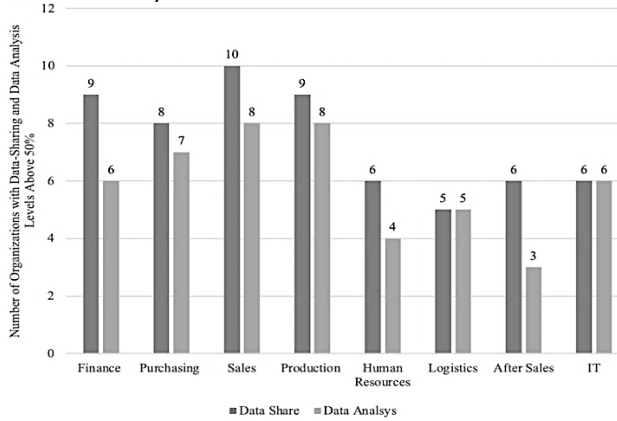


Fig. 2 Data Share and Data Analysis adoption level

The Sales department recorded the highest level of data sharing, with 10 organizations sharing data above 50%, followed by Finance, Production, and Purchasing. Logistics had the lowest data-sharing level, with only 5 organizations surpassing the 50% threshold. Sales and Production also led in data analysis, with 8 organizations reporting data analysis levels above 50%, followed by Purchasing and Finance. The After-Sales department had the lowest analytical utilization, with only 3 organizations exceeding the 50% benchmark.

I4.0 implementation driving forces

Figure 3 presents the key factors driving I4.0 implementation from the perspective of the survey respondents.



Fig. 3 I4.0 implementation driving forces

It is important to note that these percentages represent the adoption rate of each technology individually, rather than a cumulative total, and therefore do not sum to 100%. The core drivers, as indicated by the respondents

are enhancing productivity, cutting expenses, and augmenting quality.

“Improved Productivity” was identified as the leading objective by most of the respondents, with approximately 70%, highlighting their need to enhance their overall efficiency by leveraging I4.0 technologies. “Reducing Costs” is another key driver, with approximately 65%, highlighting their acceptance of I4.0 technologies role in ensuring cost-efficiency. In addition, the third most significant driver is “Improving Quality”, with approximately 60% marking it as important, thereby demonstrating their recognition of the connection between I4.0 technologies and quality improvement.

I4.0 implementation challenges

Figure 4 presents the main challenges that impede the transformation of industry towards I4.0 implementation from the perspective of the survey respondents. It is important to note that these percentages represent the adoption rate of each technology individually, rather than a cumulative total, and therefore do not sum to 100%.

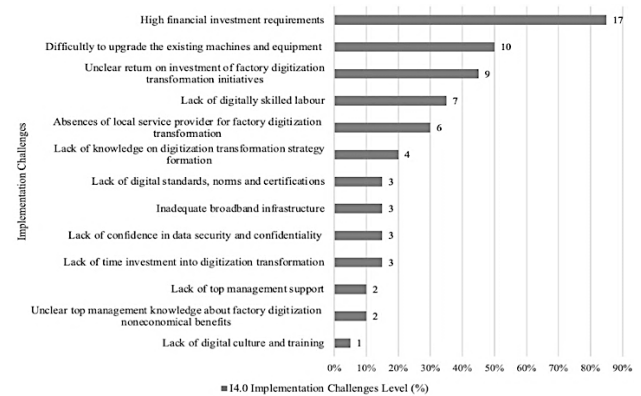


Fig. 4 I4.0 implementation challenges

"High Financial Investment Requirements" was identified as the most critical challenge by approximately 85% of respondents. This was followed by "Difficulty in Upgrading Existing Machines and Equipment" and "Unclear Return on Investment for Factory Digitization Efforts," reported by 65% and 45% of respondents, respectively, as major concerns. Furthermore, it worth mentioning that the challenges that received a response rate of 30% and above included "Lack of Digitally Skilled Labor" and "Absence of Local Service Providers for Factory Digitization Transformation".

