

The Impact of Industry 4.0 Technologies on Manufacturing Strategies: Proposition of Technology-Integrated Selection

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This work was supported by the Raytheon Chair for Systems Engineering.

ABSTRACT Industry 4.0 (I4.0) has increasingly been adopted as an advanced manufacturing strategy to counter global competition. The capability of a company to compete on various manufacturing strategy outputs (MSOs) such as cost, quality, delivery, flexibility, performance and innovativeness play a significant role in motivating the whole company to take advantage of its competitors. I4.0 is comprised of various technologies, and how I4.0 technologies can influence the MSOs are still unclear, and it took less interest in the literature. This article aims to analyze the influence of the I4.0 technologies on MSOs to achieve market competitiveness from the perspective of academic and industry experts. To do so, the influence of the adoption of various I4.0 technologies on the MSOs was investigated. Expert opinions were gathered on the relationship between manufacturing competitive capabilities and I4.0 technologies. The identification of the influential relationships provides arguments for the proposed I4.0 technology selections, which will allow companies to gain a highly competitive advantage. The results showed that the performance (regarding the MSOs) had a high potential for integration with different I4.0 technologies.

INDEX TERMS Manufacturing strategies, industry 4.0 technologies, competitive capabilities, smart manufacturing.

I. INTRODUCTION

Manufacturing strategies can be described as long-term plans to use the manufacturing system's resources to support the business strategy and in turn, to achieve business goals [1]. It is also known as a framework that aims to strengthen the organization's competitiveness by well designing, managing, and developing its manufacturing resources. Also, it forms a consistent production decision pattern that will result in an adequate mix of performance characteristics that will allow the company to compete effectively [2]. Manufacturing strategies help organizations in establishing a well-organized manufacturing structure [3]. A manufacturing company's well-organized structure enhances its performance and helps to gain a competitive advantage. This competition depends on the level of manufacturing outputs or priorities such as

cost, quality, delivery, flexibility, performance, and innovativeness that align with customer requirements [4]. Nowadays, manufacturing is gaining more importance in achieving the business competitiveness of companies through effective management of long-term strategic decisions. It becomes a strategically competitive element with such companies that can differentiate themselves from competitors [5].

Manufacturing competitiveness refers to a company's capacity to compete with other competitors' markets by offering world-class products or services that attract and enhance customer satisfaction [6]. Manufacturing strategies are utilized in sequences that begin with the formulation of strategies and end with the company's performance [7]. MSOs such as cost (production and distribution of goods at low cost), quality (production of goods with high quality), delivery (reacting quickly to customer requests to deliver quickly), and flexibility (reacting to product changes, product mix changes, design changes, material fluctuations, sequence

The associate editor coordinating the review of this manuscript and approving it for publication was Md. Abdur Razzaque.

changes) were labeled as competitive priorities in the literature [8].

Manufacturing strategies and processes need to be data-driven and instant in order to respond rapidly to changing customer demands [9], [10]. Therefore, I4.0 is a new revolutionary wave that rapidly responds to customer demands with very high efficiency. I4.0 is known as the fourth industrial revolution, began with the goal of being able to make items that reflect the needs of customers through efficient production systems; designers may refer to this concept as “flexible integration of the global value chain” [11], [12]. I4.0 contributes to the digitalization of manufacturing by encouraging industrial flexibility and the customization of goods by automation and data sharing in different settings [13]. It focuses heavily on cyber-physical systems (CPS) and smart technology that can integrate machinery, factory, and business processes. These technologies are distinguished by unique capacities, such as the ability to share information autonomously, trigger actions, make decisions and control each other separately [14]. I4.0 involves connecting and integrating the digital/virtual and real/physical world via CPS and the internet of things (IoT), where smart objects continuously interact and communicate with each other [15], [16]. I4.0 enhances industrial capability by facilitating the manufacture of the right products in the best quality, fast delivery, and lower cost, all while maintaining the environment safe [17]. I4.0 allows smart, efficient, effective, individualized, and customized products at a reasonable cost. With the assistance of faster computers, smart machines, smaller sensors, and more affordable data storage and transmission, it is possible to make machines and products smarter by allowing them to communicate with and learn from one another [18]. To improve overall production and performance, an appropriate alignment between I4.0 and MSOs is required.

