Industry 4.0 Implementation Drivers in Manufacturing Companies in Algeria: A Structural Analysis via ISM Method

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ABSTRACT
The new industrial era is characterised by an incredible speed of development, in addition to fierce competition, which prompts companies to quickly adopt Industry 4.0 to maintain their position in the future industrial market. This paper aims to identify the main drivers that facilitate the implementation of Industry 4.0 in manufacturing companies in Algeria. The Interpretative Structural Modelling (ISM) method and the Cross-Impact Matrix Multiplication Applied to a Ranking (MICMAC) method were used. The ISM-MICMAC method aims to determine interrelationships and levels of influence between different factors. This allows the identification of the key drivers for the success of Industry 4.0 implementation in manufacturing companies. The results showed that awareness of the concept of Industry 4.0, research and development, support and vision of senior management, and society acceptance of the technology, in addition to cooperation and openness, are the most important drivers that contribute to the success of the implementation of Industry 4.0. Moreover, improving production, maintenance efficiency, and improving mass customisation also play a crucial role in the adoption of Industry 4.0 in manufacturing companies.

KEYWORDS: *Algeria, digital technologies, Industry 4.0, Interpretative Structural Modelling (ISM), manufacturing.*

JEL CLASSIFICATION: *O55, L86, L60, O33, O14.*

1. INTRODUCTION

Industrial revolutions have always constituted qualitative shifts in the industry and had a profound impact on manufacturing techniques. The first industrial revolution revolved around the shift from individual manufacturing to factories and the expansion of mass production, in addition to the diffusion of inventions in various manufacturing processes (Michelsen, 2020). While the core of the second industrial revolution was the shift from agricultural society to industrial society, where machinery and factory production were heavily relied upon (Mohajan, 2019). Thereafter, the third industrial revolution emerged, characterised by the development of information technology, the emergence of computers and chips, as well as the automation of manufacturing processes (Greenwood, 1999). Then, the fourth industrial revolution appeared, known as “Industry 4.0”, marked by technological breakthroughs that allow the integration of the physical world and the digital world. The term "Industry 4.0" first appeared in Germany at the Hannover Fair in 2011, to express a forward-looking vision for the future of manufacturing in Germany (Liebrecht et al., 2021). Later, similar initiatives emerged in other countries, such as “China 2025” and “La nouvelle France”.

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Industry 4.0 can be defined as a new industrial model that aims to move to smart manufacturing, as it integrates advanced technologies into manufacturing such as IoT (Internet of Things), big data, CPS (Cyber Physical Systems), and cloud computing (Hoyer et al., 2020). However, it can be said that Industry 4.0 has an impact beyond just manufacturing, as it extends to other aspects related to daily life, such as education and health (Dikhanbayeva et al., 2021).

The integration of advanced technologies in manufacturing processes enhances decision-making, improves production quality, and facilitates communication among stakeholders, including partners, suppliers, and customers (Aripin et al., 2019). Moreover, Industry 4.0 model is characterised by improved human-machine interaction (Aripin et al., 2019; Hoyer et al., 2020).

Furthermore, the Industry 4.0 model has an impact on the three pillars of sustainability. The economic impact may be the most prominent due to the opportunities provided by Industry 4.0 such as achieving more profits, expanding into new markets, innovating new products, and creating new business models. Also, with regard to environmental sustainability, Industry 4.0 model contributes to improving the efficiency of energy consumption and reducing manufacturing waste, in addition to reducing pollution (Bai et al., 2020; Kumar et al., 2022; Rojko, 2017; Saravanan et al., 2022). Concerning social sustainability, Industry 4.0 model provides opportunities that include new jobs (Pereira & Romero, 2017), mass customisation of products (Ghadimi et al., 2022), and gaining a deeper insight into the desires and expectations of customers (Sony & Naik, 2020).

On the other hand, the implementation of Industry 4.0 at the corporate level can be challenging due to potential obstacles and problems, such as data security and privacy, insufficient environmental regulations, lack of a clear strategy, high implementation costs, as well as social problems mainly related to the less skilled workforce (Kumar et al., 2022). However, companies are seeking to implement it in order to take advantage of this new industrial model.

This study aims to identify the most important driving factors of the implementation of Industry 4.0 model in manufacturing companies in Algeria. Therefore, we pose the following problem:

What are the most important driving factors for the implementation of Industry 4.0 in manufacturing companies in Algeria?

In order to achieve the purpose of our study, we rely on an ISM-MICMAC method as it allows identifying the most significant factors for implementing Industry 4.0 in companies from Algeria.

The rest of this paper is structured as follows: section 2 presents a review of the literature that discussed Industry 4.0 concept and the impact of the implementation of Industry 4.0 in companies, as well as Industry 4.0 implementation driving factors. The methodology of the structural analysis via the ISM-MICMAC is explained in section 3. In section 4, results and discussion were reported. Finally, conclusion and some policy implications, as well as future research directions.

2. LITERATURE REVIEW

The extant literature has discussed the implementation of Industry 4.0 in manufacturing companies from several points of view. Many studies have focused on the concept of Industry 4.0, as well as its benefits for manufacturing companies. On the other hand, the literature has discussed the drivers for implementing Industry 4.0 in manufacturing companies.

2.1 Industry 4.0

The fourth industrial revolution, known as Industry 4.0, is a new industrial model that focuses on integrating advanced technologies into manufacturing, including cyber physical systems, Internet of things, big data and cloud computing, as well as virtual and augmented reality, and robotics (Ghadimi et al., 2022). The term of Industry 4.0 was first introduced at the 2011 Hannover fair in Germany. It represented a high-tech strategy for the development of manufacturing in the country (Dikhanbayeva et al., 2021; Huang et al., 2019; Liebrecht et al., 2021). Industry 4.0 can be defined as an advanced process that integrates the latest developments in information technology (IT) into manufacturing (Devi K et al., 2021). This concept is linked to other concepts such as smart manufacturing and smart factories that rely on advanced technologies (Da Silva et al., 2020). According to Aripin et al. (2019), Industry 4.0 is characterised by the increasing reliance on information technology and automation within the manufacturing environment. In the same vein, this industrial revolution encompasses the automation and digitisation of manufacturing environments, as well as new value chains that integrate operators, physical objects, manufacturing lines, machines, and processes (Devi K et al., 2021). Horváth & Szabó (2019) pointed out that five basic elements characterise Industry 4.0, consisting of digitisation, improvement and customisation of production; automation and adaptation; human-machine interaction; value-added services and stores; and data exchange and automatic communication. Moreover, Industry 4.0 is fundamentally aimed at integrating and automating manufacturing systems. It seeks to enhance the flows across the entire value chain, thereby developing more efficient relationships between suppliers, producers, and customers (Oliveira-Dias et al., 2022; Pozzi et al., 2023). Additionally, Industry 4.0 focuses on improving production processes to become more flexible, independent, and precise (Da Silva et al., 2020). Furthermore, Da Silva et al. (2020) indicated that Industry 4.0 has six principles which are virtualisation, interoperability, decentralisation, real-time capability, service orientation, and modularisation. In the same context, Hoyer et al. (2020) highlighted that the complexity of Industry 4.0 requires a comprehensive understanding for effective implementation. Hence, companies must understand this concept to align strategies with the basic elements of this industrial model in accordance with their essential strategies. Additionally, Yu and Schweisfurth (2020) stated that companies with a high level of automation and a wide range of products are more likely to implement Industry 4.0.