DISCUSSION

This discussion explores the research questions by looking at I4.0 awareness, the level of automation and digital technology adoption, the role of data sharing and analysis, the key drivers behind I4.0 adoption, and the challenges that slow down its implementation in the Metal and Metal Products manufacturing SMEs sector in the Kingdom of Bahrain. By analysing survey results and comparing them with global studies, this section provides insights into how the sector is progressing in digital transformation and what factors are helping or holding it back.

Starting with the first research question, which examines the level of I4.0 awareness among manufacturing firms. The results show that half of the respondents were unfamiliar with I4.0 concepts and their impact on manufacturing. Indicating that the present application of automation in the medium and large metal and metal products manufacturing industry is focused primarily on conventional automation, which are considered the preliminary stages of the digital factory concept. This observation is somewhat expected as, Pech and Vrchota, reported an implementation rate of less than 20% for 3D printers, virtual reality or autonomous vehicle technologies among high-tech Czech SMEs [40]. Furthermore, 30% acknowledge the importance of investigating the advancements in industrial automation and digital transformation towards I4.0. This suggests that this sector is observing the latest manufacturing trends, pointing towards an optimistic assessment consideration of I4.0 implementation. However, this level of awareness is considered low, when compared to the comparative analysis covering Europe, America, Asia, the Middle East, and Africa, presented by Ramchander [34]. Moreover, the studies conducted by Tortora et al. and Shahzad et al. exhibited a relatively high level of I4.0 awareness in comparison to the finding of this study [41, 42]. Therefore, this significant lack of awareness about I4.0 among the survey respondents is to be viewed as a critical issue to be addressed.

Building on this, the next research question looks at how much automated and digital technologies have been adopted. The findings suggest that the present application of automation in the Metal and Metal Products manufacturing SMEs is focused primarily on conventional automation, which are considered the preliminary stages of the digital factory concept. For example, many companies use CNC machines and PLC, but adoption rates for autonomous robots, cloud computing, artificial intelligence, and augmented/virtual reality are much lower. In addition, the findings indicate low utilization of advanced ICT applications that are crucial for effective CPS implementation and functionality. Thereby placing this manufacturing sector in a more challenging position towards I4.0 transformation process. This trend was rather anticipated, considering that research papers conducted in the Far East has highlighted a low consistent pattern in the adoption of similar ICT applications [32]. Overall, these findings are consistent with the observations made by Ghobakhloo et al. who noted a generally low adoption rate of automated and information technologies across Europe, South Korea, Norway, and Australia SMEs [22].

Moving to the third research question, relationship between data sharing and analysis within this sector, clearly indicates that the adoption level for Big Data and advanced analytics and collaborative robotics is not aligned with the level of required knowledge to pursue Industry 4.0. In addition, the findings indicate that these activities are relatively high in the Sales, Finance, and Production business units. However, the results also highlight that other business units exhibit limited horizontal and vertical integration to pursue I4.0. Thus, placing the industrial

sector in an extremely lagging and challenging position towards Industry 4.0 transformation process. Most Industry 4.0 readiness assessment tools and models incorporate both automated and digitized technological utilization level, as well as horizontal and vertical integration level [41]. The level of horizontal and vertical integration plays a crucial role in attaining the long-term rewards of advancing towards Industry 4.0 [43].

The fourth research question examines the key factors driving Industry 4.0 adoption. The findings reveal that the three primary drivers are productivity improvement, cost reduction, and enhanced product quality. Productivity improvement emerges as the top driver, reflecting the sector's focus on increasing overall efficiency through I4.0 technologies. Cost reduction is another critical factor, underscoring the recognition of I4.0's role in optimizing costs and ensuring business sustainability. Additionally, quality enhancement ranks as the third most significant driver, emphasizing the strong link between I4.0 technologies and improved product quality, which is crucial for maintaining competitiveness. These findings align closely with the research of Singhal and Antonino et al. [44, 45]. In addition, workforce reduction and competitors' practices were considered less significant factors by the respondents, in contrast to other regions where high labour costs drive automation. This indicates that the Metal and Metal Products Manufacturing SMEs focus more on efficiency and product quality rather than reducing labour expenses. Overall, these finding aligns with the previously cited references, except for the study by Singhal, which identified labour cost reduction as the second most significant benefit. This contradiction is likely influenced by the region's relatively low labour costs [44].