To date, several studies have been published to clarify the significance of applying I4.0 techniques to improve the MSOs. Chiarini *et al.* [19] applied I4.0 technologies (big data analytics (BD), digital supply chain, IoT, cloud computing, robotics, 3D printing, and automated guided) to improve MSOs (Cost, Performance, and Innovations) in Italy. May and Kiritsis [20] utilized the I4.0 technologies to achieve zero defects in manufacturing lines which contributed to fewer costs and a higher level of quality, customer satisfaction, competitiveness, and sustainability of manufacturing plants. Tortorella and Fettermann [21] used the I4.0 technologies such as 3-D printing, virtual model simulation/analysis, BD, cloud service, IoT, and so on to improve the MSOs such as quality and performance. Ghobakhloo [22] provided a complementary framework that can be used as a starting point by academics and practitioners toward developing a comprehensive strategic plan for a successful transition from conventional manufacturing to I4.0 which led to improving the overall performance. Ghobakhloo and Fathi [23] proposed I4.0 technologies to show how small-scale manufacturing companies can manage their IT resources to build lean-digitized production processes that increase sustainable

competitiveness and performance. Tortorella *et al.* [24] used I4.0 technologies in the relationship between lean production (LP) and improvement in operational performance in Brazil. The reported I4.0 technologies are IoT, cloud manufacturing (CM), BD, automation and industrial robotics (AIR), additive manufacturing (AM), augmented reality (AR), simulation, and cybersecurity (CS) [14], [25]–[27]. This study aims to analyze the influence of the I4.0 technologies on Manufacturing strategies. The main research contributions are listed below.

- In defining I4.0 technologies in relation to MSOs, this research contributes to a deeper understanding of the fourth industrial revolution.
- This research empirically analyzes the relationship between I4.0 and MSOs in terms of MSOs’ improvement to gain market competitiveness.
- This research provides the appropriate selection of the I4.0 technologies for manufacturing organizations in order to counter global competition.

The rest of this research is organized as follows: Section II gives a background to manufacturing outputs and I4.0 technologies. Section III describes the research methodology used in this study to select experts, gather data, and identify the influential relationship between manufacturing outputs and I4.0 technologies. Section IV presents the results and discussions. Finally, Section V presents the conclusion and future work.

II. BACKGROUND

This section presents the MSOs and how they are measured. In addition, I4.0 technologies and how the adoption of these technologies affects the manufacturing capabilities were discussed in this section.

A. MANUFACTURING STRATEGIES OUTPUTS

MSOs including cost, quality, delivery, flexibility, performance, and innovativeness, also known as competitive priorities in the literature [8] will be considered in this study. Competitive priorities play a significant role in motivating the whole company to take advantage of its competitors [8]. The MSOs (competitive priorities) can be defined as follows.

1) COST

The ability to deliver lower overall costs, at market-competitive prices. The cost can be measured by employee training cost [28], cost per unit produced [29], and operating cost [30]. Additional cost measures such as employee training cost [28], cost per unit produced [29], and operating cost [31]. The cost is also measured by unit overhead cost, unit labor cost, product R&D cost, and unit material cost [32].

2) QUALITY

The ability to maintain a high level of customer satisfaction and to establish high standards, quality control, and supervision [3], [33]. It can be measured by defective

products [34], customer satisfaction [35], machine state condition monitoring [36], [37], and the number of customer complaints [35]. Other measures of quality include warranty claims [38], scrap rate [39], defective product [34], and customer satisfaction [35].