On the other hand, Majumdar et al. (2021) argued that there is still disagreement about the correct definition of Industry 4.0, as most of its core technologies are still under development. Also, Sony and Naik (2020) believe that the concept of Industry 4.0 extends beyond transformation in manufacturing or supply chain. It covers every aspect of a company, sector, or society. Similarly, Dikhanbayeva et al. (2021) pointed out that Industry 4.0 concept addresses issues related to social, environmental, and economic sustainability. Thus, concepts such as Health 4.0 and Education 4.0 emerged. Nevertheless, Da Silva et al. (2020) stated that there could be negative implications for Industry 4.0, such as loss of jobs or switching to other activities due to inability to compete, in addition to insufficient qualifications of workers.

Moreover, the ambiguous returns of Industry 4.0 contrast with the significant investments needed to implement it. In a similar vein, V. Kumar et al. (2022) pointed out that the implementation of Industry 4.0 faces some challenges such as data security and privacy, insufficient environmental regulations, lack of a clear strategy, as well as social problems mainly related to the less skilled workforce. In addition, Vuksanović Herceg et al. (2020) added that the lack of competency of managers, huge implementation costs, resistance to change, lack of standards in technology and processes, and the inappropriate organisational structure for implementing Industry 4.0 are essential obstacles to implementing Industry 4.0. However, it should be noted that there are many positive implications for Industry 4.0. For instance, Industry 4.0 can play a major role in improving manufacturing sustainability by enhancing the innovation process, efficiency, productivity, and production quality, as well as reducing costs and improving profitability (El Baz et al., 2022).

2.2 Industry 4.0 implementation key drivers

The implementation of Industry 4.0 in companies is still a subject of discussion regarding the methods and measures of implementation, as well as the expected results. Some companies are still lagging behind in adopting Industry 4.0 due to the ambiguity of its results. However, Industry 4.0 can be said to have gained significant popularity in the last decade. Many companies have rushed to adopt this industrial model, driven by numerous factors that have accelerated its implementation in companies. These driving factors can be classified into internal factors and external factors.

2.2.1 Internal factors

In order to implement Industry 4.0 in manufacturing companies, several driving factors must be included in the process. These factors can be classified according to their nature. Firstly, managerial factors, where perhaps the most important driving factor is awareness of Industry 4.0 (Da Silva et al., 2020; Stentoft et al., 2021; Türkeș et al., 2019; Wong & Kee, 2022). The knowledge of this complex model enables a company to align its strategies with the aim of moving to Industry 4.0. This brings us to the second point, which is management vision (Huang et al., 2019; Majumdar et al., 2021). Top management awareness of the importance of Industry 4.0 makes its implementation a crucial aspect of long-term strategy. Similarly, management's support and desire to transition to Industry 4.0 are vital in the implementation process (El Baz et al., 2022; Kumar et al., 2022; Majumdar et al., 2021; Müller et al., 2018; Sony & Naik, 2020; Türkeș et al., 2019). It contributes to utilising all capabilities and motivating partners, employees, and customers to participate in Industry 4.0 implementation. Furthermore, technological culture within companies contributes to reducing resistance to transitioning to Industry 4.0 (Dikhanbayeva et al., 2021). This is attributable to the awareness of managers and employees about the significance of technology. Second, strategic factors, which are factors related to companies' long-term and short-term strategy. Among these factors is flexible strategic planning (Liebrecht et al., 2021). It plays an important role in dealing effectively with unexpected challenges during the transition to the Industry 4.0 model. Moreover, the adoption of advanced technologies in companies could contribute to accelerating the implementation of Industry 4.0 (Da Silva et al., 2020; Dikhanbayeva et al., 2021; Horváth & Szabó, 2019; Stentoft et al., 2021; Türkeș et al., 2019; Vimal et al., 2022). This is due to advanced technologies being the main pillars of this industrial model. In addition, innovative business models are essential drivers of Industry 4.0 implementation (Ghadge et al., 2020; Müller et al., 2018). With their flexibility and adaptability, they contribute to the effective utilisation of opportunities offered by technological developments. Furthermore, IT infrastructure is a key element in the transition to Industry 4.0 (Da Silva et al., 2020; Dikhanbayeva et al., 2021; El Baz et al., 2022; Rezqianita & Ardi, 2020). Adequate IT infrastructure enables the integration of advanced technologies into a reliable and efficient ecosystem, mainly by improving connectivity and enhancing reliability. Third, there are driving factors for implementing Industry 4.0 related to production, warehousing, and logistics operations. Perhaps the most prominent of these drivers is the improvement of production efficiency (Aripin et al., 2019; Devi K et al., 2021; Pozzi et al., 2023; Vimal et al., 2022; Vuksanović Herceg et al., 2020), which aims at more efficient resource utilisation. Consequently, leading to the enhancement of sustainable production. In addition, reducing production costs is a crucial driving factor in implementing Industry 4.0 (Aripin et al., 2019; El Baz et al., 2022; Stentoft et al., 2021; Yu & Schweisfurth, 2020). This contributes to enhance competitiveness and fosters economic sustainability. Moreover, enhancing productivity is considered as one of the most important reasons for the transition to Industry 4.0 (Horváth & Szabó, 2019; Kamble et al., 2018). It has an impact on enhancing competitiveness and improving companies' market position. Furthermore, enhancing production quality is considered a key driver in the transition to Industry 4.0 (Aripin et al., 2019; Müller et al., 2018; Vimal et al., 2022; Vuksanović Herceg et al., 2020). This directly aids in maximising profits and reinforcing the corporate brand. Devi K et al. (2021) also noted that the mass customisation of products is a significant driver for companies to adopt Industry 4.0. It aims to meet the increasing demand for personalised products and services, as well as benefit from new income opportunities. Similarly, preventive maintenance emerges as an important driver for adopting Industry 4.0 technologies in companies (Horváth & Szabó, 2019), aiming to prevent major breakdowns and minimise production downtime.

