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Prioritizing of the Internet of Manufacturing Things (IoMT) Challenges in Automotive Industry by Using Interpretive Structural Modeling (ISM)

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ABSTRACT

Smart manufacturing can be referred to as an important consequence of the Fourth Industrial Revolution. With the advent of this revolution, manufacturing companies must use numerous new technologies to become smart. Companies face multifaceted challenges because of these new technologies. The Internet of Things (IoT) technology is one of the achievements of Industry 4.0, which plays an important role in implementing smart manufacturing. IoT used in smart manufacturing is called the Internet of Manufacturing Things (IoMT Like other technologies, IoMT has its challenges. Therefore, manufacturing organizations must be able to identify these challenges and concentrate on them based on their priority. This study identified the challenges of using the Internet of Things in smart manufacturing were identified by reviewing the literature. The Interpretive Structural Modeling (ISM) technique was used to prioritize challenges in the automotive industry. Based on the research findings, the challenges were classified into three levels. This leveling provides a suitable model for automotive industry managers prioritize their strategies and actions accordingly.

Keywords

Smart manufacturing, Internet of things, Internet of Manufacturing Things, Challenges, Interpretive Structural Modeling.

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1. Introduction

In recent years, in wireless communications and networking, a new paradigm called the Internet of Things (IoT) has attracted the attention of many researchers and industrialists. The Internet of Things can be defined as a network of physical objects that are digitally connected so that they can sense, monitor, and influence each other (Xu et al., 2023). A supply chain is also a network that requires monitoring and controlling relationships between components. Therefore, using IoMT in different parts of the supply chain can facilitate communication and cooperation between partners and processes. Smart manufacturing is formed by using the Internet of Things in manufacturing (as part of supply chain processes). According to the definition presented by the Smart Manufacturing Leadership Coalition (SMLC), smart manufacturing is "the right data in the right form, the right people with the right knowledge, the right technology, and the right operations, whenever and wherever the production needed throughout the manufacturing enterprise" (Edgar and Pistikopoulos, 2018). Another definition was provided by the National Institute of Standard and Technology (NIST), based on which smart manufacturing is "fully integrated, collaborative manufacturing systems that respond in real-time to meet changing demands and conditions in the factory in the supply network, and customer needs".

As with previous manufacturing parameters, smart manufacturing has also developed in the automotive industry. The automotive industry is regarded as a key industry in terms of its extensive relationship with a chain of industries before and after. It has a high potential for economic development. As stated in the philosophy of production paradigms, concepts such as mass production, lean production, and world-class manufacturing, which have revolutionized various industries, were first introduced and implemented in the automotive industry (mass production at Ford Motor Company, lean production and world-class manufacturing at Toyota) (Ebrahimi et al., 2019). Consequently, the present study examines the Internet of Things challenges in smart manufacturing as a new production paradigm in the automotive industry.

In addition to the dramatic change in the automotive industry, the Internet of Manufacturing Things has affected the performance of auto manufacturers and the software they use, thus trying to maximize values (Krasniqi and Hajrizi, 2016). Smartening the automotive industry will bring lower costs, energy savings, environmental protection, and efficient after-sales services (Liu et al., 2012). There are serious challenges in smartening and implementing IoMT to achieve these goals. In the last decade, these challenges have been introduced in conducted research in the field of smart manufacturing and the Internet of Things (Afzal et al., 2019; Chen et al., 2014; Cooper and James, 2009; Farahani et al., 2018; Werlinger et al., 2009; Kumar and

Mallick, 2018; Lee and Lee, 2015; Lim et al., 2018; Makhdoom et al., 2019; Reyna et al., 2018). However, it is impossible to consider and address all challenges simultaneously. Therefore, it must be determined at which level each challenge is and which are prioritized. Using the ISM technique to level the challenges and, consequently, their management in IoMT deployment is also considered a contribution of the innovation in the present study. In conclusion, this study addresses these two primary questions: What difficulties does the Internet of Manufacturing Things present? Given the restricted resources, which issues ought to be managers' top priorities?

This paper is organized as follows. In section 2, the IoMT implementation challenges were extracted by reviewing the IoMT literature and its application in smart manufacturing. Section 3 describes the steps of research and the ISM technique. Section 4 includes the leveling of the challenges introduced in this research. Finally, section 5 presents the results of the research.