3) DELIVERY

The time between order collection and distribution to the customer. Also can be defined as the capability to provide shorter lead times in the supply chain including logistics, production, and design [40]. The delivery can be measured by on-time delivery, speed delivery, overall reliability, time flexibility, and reduced lead time [41].

4) PERFORMANCE

The features that allow the product to do things that other products cannot do [3]. Leong, Snyder, et al. [42] reported the performance measures are the number of standard features, number of advanced features, product resale price, number of engineering changes, and mean time between failures.

5) FLEXIBILITY

The ability to offer custom goods and services and to increase or decrease the number of existing products to adapt rapidly to the needs of customers [3], [40]. It can be measured

by product customization [43], product mix flexibility [44], process flexibility [44], and volume flexibility [45]. Further flexibility measures include product customization [43], product mix flexibility [44], process flexibility [45], volume flexibility [46], and machine flexibility [45]. The flexibility is also measured by product features, and product varieties [32].

6) INNOVATIVENESS

The capability to introduce new products rapidly or to change the design of existing products [3]. Some innovativeness measures such as the number of new products introduced each year, lead time to design new products, lead time to prepare customer drawings, level of R&D investment, and consistency of R&D investment over time have been reported by [47].

B. INDUSTRY 4.0 TECHNOLOGIES

I4.0 is creating a new industrial field that will depend on data acquisition and sharing along the entire supply chain. I4.0 encompasses “new technologies that integrate the physical, digital, and biological worlds and have an impact on all disciplines, economies, and industries.” These technologies have the potential to link billions of more people to the internet and significantly increase commercial and organizational efficiency. According to the reported studies [8], [22], [48]–[51],

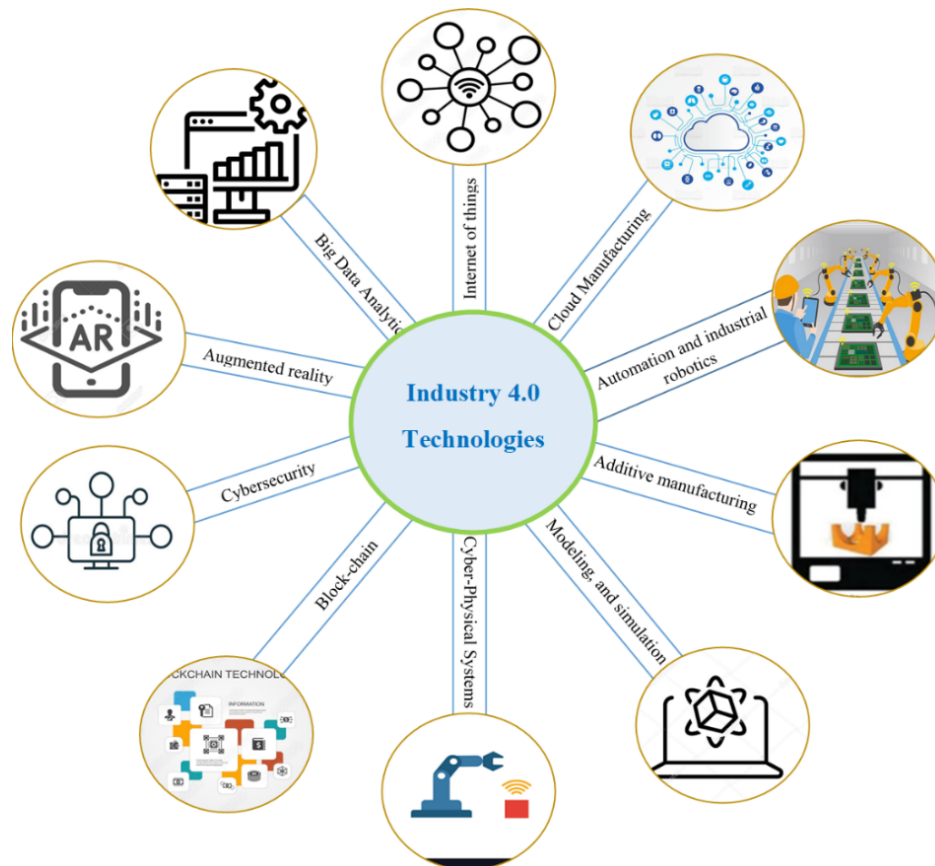


FIGURE 1. Industry 4.0 technologies.

the I4.0 technologies are the IoT, CM, BD, AR, AIR, AM, modeling and simulation (MS), CPS, CS, and block-chain (BC) as shown in Figure 1.