2.2.2 External factors

As for external factors, these are primarily associated with the pillars of sustainability. Firstly, considering social factors, employee skills are crucial in driving the implementation of Industry 4.0 in companies (Huang et al., 2019; Majumdar et al., 2021; Sony & Naik, 2020; Stentoft et al., 2021; Türkeş et al., 2019). This is because highly skilled employees are more qualified to manage advanced technologies. Moreover, ensuring a safe work environment stands as an important driver for implementing Industry 4.0 (Müller et al., 2018; Verma & Venkatesan, 2022). It fosters productivity and job satisfaction, ultimately reflecting positively on the overall performance of companies. Also, according to Kamble et al. (2018), one of the most important social motivations for implementing Industry 4.0 is providing new job opportunities with high and competitive salaries. In addition, meeting customer expectations represents an important driver for the shift to Industry 4.0 (Stentoft et al., 2021; Vuksanović Herceg et al., 2020; Wong & Kee, 2022). This is due to the key role of modern technologies in enhancing the services provided and streamlining the product customisation process. Furthermore, society's acceptance of technology motivates companies to adopt the Industry 4.0 model as society becomes ready to move towards the new industrial era (Sony & Naik, 2020). Secondly, with regard to economic factors, Vimal et al. (2022) stated that maximising profitability is one of the most important economic drivers for implementing Industry 4.0. This is due to its crucial role in enhancing the economic sustainability of companies and improving the well-being of stakeholders. Along the same lines, enhancing competitiveness is a critical driver for adopting Industry 4.0 technologies (El Baz et al., 2022; Horváth & Szabó, 2019; Hoyer et al., 2020; Kamble et al., 2018; Pozzi et al., 2023; Vimal et al., 2022; Vuksanović Herceg et al., 2020). This approach is fundamentally aimed at improving a company's market position. Thirdly, environmental sustainability factors play an important role in driving the adoption of Industry 4.0, as they enhance customer and partner satisfaction. One of the key drivers is waste reduction (El Baz et al., 2022; Müller et al., 2018), which allows reducing pollution, preventing diseases, and protecting the planet for future generations. In a similar vein, reducing energy consumption constitutes an important motivation to move towards the Industry 4.0 model (Müller et al., 2018). This is imperative for rationalising the exploitation of resources and preserve them for future generations. Additionally, stringent environmental regulations in some countries can be a major driver for the adoption of Industry 4.0 (Ghadge et al., 2020; Kumar et al., 2022). Finally, there are other external factors that encourage the implementation of Industry 4.0. The most notable is government support such as various government initiatives and programs that aim to transition to the new industrial era and implement advanced technologies in various sectors (Dikhanbayeva et al., 2021; El Baz et al., 2022; Hoyer et al., 2020; Huang et al., 2019; Majumdar et al., 2021; Müller et al., 2018; Rezqianita & Ardi, 2020; Türkeș et al., 2019). Moreover, research and development (R&D) plays an essential role in the successful transition to the new industrial model (Liebrecht et al., 2021; Majumdar et al., 2021). It contributes to the introduction of advanced technologies and the integration of these technologies within companies. Furthermore, companies' openness and cooperation with each other as well as other institutions constitute an important factor in accelerating the transition to Industry 4.0 (Hoyer et al., 2020). This exchange of experiences and continuous cooperation in research and development facilitate the implementation of Industry 4.0 in companies.

Based on previous studies, it can be said that full awareness of the concept of Industry 4.0 model, senior management’s commitment to moving to Industry 4.0, and achieving sustainability are the most important drivers for implementing Industry 4.0. Therefore, it is useful to identify the key drivers for implementing Industry 4.0, as well as how these different drivers interact and influence each other. This understanding is crucial for decision-making and strategic planning within companies considering the adoption of Industry 4.0. In this paper, we will focus on identifying the main drivers that drive the successful implementation of Industry 4.0 in manufacturing companies in Algeria, in order to assist companies in effective strategic planning for transition to Industry 4.0.

3. DATA AND METHODOLOGY

The use of interpretative structural modelling aims to analyse and understand the relationships between the study variables, which allows to know the variables that are necessary to develop the system related with the problem posed.
In this study, we used the SmartISM tool, which was developed by Ahmad & Qahmash (2021). This tool is an end-to-end software tool for implementing ISM in an error-free, easy-to-use, and graphical manner. In addition to automating existing ISM procedures, the Warshall algorithm is used for transitivity calculations, and a new algorithm, a reduced conic matrix, has been introduced to convert the digraph into a final form with fewer edges while retaining the digraph structure and reachability of variables (Ahmad & Qahmash, 2021).

3.1 Interpretative Structural Modelling Methodology

Interpretive Structural Modelling is a directional structuring technique based on contextual relationships identified by field experts, using computerised transformation of the relationships into a pictorial model using matrix algebra and graph theory (Ahmad & Qahmash, 2021). Moreover, Kaur et al. (2019) define ISM as a mathematical technique proposed by Warfield (1974), which aims to identify the interrelationship between factors or attributes or enables the solution of a particular problem or issue. This methodology is characterised by being interpretive because it was used to extract the contextual relationship between different elements through group consultation or brainstorming sessions (Kaur et al., 2019). Furthermore, the ISM model builds a structural framework that represents the relationships between variables based on expert opinions as well as literature reviews. The ISM model contributes to an improved understanding of complex relationships in order to enhance research processes, enable researchers and decision-makers to make assessments and predictions about the behaviour of the system under study, and to improve the decision-making process. The ISM model is used in several fields, such as management, engineering, and social sciences. Many researchers have adopted ISM with MICMAC analysis in their research (P. Kumar et al., 2021). The motivation behind MICMAC is to analyse the dependence and momentum of each factor or element, which is determined in the construction of the conical matrix (Kaur et al., 2019). The steps to develop an ISM model are shown in Figure 1.

To implement the ISM methodology in our research, as illustrated in Figure1, we followed a systematic procedure. Initially, we identified relevant factors or variables associated with our study topic through a literature review and expert consultations. In this instance, the factors were related to the implementation of Industry 4.0 in manufacturing companies.
Following the identification of these key factors, we reached out to experts to assess the contextual relationships between them. The experts provided insights on the direction of relationships between each pair of factors, leading to the development of the Structural Self-Matrix (SSIM).