2. Literature and research background

2.1. Internet of things (IoT) and internet of manufacturing things (IoMT)

Chinese Premier Li Keqiang has developed the Internet Plus initiative to accelerate China's slowing economy. This initiative aims to link the Internet and related information technology to current industries to increase productivity and economic growth. Cloud computing, mobile Internet, big data utilization, and the Internet of Things are the pillars of Internet Plus (Hristov, 2017). The Internet of Things was first introduced by Kevin Ashton in 1999 through the Auto-ID Center at MIT. For Ashton, "Internet of Things" means all objects and people equipped with computers, sensors, and the Internet that can be managed. He also introduced Radio-Frequency Identification (RFID) as a prerequisite (Dhumale, et al., 2017). The Internet of Things has features such as connectivity to remote data collection, analysis, and management capabilities that minimize human intervention in producing, transmitting, and using data (Rose et al., 2015).

There are two different aspects to the Internet of Things (See Figure (1)): Information Technology (IT) and Operational Technology (OT) (Khan et al., 2020) .. IT is the “objects” such as servers, databases, and applications. Networks run these objects while IT controls them. IT ensures that the connections between data in a company are safe and reliable. OT is mainly concerned with industrial interactions. This aspect consists of sensors, systems connected to machines, and other types of equipment that control the performance of physical systems. Before IoT, the two concepts of IT and OT were two different poles that worked separately and

did not need to interact with each other. However, IoT is here to combine these two concepts as they are based on a world of interrelated objects (Khan et al., 2020).

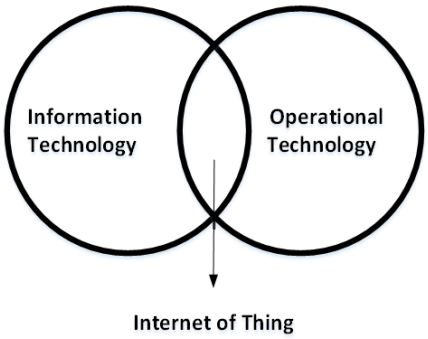

Figure 1. Venn diagram of IoT (Khan et al. 2020)

According to research conducted in this area, several researchers have proposed some definitions for IoT (Table 1), although there is an overlap in these definitions.

Table 1. Definition of IoT

References	Definitions
(Satyavolu et al., 2015)	The Internet of Things includes objects or 'things' with sensors embedded to enable them to communicate their state with other objects and automated systems in the environment.
(Dorsemaine et al., 2015).	IoT "connects a group of interconnected infrastructures and objects and allows their management to extract and analyze data. In IoT, connected objects are sensors that create a specific function and communicate with other equipment".
(Rose et al., 2015)	IoT refers to extending network connectivity and the capability to compute objects, devices, and sensors that are generally not considered computers. These smart objects require minimal human intervention in producing, exchanging, and consuming data. They often include features that can be used to connect connectivity to remote data collection, analysis, and management capabilities.

The objects mentioned in the above definitions represent a node in a virtual network that continuously transmits a large volume of data about itself and other network components (Satyavolu et al., 2015). Things that are deployed in IoT are (i) RFID tags for unique identification, (ii) sensors for detecting physical changes in the environment, and (iii) actuators for transmitting information to the environment (Lanotte and Merro, 2018).

In IoT, objects are generally objects of physical things or virtual things that can be identified and integrated into communication networks. Physical objects exist in the physical world and can be sensed and/or acted upon and/or connected. The sensors of surrounding environments, industrial robots, goods, and electrical equipment are examples of physical objects. Virtual objects exist in the virtual world and can be stored, processed, and accessed. Examples of virtual objects include multimedia content, application software, and service representations of physical things (Lee et al., 2013).

The endpoint of communication in IoT can be humans or objects (devices/machines). Consequently, two categories of communication are considered for IoT (Lee et al., 2013). Human-to-Object (Thing) Communication: Humans communicate with a device to obtain specific information, which includes remote access to objects by humans. Object-to-Object (Thing-to-Thing) Communication: An Object delivers information to another object that may or may not be human.