1) INTERNET OF THINGS

IoT allows physical things to communicate with each other as well as share information and coordinate decisions [52]. In the context of I4.0, the IoT is generally referred to as the industrial internet of things (IIoT), which deals with the industrial application of the IoT [53]. The IoT is widely used, for example, in transportation, health care, and facilities [54]. It forms Thing to-Thing and human to the human network. IoT applications in manufacturing systems result in a reduction in product recall size, earlier identification of defective products, change of product design, and improved performance [55].

2) CLOUD MANUFACTURING

CM may be defined as “a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable manufacturing resources (e.g., manufacturing software tools, manufacturing equipment, and manufacturing capabilities) that can be rapidly provisioned and released with minimal management effort or service provider interaction [56]. CM involves transforming manufacturing resources (hardware and software) and capabilities into the cloud as cloud services and providing some sort of service control and management capabilities to manage manufacturing resources, processes, operations, and transactions over the Internet [57]. CM offers cloud-based applications, a web-based management dashboard, and cloud-based collaboration to manufacturers. CM enables distributed manufacturing resources to be integrated and a shared and scalable platform to be built across geographically distributed manufacturing sites and services [57]. In CM, distributed resources are centrally controlled and packaged into cloud services that can be employed in accordance with the clients’ requirements [56]. All stages of a product life cycle (e.g., product design, manufacturing, testing, and management) can be requested by cloud users [56]. CM computing increases the performance, product quality, and capacity of manufacturers to meet consumers’ changing demands [58].

3) BIG DATA ANALYTICS

BD is defined as large sets of heterogeneous data, coming from various sources, having different formats, and flowing in real-time [59]. BD technologies demonstrate a new generation of technologies and systems that enable organizations to gain economic benefit through the discovery, processing, and analysis of very large volumes of a wide variety of data [60]. Companies are now moving towards big data analytics to identify meaningful patterns and trends of big data sources to make immediate decisions and maintain competitiveness [61]. The use of big data offers a commercial advantage through the opportunity to generate value-added [62]. Big data has influenced production and led to

more efficient production, better quality, and more personalized goods [63].

4) AUTOMATION AND INDUSTRIAL ROBOTICS

AIR is clearly on the rise, particularly in manufacturing and, increasingly, in everyday environments [22]. Advanced robot technology will increasingly be required to support high-growth industries (electronics, food, logistics, and life sciences) and emerging manufacturing processes (gluing, coating, laser-based processes, precision assembly, and fiber material processing), as well as to comply with sustainability regulations. Industrial robotics and automation offer numerous benefits, including decreased part cycle time, decreased defect rate, increased quality, and reliability, decreased waste, and improved floor space utilization, making them indispensable to world-class manufacturers [64].

5) ADDITIVE MANUFACTURING

AM is defined as the joining of materials to create objects from three-dimensional (3D) model data, typically layer by layer [64], [65]. AM techniques are increasingly developing and take highly viable applications into the real industry [66]. Am technology was originally digital, because it was produced after the advent of personal computers, and its manufacturing process depends on the use and processing of digital data. the digital data stream flows out of the three-dimensional virtual prototype of the product by completing the building of physical objects [59] I4.0 brings customers and suppliers closer together and establishes a standard way for clients to communicate production orders directly in real-time to their manufacturing partners using additive manufacturing. [67]. Additive manufacturing can achieve manufacturing outputs such as time reduction, supply chain reductions, and rapid prototyping [68], [69].