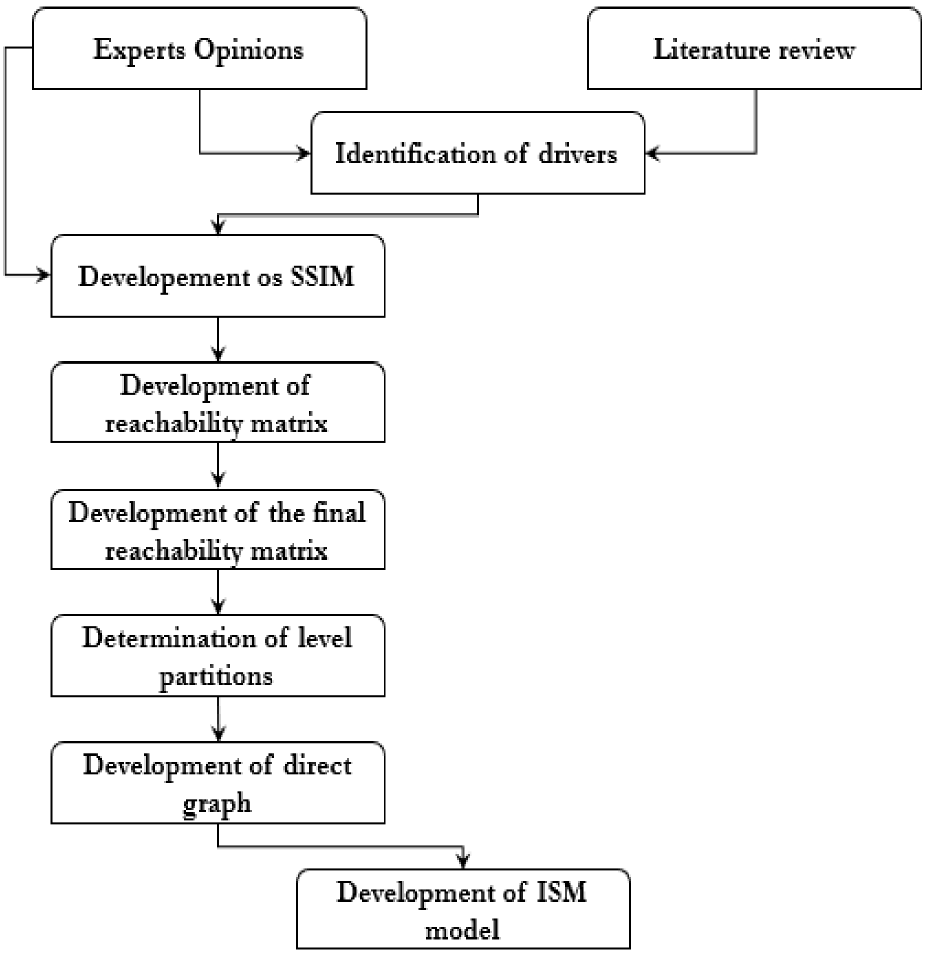

Figure 1. Interpretative Structural Modelling methodology
Source: Own elaboration

Subsequently, the Reachability Matrix (RM) is developed. In this stage, the qualitative assessments of contextual relationships gathered from SSIM were transformed into a binary format. This transformation was crucial in identifying direct relationships between the factors. The next step was the development of the Final Reachability Matrix (FRM). This stage enhanced the RM by incorporating the concept of transitivity, aiming to determine both direct and indirect relationships between factors.

Then, we defined Level Partitions (LP), where factors were classified into different hierarchical levels based on their influence and dependencies as delineated in the FRM.

The final stage of the ISM methodology is the development of the directed graph and the ISM model. This involved creating a visual representation of the hierarchical structure of the factors, along with the comprehensive ISM model. This model provides an organised overview of the key factors and their interconnections in the implementation of Industry 4.0. Finally, MICMAC analysis is used with the ISM model. Whereas, MICMAC analysis is considered a strategic tool to enhance understanding of the interdependencies and influence of identified variables in the ISM process. First, by directly ranking variables based on their direct impact within the system. This is followed by an indirect ranking, which takes into account the indirect effects of variables by repeatedly multiplying the matrix until it stabilises. The direct and indirect analysis in MICMAC, combined with the hierarchical structuring of the ISM, allows a more precise comprehension of the roles of variables and their overall importance within the system.

3.2 Determine the study variables

Determining the study variables is the first and most important step, as the variables are identified by reviewing the literature and expert opinions. In addition, these variables are defined based on their objectives and indicators.

There are other methods to determine the variables, such as the use of objective analysis, higher-level theory, contingency theory, content analysis, strengths, weaknesses, opportunities and threats (SWOT) analysis, engineering ideas workshop, and Delphi technique (Ahmad & Qahmash, 2021). However, it can be argued that the identification of variables through a combination of literature reviews and expert opinions offers several distinct advantages. This method ensures that the variables are relevant to the specific context of the study, offering a distinct advantage over alternative methodologies like objective analysis or content analysis. As the variables can be continually refined based on ongoing input from both literature and experts, enhancing the robustness of the research.

Additionally, expert opinions often provide practical insights that might not be captured in theoretical models such as higher-level theory or contingency theory. Furthermore, this approach is more flexible and less time-consuming compared to some other methods such as the Delphi technique, which may be more time-consuming. Table 1 shows the list of variables that were identified by the research team based on the literature review and expert opinions. An expanded list of variables related to the study was identified through the literature review, and after consulting experts, a list consisting of 17 variables was selected for the study.

Table 1. List of Industry 4.0 drivers

	Industry 4.0 Drivers	Literature support
1	Awareness of the concept of I4.0	(Da Silva et al., 2020; Stentoft et al., 2021; Türkeş et al., 2019; Wong & Kee, 2022)
2	Management vision	(Huang et al., 2019; Majumdar et al., 2021)
3	Management support and desire to move to I4.0	(El Baz et al., 2022; V. Kumar et al., 2022; Majumdar et al., 2021; Müller et al., 2018; Sony & Naik, 2020; Türkeş et al., 2019)
	Industry 4.0 Drivers	**Literature support**
4	Flexible strategies	(Liebrecht et al., 2021)
5	Adopting technological advancement	(Da Silva et al., 2020; Dikhanbayeva et al., 2021; Horváth & Szabó, 2019; Stentoft et al., 2021; Türkeş et al., 2019; Vimal et al., 2022)
6	Production efficiency	(Aripin et al., 2019; Devi K et al., 2021; Pozzi et al., 2023; Vimal et al., 2022; Vuksanović Herceg et al., 2020)
7	Productivity	(Horváth & Szabó, 2019; Kamble et al., 2018)
8	Mass customisation	(Devi K et al., 2021)
9	Preventive maintenance	(Horváth & Szabó, 2019)
10	Reducing production cost	(Aripin et al., 2019; El Baz et al., 2022; Stentoft et al., 2021; Yu & Schweisfurth, 2020)
11	Society's acceptance of technology	(Sony & Naik, 2020)
12	Improving working environment conditions	(Müller et al., 2018; Verma & Venkatesan, 2022)
13	Profitability	(Vimal et al., 2022)
14	Reduce energy consumption	(Müller et al., 2018)
15	Research and development	(Liebrecht et al., 2021; Majumdar et al., 2021)
16	Cooperation and openness	(Hoyer et al., 2020; Müller et al., 2018)
17	Optimize supply chain flows	(Ghadge et al., 2020; Sony & Naik, 2019)

Source: Own elaboration

4. RESULTS AND DISCUSSION

4.1 Determine the contextual relationship

After identifying the enabling variables or drivers related to the study, the relationship between the elements must be built bilaterally, which is a contextual relationship, as it depends on the definition of "influencing" or "reaching", that is, how one element influences other elements (Kaur et al., 2019).

4.2 Development of Structural Self-Interaction Matrix

In order to determine the relationship between two variables (i and j) and the direction of the relationship, experts were sought to determine the contextual relationships between the identified variables. The experts were mainly manufacturing managers, production managers, management controllers, and managers with 5 to more than 20 years of experience in various manufacturing industries. The following four symbols are used to indicate the direction associated with the relationship between two variables.
V => Variable i will affect barrier j,
A => Variable j will affect barrier i,
X => Variable i and j will affect each other,
O => Variable i and j are unrelated or will not influence each other.
Based on contextual relationships developed between the variables after considering responses from experts, SSIM is constructed using symbols V, A, X and O.