Concluding with the final research question on the key challenges to I4.0 adoption, the survey results reveal several financial, technical, and organizational barriers. The survey results highlight several financial, technical, and organizational barriers. The biggest challenge identified is the high cost of investment. Advanced machinery, robotics, and automation technologies require large financial commitments, making it difficult for Small and Medium-Sized enterprises (SMEs) to adopt them. Similar concerns are reported in studies, which show that high capital costs are a major obstacle to smart factory adoption [40, 44, 46, 47, 48].

Another common challenge is the difficulty of upgrading existing machines and equipment, as many companies struggle to integrate their legacy systems with modern digital technologies, a process that is both costly and technically complex. Additionally, concerns about an unclear ROI, with companies hesitant to fully commit to digital transformation due to the lack of clear financial benefits or measurable outcomes. This reflects the challenges in investment decision-making, particularly the difficulty in justifying substantial returns relative to the financial and time investments required.

Furthermore, other key challenges include the lack of digitally skilled labour and the absence of local service providers for factory digitization transformation, further

hindering progress in adopting Industry 4.0 technologies. These findings are consistent with the observations made by Ricci et al., Hamim et al., and Ben Ruben et al., except for Lu, Raj et al., Horváth and Szabó, Tortora et al., Singhal, and whose research findings revealed that the internal digital skills and training were among the primary challenges [13, 33, 41, 44, 46, 47, 48]. This could be attributed to the insufficient local manufacturing advancements and investments in the Cyper-Physical Systems.

CONCLUSION

The study examined the level of I4.0 awareness, the extent of automation and digital technology adoption, the role of data sharing and analysis, the key drivers influencing digital transformation, and the main challenges hindering I4.0 implementation in the Kingdom of Bahrain's Metal and Metal Products manufacturing SMEs sector. The findings highlight both opportunities and barriers that shape the sector's progress toward digital transformation. The study revealed that I4.0 awareness among Bahrain's Metal and Metal Products manufactures remains relatively low, with only 25% of firms fully understanding its concept, while another 25% have partial awareness, demonstrating a substantial awareness gap compared with the leading countries that have advanced further stages in implementing Industry 4.0.

Regarding automation and digital technology adoption, the findings indicate that traditional automation is well-established, with 65% of firms using CNC machines and 55% utilizing PLC. However, more advanced I4.0 technologies remain underutilized, with only 20% of companies adopting autonomous robots, and 30% implementing cloud computing. Furthermore, in terms of ICT, 95% of the participants use CAD/CAE software, and 65% use ERP software. While advanced ICT applications had lower utilization rates, varying from 30% to 15%. This suggests that while manufacturers have integrated basic automation, the shift toward CPS and fully digitalized manufacturing processes is still in its early stages.

In terms of Data sharing and analysis significant disparities existed across business departments. While Finance, Sales, and Production departments exhibit high levels of data sharing, other areas, such as Purchasing, Human Resources, Logistics, After-Sales, and IT, show much lower levels of integration.

The primary drivers for adopting Industry 4.0 technologies, reported by the participants, were improved productivity 70%, reduced costs 65%, and enhanced quality 60%. However, the significant barriers were found to be high financial investment requirements 85%, difficulty in upgrading existing machinery 50%, and unclear return on investment for factory digitization efforts 45%. Additionally, it was discovered that the lack of digitally skilled labour and local service providers posed distinct challenges beyond the three primary drivers.

Although, this study successfully met its objectives, there are opportunities for further in-depth investigation to explore how Bahrain's manufacturing industries, including the metal and metal products sector, can advance

towards higher levels of Industry 4.0 readiness and maturity. Future studies could also explore how Bahrain's manufacturing industries might adopt Industry 5.0 to strengthen the long-term impact of digital transformation and build a future-ready, ethical, and inclusive industrial ecosystem. This includes assessing not just technological readiness but also human-centricity, sustainability, and resilience.

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