6) AUGMENTED REALITY

AR is considered as a highly promising technology to visualize computer graphics in real environments [70]. AR technologies can be found in a variety of areas, including entertainment, marketing, tourism, surgery, transportation, manufacturing, and servicing [71]. The purpose of AR is to enhance human performance by providing the knowledge required for a particular task [72]. The development of technology has brought it possible to simulate, assist, and improve industrial processes before they are carried out [59]. According to industry reports, AR has been used by modern manufacturers to facilitate workforce preparation and simplify maintenance as well as quality control [73]

7) MODELING AND SIMULATION

The purpose of modeling and simulation techniques is to ease a manufacturing system’s design, implementation, testing, and control in real-time [74]. Due to the complexity of I4.0 and the challenges associated with its implementation and coordination, simulation can be used to facilitate the usage of all components of such systems, such as robots, information

technology, manufacturing, and logistics [59]. MS technology can be used to solve manufacturing industry challenges, deal with complex systems, solve uncertain problems, and problems that cannot be solved by conventional mathematical models [75], [76]. MS technologies are being used to simulate and model processes and products (for example, finite element analysis (FEA)), production lines, workstations, and internal logistics (for example, discrete event simulation (DES)), and enterprises, supply chains, and networks (for example, system dynamics (SD) and agent-based simulation (ABS)) [59]. Smart factories employ MS to take advantage of real-time data to represent the physical environment of a virtual model [77]. Modeling and simulation help to minimize costs, reduce development cycles, and improve the quality of products [78].

8) CYBER-PHYSICAL SYSTEMS

CPS are “systems of cooperating computational entities that are intimately connected to the real world and its ongoing activities, simultaneously delivering and utilizing data-access and data-processing services available on the internet” [79]. Computer-based algorithms monitor and control CPS, which is strongly integrated with its users (objects, humans, and machines) via the internet [22]. Distributed manufacturing systems enabled by CPS provide many promising capabilities in terms of effective and flexible manufacturing [80].

9) CYBERSECURITY

CS is a new concept for high information security that is expanded to include IIoT environments with the word cyber. CS technologies include threat identification and detection, as well as data loss prevention. CS is a technology that senses, defends, and responds to attacks [81]. Such attacks could delay the launching of a product, result in a ruin of the customer confidence or the cost of warranty [82]. CS is a core component of, considering that all internet-based companies are at risk of being attacked. Information and data protection is essential to the growth of the industry. Data must be accessible only to approved persons. A large number of interconnected items in I4.0 need safe, secure, and accurate communication so that all decisions and actions taken are based on reliable and properly authorized information [83].

10) BLOCK-CHAIN

BC is a platform for a modern decentralized and transparent transaction system in industries and businesses. Durability, transparency, immutability, traceability, and process integrity are the key characteristics of BC technology [84]–[86]. Industry 4.0 develops on a foundation of automation and block-chain technology, which may be utilized as a ledger to facilitate trustworthy and autonomous interactions between the numerous components of smart factories, suppliers, and even customers in the supply chain [22]. CPS includes smart elements or machines with augmented intelligence and the ability to communicate with each other to make part of planning, unique or non-repetitive tasks. In addition to controlling

the needs of work-pieces, these smart elements can adjust manufacturing strategies for optimal output and choose (if an existing strategy is already in place) or discover a new strategy on their own [48]. BC application can be used for any kind of digital knowledge transfer. BC has been adopted in various applications including design, manufacturing, finance, supply chain, and social [84].

III. RESEARCH METHODOLOGY

This study adopted a methodology in a similar way to that in [87]. In this study, experts were selected in terms of knowledge and experience level [87]. Experts with a minimum professional experience of ten years, as suggested by [88], in academia, industry, or both were considered to be acceptable [88]. Experts should have deep knowledge of manufacturing strategies with special emphasis on manufacturing strategy competitive outputs. Besides that, experts should be familiar with I4.0 technologies either using practice or theory, as recommended by [21]. Furthermore, experts were individually interviewed to clarify the research and for those experts who cannot access it due to their location, an online interview was conducted. The authors began by identifying eighteen experts who met the aforementioned criteria. An email was sent to them first to explain the purpose of the study and to confirm their willingness to participate. Eleven of them responded positively to the email. After matching the research criterion, six experts matched this research criterion.