Table 2 represents the structural self-interaction matrix that was developed based on contextual relationships between variables.

Table 2. Structural Self-Interaction Matrix

Driver	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
1	O	V	X	O	O	O	V	O	O	O	O	O	V	V	V	V	
2	O	X	A	O	O	O	X	O	O	O	O	O	V	V	X		
3	O	X	A	O	O	O	X	O	O	O	O	O	V	V			
4	V	A	A	O	O	O	A	O	V	V	O	V	X				
5	V	A	A	O	O	O	A	O	V	V	V	V					
6	X	O	O	V	O	O	O	V	X	X	V						
7	O	O	O	A	V	A	O	A	O	O							
8	X	O	O	V	V	V	A	V	X								
9	X	O	O	V	O	O	O	V									
10	A	O	O	A	V	O	O										
11	O	X	A	O	O	O											
12	V	O	O	O	V												
13	O	O	O	A													
14	V	O	O														
15	O	V															
16	O																
17																	

Source: Own circulations using SmartISM

4.3 Initial Reachability Matrix (RM)

The reachability matrix defines the relationship between variables or elements in binary numbers: 0 and 1 (Kaur et al., 2019). This matrix is created by substituting the symbols used in SSIM (Table 2) into binary values 1 and 0 to obtain the initial reachability matrix. The symbols V, A, X, and O have been replaced with 1 or 0.

1- If the symbol (i, j) in SSIM is V, then replace it with 1 in the initial reachability matrix and the corresponding entry becomes (j, i) 0.

2 - If the symbol (i, j) in SSIM is A, then replace it with 0 in the initial reachability matrix and the corresponding entry (j, i) becomes 1.

3 - If the symbol (i, j) in SSIM is X, then replace (i, j) and (j, i) both entries as 1.

4 - If the symbol (i,j) in SSIM is O then replace both inputs (i,j) and (j,i) both inputs as 0.

After the process of replacing symbols with binary values 1 and 0 is over, the initial reachability matrix is formed, as shown in Table 3.

Table 3. Initial reachability matrix

Drivers	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**Driving power**
1	1	1	1	1	1	0	0	0	0	0	1	0	0	0	1	1	0	8
2	0	1	1	1	1	0	0	0	0	0	1	0	0	0	0	1	0	6
3	0	1	1	1	1	0	0	0	0	0	1	0	0	0	0	1	0	6
4	0	0	0	1	1	1	0	1	1	0	0	0	0	0	0	0	1	6
5	0	0	0	1	1	1	1	1	1	0	0	0	0	0	0	0	1	7
6	0	0	0	0	0	1	1	1	1	1	0	0	0	1	0	0	1	7
7	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	2
8	0	0	0	0	0	1	0	1	1	1	0	1	1	1	0	0	1	8
9	0	0	0	0	0	1	0	1	1	1	0	0	0	1	0	0	1	6

Drivers	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**Driving power**
10	0	0	0	0	0	0	1	0	0	1	0	0	1	0	0	0	0	3
Drivers	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Driving power
11	0	1	1	1	1	0	0	1	0	0	1	0	0	0	0	1	0	7
12	0	0	0	0	0	0	1	0	0	0	0	1	1	0	0	0	1	4
13	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
14	0	0	0	0	0	0	1	0	0	1	0	0	1	1	0	0	1	5
15	1	1	1	1	1	0	0	0	0	0	1	0	0	0	1	1	0	8
16	0	1	1	1	1	0	0	0	0	0	1	0	0	0	0	1	0	6
17	0	0	0	0	0	1	0	1	1	1	0	0	0	0	0	0	1	5
Dependence power	2	6	6	8	8	6	6	7	6	6	6	2	6	4	2	6	8	

Source: Own circulations using SmartISM

4.4 Final Reachability Matrix (FRM)

The final reachability matrix (FRM) is then constructed from RM by integrating the transitivity property from one element to another (Kaur et al., 2019). The transformation in the initial reachability matrix is done according to the transitivity rule that if variable A is related to variable B and variable B is related to variable C, then variable A will certainly be related to variable C. After the transitivity is performed, the final reachability matrix is generated as it is shown in Table 4.

Table 4. Final reachability matrix

Drivers	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**Driving power**
1	1	1	1	1	1	0	0	0	0	0	1	0	0	0	1	1	0	8
2	0	1	1	1	1	0	0	0	0	0	1	0	0	0	0	1	0	6
3	0	1	1	1	1	0	0	0	0	0	1	0	0	0	0	1	0	6
4	0	0	0	1	1	1	0	1	1	0	0	0	0	0	0	0	1	6
5	0	0	0	1	1	1	1	1	1	0	0	0	0	0	0	0	1	7
6	0	0	0	0	0	1	1	1	1	1	0	0	0	1	0	0	1	7
7	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	2
8	0	0	0	0	0	1	0	1	1	1	0	1	1	1	0	0	1	8
9	0	0	0	0	0	1	0	1	1	1	0	0	0	1	0	0	1	6
10	0	0	0	0	0	0	1	0	0	1	0	0	1	0	0	0	0	3
11	0	1	1	1	1	0	0	1	0	0	1	0	0	0	0	1	0	7
12	0	0	0	0	0	0	1	0	0	0	0	1	1	0	0	0	1	4
13	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
14	0	0	0	0	0	0	1	0	0	1	0	0	1	1	0	0	1	5
15	1	1	1	1	1	0	0	0	0	0	1	0	0	0	1	1	0	8
16	0	1	1	1	1	0	0	0	0	0	1	0	0	0	0	1	0	6
17	0	0	0	0	0	1	0	1	1	1	0	0	0	0	0	0	1	5
Dependence power	2	6	6	8	8	6	6	7	6	6	6	2	6	4	2	6	8	

Source: Own circulations using SmartISM

4.5 Level partitions

To find the partition level, three groups will be extracted from the final RM mentioned below. Reachability set, Antecedent set, Intersection set (Kaur et al., 2019). Reachability and antecedent groups for each variable were inferred from the final reachability matrix analysis. The reachability set consists of itself and all the variables affecting it, and the antecedent set consists of itself and all the variables affecting it (Ahmad & Qahmash, 2021). The intersection group for each variable was derived from reachability and the antecedent group. Variables with reachability and intersection set that are identical are at the first higher level in the model and indicated that they would not help drive any other variable. Once the first level is identified, it is removed from all groups, and the same procedure is applied to learn the levels of the other models. Table (5) shows the specific levels that are considered the basis for building the ISM model.

Table 5. Partitioning of variables

Elements (Mi)	Reachability Set R(Mi)	Antecedent Set A (Ni)	Intersection Set R(Mi)∩A(Ni)	Level
1	1, 15,	1, 15,	1, 15,	7
2	2, 3, 11, 16,	1, 2, 3, 11, 15, 16,	2, 3, 11, 16,	6
3	2, 3, 11, 16,	1, 2, 3, 11, 15, 16,	2, 3, 11, 16,	6
4	4, 5,	1, 2, 3, 4, 5, 11, 15, 16,	4, 5,	5
5	4, 5,	1, 2, 3, 4, 5, 11, 15, 16,	4, 5,	5
6	6, 8, 9, 12, 14, 17,	1, 2, 3, 4, 5, 6, 8, 9, 11, 12, 14, 15, 16, 17,	6, 8, 9, 12, 14, 17,	4
7	7	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 14, 15, 16, 17,	7	2
8	6, 8, 9, 12, 14, 17,	1, 2, 3, 4, 5, 6, 8, 9, 11, 12, 14, 15, 16, 17,	6, 8, 9, 12, 14, 17,	4
9	6, 8, 9, 12, 14, 17,	1, 2, 3, 4, 5, 6, 8, 9, 11, 12, 14, 15, 16, 17,	6, 8, 9, 12, 14, 17,	4
10	10	1, 2, 3, 4, 5, 6, 8, 9, 10, 11, 12, 14, 15, 16, 17,	10	3
11	2, 3, 11, 16,	1, 2, 3, 11, 15, 16,	2, 3, 11, 16,	6
12	6, 8, 9, 12, 14, 17,	1, 2, 3, 4, 5, 6, 8, 9, 11, 12, 14, 15, 16, 17,	6, 8, 9, 12, 14, 17,	4
13	13	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17,	13	1
14	6, 8, 9, 12, 14, 17,	1, 2, 3, 4, 5, 6, 8, 9, 11, 12, 14, 15, 16, 17,	6, 8, 9, 12, 14, 17,	4
15	1, 15,	1, 15,	1, 15,	7
16	2, 3, 11, 16,	1, 2, 3, 11, 15, 16,	2, 3, 11, 16,	6
17	6, 8, 9, 12, 14, 17,	1, 2, 3, 4, 5, 6, 8, 9, 11, 12, 14, 15, 16, 17,	6, 8, 9, 12, 14, 17,	4

Source: Own circulations using SmartISM

4.6 ISM based model construction

Figure 2 shows the structural model of the variables resulting from the final reachability matrix. In this model, we have seven levels of variables derived from the level partitioning iteration process. Figure 2 shows that the “Awareness of I4.0” and "R&D" are the most important drivers for Industry 4.0 implementation in manufacturing companies in Algeria based on the ISM model.

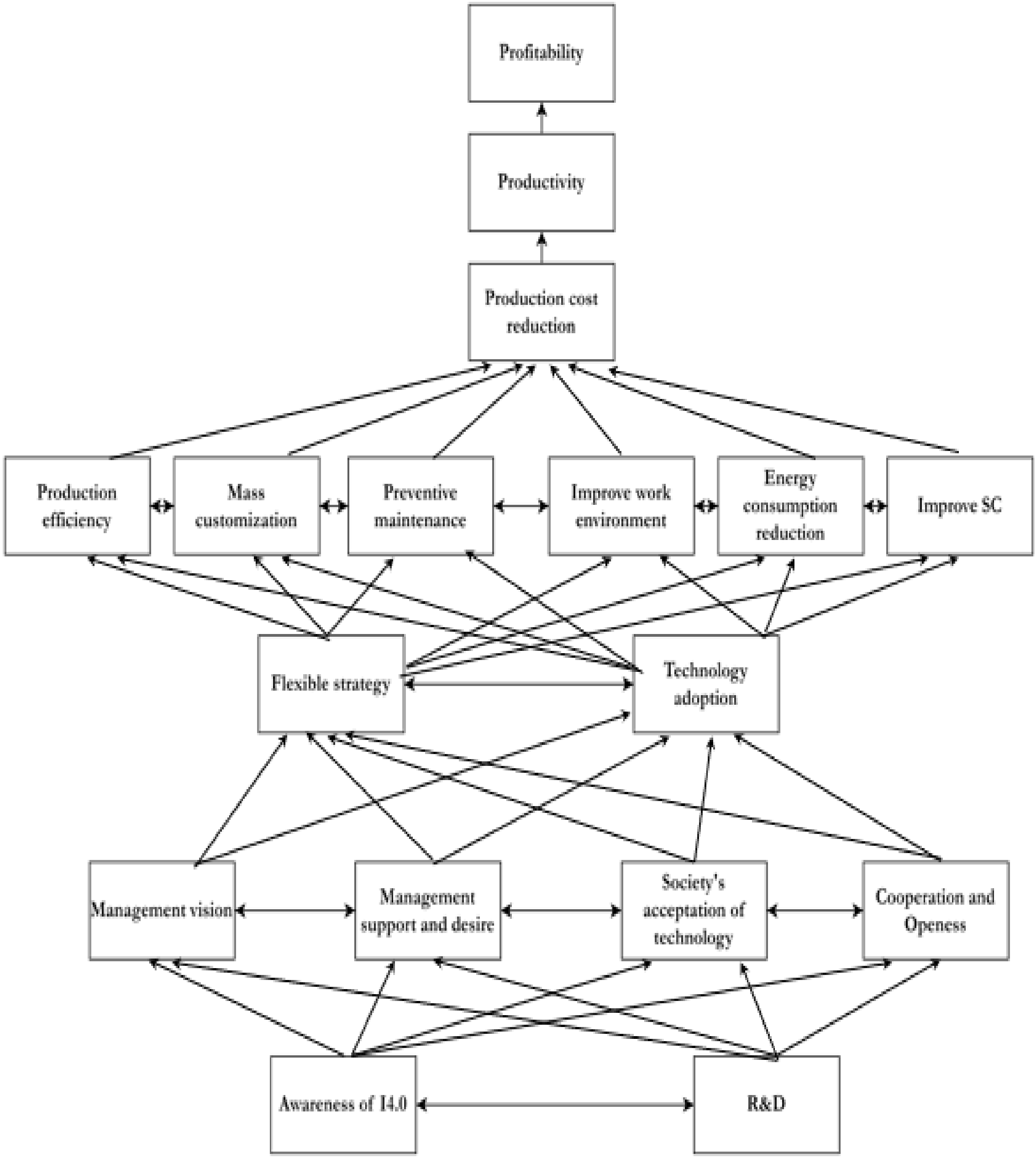

Figure 2. Interpretative Structural model
Source: Own circulations using SmartISM

4.7 MICMAC Analysis

The MICMAC method, which refers to Matrix of Cross Impacts, Multiplication Applied to a Ranking, was initially proposed by Michel Godet and Jean-Claude Duperrin in 1974 (Hatem, 1993).

The purpose of Micmac is to identify the most influential and most dependent variables (key variables), by creating a typology of variables in direct and indirect classification (Godet, 2007).

MICMAC analysis is performed on the basis of driving and power-dependent variables. The driving force of a variable is the sum of every 1s in the corresponding row in the final reachability matrix, and the dependence force of a variable is the sum of every 1s in the corresponding column in the final reachability matrix. The driving force of a variable means that the variable affects other variables. On the other hand, the strength of dependence of a variable means that the variable depends on other variables. MICMAC analysis classifies the variables into four groups, which are illustrated in Figure 3.