For the MSOs, we adopted the six MSOs used in [89]–[91] and denoted here by O_i ($i = 1 \dots 6$). Proof of their utilization is substantial (e.g. [3], [91], [92]). Regarding the I4.0 technologies, the ten technologies T_j ($j = 1 \dots 10$) described in section II.2 were adopted based on the reported studies in [22], [48], [49]. The experts were then asked: ‘what is the strength of the relationship between the MSOs O_i and the I4.0 technology T_j ?’ Responses (res_{ijk}) were given on a ten-point continuous scale (from 0 to 9), where 0 indicated ‘no relationship’ and 9 indicated ‘maximum strength’ of O_i - T_j relationship. The relationship (Rel_{ij}) was expressed as following:

$$Rel_{ij} = \sum_{k=1}^n res_{ijk} * w_k, \quad k = 1, 2, \dots, n \quad (1)$$

where, res_{ijk} represent the k expert’s response on the relationship between O_i and T_j , w_k represents the k expert’s opinion weight, and n represents the number of experts. It should be noted that the expert weights were considered as a function of years of experience and it was calculated as follows in equation 2 [87]:

$$w_k = \frac{\text{Expert's } k \text{ years of experience}}{\sum_{i=1}^n \text{Expert's } i \text{ years of experience}} \quad (2)$$

The relationship values Rel_{ij} were included in the matrix M presented in Table 1, which includes six O_i (rows) and ten T_j (columns). The M matrix represents the overall scores for the relationship strengths, as illustrated in Table 1. Moreover,

the sum of the relationship values of each row and column was added to the M , which provides the total potential for the integration of each manufacturing strategy output and technology, respectively. In other words, a higher total value for a specified output O_i is an output that can be more sensitive to the I4.0 technologies implementation. Higher total values for T_j , meanwhile, reflect the overall prevalence that such technology may have when improving manufacturing outputs. The significant relationship between the manufacturing output O_i and the I4.0 technologies T_j was determined based on z-score, differentiation index z_{ij} [87]. The z_{ij} represents how many standard deviations each individual value of Rel_{ij} are away from the average value of the corresponding O_i . The resulted standardized scores z_{ij} are included in the M matrix as shown in Table 1. Values greater than or equal to 1.0 were considered to indicate a significant relationship between O_i and T_j and thus priority was given to T_j technology for improving O_i .

IV. RESULTS AND DISCUSSIONS

The relative relationships and differentiation indices consolidated results are shown in Table 1. Table 1 reveals that the performance manufacturing output is considered to have the highest potential for integration with different I4.0 technologies with a total score of 70.59, followed by flexibility, innovativeness, and quality, which have a total score of 67.90, 65.30, and 62.39, respectively. Performance has the most relationship with IoT, automation and industrial robotics, and cyber-physical systems technologies. The performance means that, the features of the product and how much the features allow the product to do things that other products cannot do [3]. Industry 4.0 technologies will boost the performance of a company significantly [93]. Regarding the most I4.0 technologies that have the most impact on MSOs, Table 2 shows that the automation and industrial robotics I4.0 technology has the highest total score of 45.23 across all the MSOs, followed by cyber-physical systems, the IoT, and big

TABLE 1. Relationships between MSOs and I4.0 technologies.