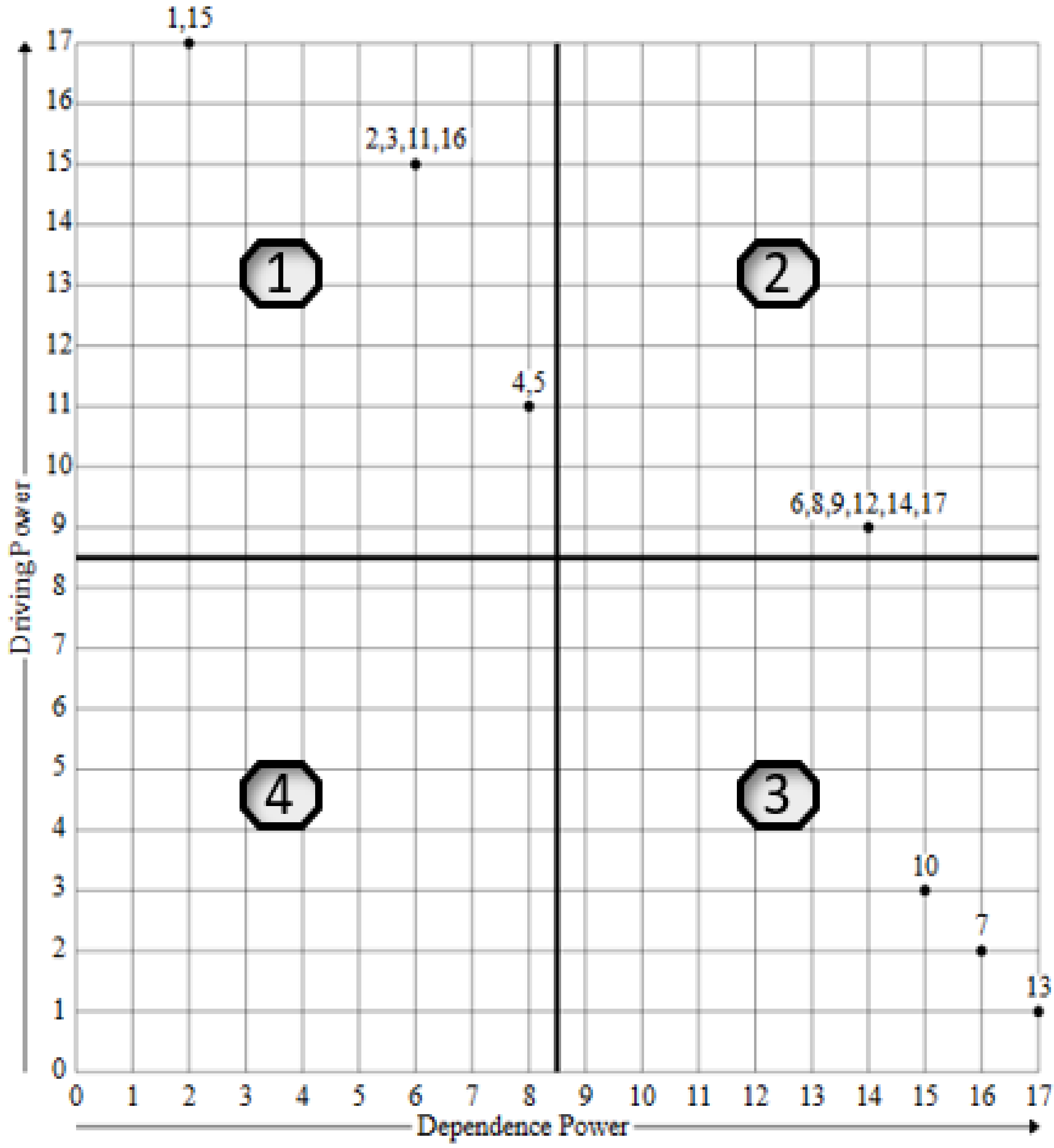

Figure 3. MICMAC graph

Source: Own circulations using SmartISM

Sector 1: The variables of this sector are characterised by high influence and low dependency. These variables are substantial in the system, as they are the explanatory variables that determine the rest of the system. These variables are awareness of the I4.0 concept, research and development, management vision, management support, and desire to move to I4.0, society's acceptance of technology, and cooperation and openness, as well as flexible strategy planning and adoption of advanced technologies.

Sector 2: This sector's variables have high influence and high dependency. For that, any change related to these variables will have an effect on the rest of the system and its outputs.

Moreover, these variables represent the challenges of the system. These variables are production efficiency, mass customisation, preventive maintenance, improved work environment conditions, energy consumption reduction, and improved supply chain flows.

Sector 3: This sector represents the result variables which are characterised by low influence and high dependency. The evolution of these variables is explained by the variables of sectors 1 and 2. These variables are production cost reduction, productivity, and profitability.

Sector 4: These variables are excluded, as they are characterised by low influence and low dependency, which means that they are not determinants of the future of the system. No such variables are there in this study.