OUTPUT (O_i)		I4.0 TECHNOLOGIES (T_j)										TOTAL SCORE
		IOT	CM	BD	AIR	AM	AR	MS	CPS	CS	BC	
COST	Rel_{ij}	5.64	5.43	6.74	6.20	6.36	4.66	6.86	5.57	4.66	4.60	56.71
	z_{ij}	-0.04	-0.30	1.32*	0.65	0.85	-1.25	1.46	-0.12	-1.25	-1.32	
QUALITY	Rel_{ij}	7.14	6.14	7.53	8.11	6.21	5.41	6.67	7.06	3.27	4.83	62.39
	z_{ij}	0.67	-0.07	0.95	1.39	-0.02	-0.61	0.32	0.60	-2.19	-1.04	
DELIVERY	Rel_{ij}	7.59	5.69	7.69	7.47	5.50	3.21	4.57	6.83	3.43	3.47	55.44
	z_{ij}	1.19	0.08	1.25	1.13	-0.03	-1.36	-0.57	0.75	-1.24	-1.21	
FLEXIBILITY	Rel_{ij}	7.54	7.41	7.41	8.41	8.79	5.61	6.13	8.61	3.74	4.23	67.90
	z_{ij}	0.44	0.37	0.37	0.95	1.17	-0.69	-0.39	1.07	-1.79	-1.51	
PERFORMANCE	Rel_{ij}	8.40	7.43	7.84	8.40	6.34	6.67	7.26	8.46	4.41	5.37	70.59
	z_{ij}	1.03	0.29	0.60	1.03	-0.55	-0.30	0.15	1.08	-2.04	-1.30	
INNOVATIVENESS	Rel_{ij}	8.00	7.44	6.84	6.63	8.34	6.83	5.96	8.17	2.97	4.11	65.30
	z_{ij}	0.88	0.55	0.19	0.06	1.08	0.18	-0.34	0.98	-2.13	-1.44	
TOTAL SCORE		44.31	39.54	44.06	45.23	41.54	32.40	37.44	44.70	22.49	26.61	

*The most important relationships (≥ 1.0) between I4.0 technologies and selections for MSOs are referred to in bold numbers.

TABLE 2. The proposition of output-technology selection.

MSOs	Most importantly related I4.0 technologies
Cost	Big data analytics
	Modeling and simulation
Quality	Automation and industrial robotics
Delivery	Internet of things
	Big data analytics
	Automation and industrial robotics
Flexibility	Additive manufacturing
	Cyber-physical systems
Performance	Internet of things
	Automation and industrial robotics
	Cyber-physical systems
Innovativeness	Additive manufacturing

data, which have a total score of 44.70, 44.31, and 44.06, respectively. This indicates the significance of automation and industrial robotics, cyber-physical systems, the internet of things, and big data in Industry 4.0.

It should be noted that while the delivery output had lower overall scores than Performance despite that it has three significant relationships with I4.0 technologies.

The cost can be defined as the cost of material, overhead labor, and other resources used to manufacture a product [3] which should be able to offer competitive prices on the market for lower total costs [40], [94]. BD gains economic benefit through the discovery, processing, and analysis of very large volumes of a wide variety of data [60]. Manufacturers would use big data to minimize costs [95]. MS can simplify and encourage the design, implementation, tests, and running of a live operation of a manufacturing system [74]. Simulation technology holds great potential to reduce manufacturing costs [85], [96]. The quality is to maintain a high level of customer satisfaction and to establish high standards, quality control, and supervision of production [3], [33]. Over the last few years, the importance of automation and industrial robotics technology in manufacturing has increased significantly. This technology showed the ability to improve quality [97], [98]. The delivery is the time between order collection and distribution to the customer to provide shorter lead times in the supply chain including logistics, production, and design [40]. By implementing the IoT, distribution or delivery becomes an integral part of e-commerce [99]. IoT improves the delivery to ensure timely and efficient delivery to customers [100]. BD technology is used to pre-process and analyze the manufacturing data output, to reveal the hidden rules and relationships between them. With the assistance of the relationships identified, managers are provided with better decision-making for the delivery time [101]. By applying AIR, the delivery has been improved between order collection and distribution to the customer [102]. Flexibility is the ability to offer custom goods and to increase or decrease the number of products and the volume to adapt rapidly to the needs of customers [3], [40], [45]. The employment of AM can be seen as a proactive flexibility strategy [103]. It allows an intensified customer orientation with individualized products. The employment of AM technology enables companies to develop product varieties at very limited marginal costs [104]. The change of this cost may lead, in terms of product individualization of the consumers, to put pressure on competitors in the market [104]. Modern distributed manufacturing within I4.0, assisted by CPS provides many promising capabilities for productive and flexible manufacturing [80]. The performance of manufacturing systems is affected by both the behavior of independent machines and by their interactions [105]. Investing in I4.0 technologies such as the IoT and CPS to manage system complexity enables businesses to boost production performance and acquire a competitive edge in the global market [106]. CPS tightly integrates manufacturing enterprises in the physical world

with virtual enterprises in cyberspace. AIR has a significant impact on manufacturing performance [107]. Innovativeness is the capability to introduce new products rapidly, to change the design of existing products [3], and to introduce engineering changes [42]. AM is emerging as a key technology for enabling innovative product development [108].

V. CONCLUSION

This research aimed to analyze the influence of I4.0 technologies on manufacturing strategies. This research's contribution is relevant from both a practical and theoretical perspective. It contributes to a deeper perception of the fourth industrial revolution by identifying and defining I4.0 technologies, as well as identifying and defining the MSOs. The influences of I4.0 technologies on MSOs were quantitatively investigated, consolidating the understanding of the relationship between I4.0 technologies and MSOs. First, in theoretical terms, this study has provided theoretical arguments for empirically analyzing the relationship between I4.0 and MSOs in terms of MSOs' improvement to gain market competitiveness. More precisely, the research findings suggest that manufacturing organizations should select the appropriate I4.0 technologies in order to counter global competition. A practical perspective on selecting I4.0 technologies for manufacturing strategies was provided. The selection enables companies to fully benefit from implementing these technologies into well-designed and well-established processes (either at the strategic or operational level). Such technologies selection may allow superior performance and achieve competitiveness. Moreover, this research helps companies to make a shift from traditional manufacturing to smart manufacturing, emphasizing how these technologies can play a significant role in motivating the company to take advantage of its competitors. Based on the expert's opinions on the relationship between MSOs and I4.0 technologies, several conclusions have been drawn as follows:

- Regarding the MSOs, the performance was considered to have the highest potential for integration with different I4.0 technologies. It shows an utmost relationship with IoT, automation and industrial robotics, and cyber-physical systems technologies.
- Regarding the I4.0 technologies, automation and industrial robotics is the most influential I4.0 technology on manufacturing outputs due to their highest total score, followed by cyber-physical systems, the internet of things, and big data analytics.
- It was found that the cost is significantly affected by big data, modeling, and simulation.
- Results revealed that quality has a significant relationship with automation and industrial robotics technology.
- It was found that the delivery has a noteworthy relationship with the internet of things, big data, and, automation and industrial robotics.
- The results revealed that flexibility could be significantly improved with additive manufacturing and cyber-physical systems.

- Augmented reality, cybersecurity, and blockchain technologies are considered the least influential in relation to MSOs

We are limited in our work to selecting the appropriate I4.0 technologies in order to increase market competitiveness. Therefore, future research can focus on developing various scenarios and addressing the opportunities and difficulties associated with implementing the developed scenarios.

ACKNOWLEDGMENT

The authors are grateful to the Raytheon Chair for Systems Engineering for funding.

AUTHOR CONTRIBUTIONS

F.M.A.: Conceptualization, Data curation, Investigation, Methodology, Visualization, and writing—original draft, writing—review and editing; M.S.: Conceptualization, Data curation, Investigation, Methodology, Visualization, Writing—original draft, Writing—review and editing. A.M.A.-A.: Conceptualization, Funding acquisition, Investigation, Resources, Supervision, and writing—review and editing; S.A.: Supervision, and writing—review and editing. All authors have read and agreed to the published version of the manuscript.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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