Through the influence and dependency plan, we can draw several conclusions. First, there are multiple determinants to implement Industry 4.0 in manufacturing companies in Algeria. One key determinant is the awareness of Industry 4.0. Understanding the promising possibilities of this new industrial model is crucial, as it forms the basis for implementing Industry 4.0. Realising its importance is an essential part of the industrial future, and even in other fields such as health, education, etc. This is consistent with the conclusions of Da Silva et al. (2020) and Stentoft et al. (2021). Similarly to the results obtained by Liebrecht et al. (2021); Majumdar et al. (2021), the findings of our study indicated that research and development is considered a very important element in implementing Industry 4.0. It fundamentally contributes to improving companies' awareness of the concept of Industry 4.0, and significantly contributes to the development of Industry 4.0, by supporting innovation and continuous improvement of Industry 4.0 technologies. Research and development also contribute to the adaptation of advanced technologies to the needs of companies to improve the efficiency of operations and enhance productivity. It also allows reducing the risks of implementing Industry 4.0 by identifying potential challenges, which allows the development of strategies to implement Industry 4.0 more smoothly. It also allows reducing the risks of implementing Industry 4.0 by identifying potential challenges, which allows developing strategies to implement Industry 4.0 more smoothly. Our findings also indicated that management vision, as well as management support and desire to shift towards Industry 4.0 model, are important drivers for implementing Industry 4.0. This is consistent with the results of both Huang et al. (2019) and Majumdar et al. (2021), respectively. It can be said that the participation and commitment of senior management represents a fundamental driver for the implementation of Industry 4.0. It accelerates the process by defining a clear roadmap for the integration of Industry 4.0 with corporate goals. Also, management support leads to the allocation of sufficient resources to implement Industry 4.0. In addition to management's ability to lead change through arranging organisational and production structures (Müller et al., 2018), as well as mitigate concerns associated with Industry 4.0. This includes urging partners to commit to implementing Industry 4.0, and urging employees to accept the shift to Industry 4.0 model. In addition, flexible strategies play an essential role in implementing Industry 4.0. This allows a rapid response to changes (Liebrecht et al., 2021) and ensures alignment with Industry 4.0, helping to overcome potential challenges. Also, the adoption of advanced technologies contributes to improving the automation of various processes, especially reliance on cyber-physical systems in the production lines (Türkeș et al., 2019), as well as improving communication between devices and making the most of data to improve decision-making, which confirms the results of the study conducted by (Da Silva et al., 2020; Dikhanbayeva et al., 2021). Moreover, openness and cooperation with other companies, as well as various institutions, whether local or foreign, constitutes a strong driver for the transition to Industry 4.0 (Hoyer et al., 2020; Müller et al., 2018). It enables companies to enhance their knowledge, develop their capabilities, and improve their network, which facilitates the adoption of Industry 4.0 (Müller et al., 2018). Finally, similar to the findings of Sony & Naik (2020), our study concluded that society's acceptance of technology represents a major driver for the application of Industry 4.0 in manufacturing companies. It encourages companies to adopt modern technologies and provide smart products and services due to increased demand. Also, community acceptance influences technology-related policies and encourages the enhancement of technological knowledge and the implementation of Industry 4.0 model. Second, factors within the linkage group, which are characterised by strong driving power and strong dependence power. Improving efficiency using technologies such as drones and robotics (Aripin et al., 2019), as well as improving efficiency through lean production practices (Pozzi et al., 2023), is considered one of the most important drivers motivating companies to implement Industry 4.0. In addition, mass customisation enabled by advanced technologies such as additive manufacturing (Devi K et al., 2021) is an important driver for the implementation of Industry 4.0. Companies are motivated by the new revenue opportunities that mass customisation provides, allowing them to increase profits and improve customer service. Also, preventive maintenance is considered a powerful driver for the implementation of Industry 4.0 (Horváth & Szabó, 2019). Modern technologies contribute to improving preventive maintenance, which, in turn, improves productivity and reduces delays and breakdowns. Moreover, improving the work environment by designing new jobs, training employees, improving compensation, and improving employee safety and security is among the most important drivers of implementing Industry 4.0 in companies (Verma & Venkatesan, 2022). This positively affects the performance of companies in general and contributes to increasing society's acceptance of technology, which accelerates the implementation of Industry 4.0.

Furthermore, environmental opportunities are important drivers for implementing Industry 4.0. The most notable of which is reducing energy consumption (Müller et al., 2018). Industry 4.0 technologies contribute to reducing energy consumption through constant monitoring and identifying consumption patterns through data analysis. This increases the efficiency of energy consumption and reduces associated costs. Also, improving supply chain flows by integrating modern technologies is considered a fundamental driver for implementing Industry 4.0 (Ghadge et al., 2020; Sony & Naik, 2019). This contributes to increasing the transparency of the supply chain, improving cooperation and data exchange. These improvements enhance planning and inventory management processes. Additionally, they enhance flexibility along the supply chain to respond to changing conditions (Ghadge et al., 2020), and improve efficiency and effectiveness (Sony & Naik, 2019). Finally, factors within the result group. These factors are characterised by weak driving power and strong dependence power. Economic motivations are considered to be strong drivers for the adoption of Industry 4.0. Reducing the cost of production is a fundamental driver for implementing Industry 4.0 due to its economic and even social importance (Aripin et al., 2019; El Baz et al., 2022; Yu & Schweisfurth, 2020). In addition, improving productivity through the adoption of advanced technologies in order to enhance the competitiveness of companies is one of the most important drivers for the implementation of Industry 4.0 (Horváth & Szabó, 2019; Kamble et al., 2018). Finally, maximising profitability appears as a fundamental driver of the process of implementing Industry 4.0 in companies (Vimal et al., 2022), as it can be said that it is the ultimate goal of companies in order to achieve well-being and prosperity.

5. CONCLUSIONS

In an era characterised by fierce competition, companies aim to adopt the Industry 4.0 model to ensure their position in the new industrial future. This paper aimed to identify the most important drivers for implementing Industry 4.0 in manufacturing companies in Algeria. It first addressed the development of Industry 4.0 and the most important drivers for its implementation, where 17 main drivers for implementing Industry 4.0 were identified after reviewing the literature and consulting experts. Structural analysis via ISM-MICMAC method was then used with the help of experts in order to identify the most important drivers that contribute to the implementation of Industry 4.0 model in manufacturing companies in Algeria. The results indicated that the awareness of Industry 4.0, in addition to research and development, senior management's commitment to the transition to Industry 4.0, and society's acceptance of technology are the most important determinants of the implementation of Industry 4.0. In addition, production efficiency, mass customisation, and optimisation of supply chain flows are key factors for the successful implementation of Industry 4.0, while the most important results expected from the implementation of Industry 4.0 were improving productivity and maximising profitability.

This study has practical implications that may help practitioners effectively implement Industry 4.0. First, increasing awareness of the concept and importance of Industry 4.0 is crucial. This includes enhancing the technological culture of companies, developing employees' technological knowledge, and working to enhance society's awareness of the importance of technology. Second, openness and cooperation are essential for implementing Industry 4.0. Enhancing cooperation among companies as well as with academic institutions facilitates research, development, and knowledge exchange on Industry 4.0 developments. Third, top management support and commitment will greatly help in implementing Industry 4.0 model. Encouraging all partners, including shareholders, suppliers, customers, and employees, to accept the adoption of advanced technologies contributes greatly to accelerating the transition to Industry 4.0. Moreover, adopting Industry 4.0 technologies is crucial, as it enhances communication and enables the integration of various processes. Finally, relying on flexible strategies represents an important factor for the success of implementing Industry 4.0, as it enables us to quickly adapt to changes and overcome obstacles facing the successful implementation of Industry 4.0 in manufacturing companies. In general, these policy implications aim to successfully implement Industry 4.0 in manufacturing companies, enhance innovation competitiveness, and achieve sustainability.

Future research should concentrate on exploring several interconnected aspects to enhance the implementation of Industry 4.0 in manufacturing companies. Initially, it is crucial to study the challenges and obstacles encountered during this implementation. This involves a comprehensive investigation into various difficulties, including technological and financial barriers, as well as regulatory and cultural challenges. A deep understanding of these obstacles is vital for developing effective strategies to facilitate a smoother adoption of Industry 4.0. Furthermore, sector-specific analyses should be conducted, focusing on specific manufacturing industries. This approach allows for a more precise identification of the unique challenges and opportunities associated with Industry 4.0 in each sector, considering their specific characteristics. Lastly, detailed case studies of companies that have successfully implemented Industry 4.0 will provide valuable insights into effective practices and strategies.

Overall, these research directions can significantly enhance our comprehension of Industry 4.0 implementation process, improving the ability of manufacturing companies to use these technologies to boost their productivity and competitiveness.

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