Before industrialization, most of the work had to be done by the workforce. After the first industrial revolution, machines and human resources started a corroboration by which the manufacturing time was reduced, the quality of the products was increased, and the general productivity was ameliorated. Even now, in the era of the Fourth Industrial Revolution, Technologies like IoT are used to improve productivity, reliability, and accessibility of financial resources to open new doors to how products are made and introduced to the market. Internet of Manufacturing Technology (IoMT) is the application of IoT in Manufacturing. IoT systems are introduced in the previous section. Before defining IoMT, it is better to define Manufacturing Things. Manufacturing Things are all the essential instruments and physical equipment a factory needs to turn raw material into the finished product. Workforce, machines, work-in-progress items, and many other company objects are considered manufacturing things (Zhang et al., 2014). IoMT is an optimized system for managing and driving manufacturing data that optimally controls manufacturing processes, from placing orders to manufacturing and selling the finished product(Zhang et al., 2014). In another sense, IoMT is all the manufacturing steps, processes, and generally the whole manufacturing cycle in a factory. IoMT is an open network system that combines advanced manufacturing, IoT, information, and modern management (Li et al., 2018). IoM has two parts: software and hardware. Hardware is all Auto-ID systems that hold manufacturing data, while software is several application services responsible for backing up the decision-making process (Zhang et al., 2014).

2.2. The application of the internet of things in smart manufacturing

The application of IoT in various fields is increasing rapidly. The Internet of Things can be used in various areas, including smart manufacturing, smart grid, smart healthcare, smart home, and smart city.

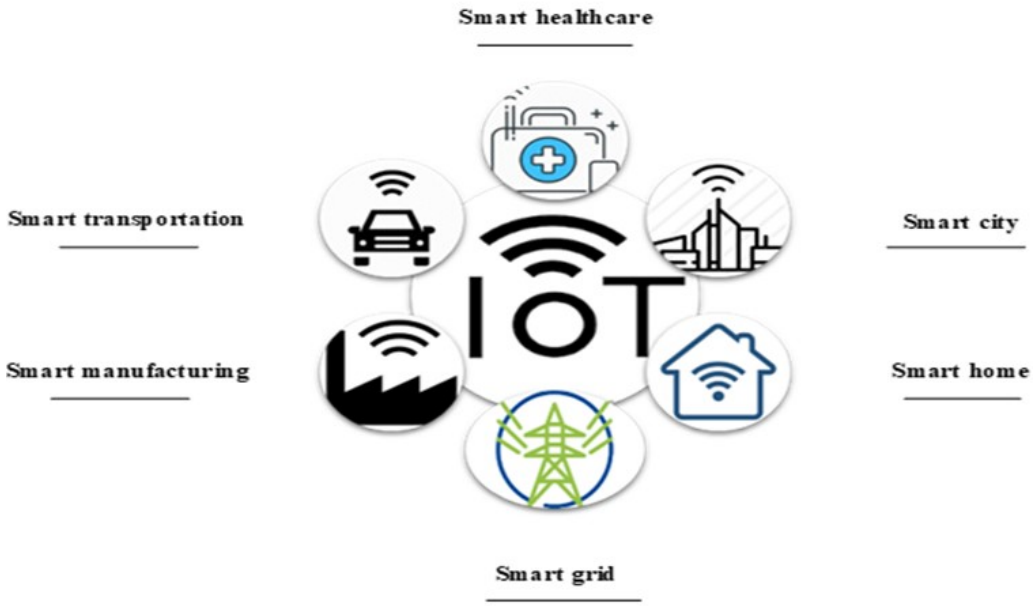

Figure 2. IoT application

As shown in Figure (2), one of the Internet of Things applications is smart manufacturing. Smart manufacturing aims to improve final product productivity, efficiency, reliability, and control(Kouicem et al., 2018). Smart manufacturing includes new technologies such as machine-to-machine (M2M) communication, wireless sensor networks (WSNs), automation technologies, big data, and the Internet of Things.

The IoT approach is an ideal solution for automating and controlling the manufacturing process and plays an important role in creating a communication infrastructure for information acquisition and sharing. Real-time data of actuators is not limited and resilient to changes, but RFID and WSN are effective tools in supporting the distribution and decentralization of production resources. The dynamic IoT architecture facilitates information integration by combining the host company and other virtual companies to conduct projects throughout the company. Dynamic relationships are created for specific projects. After the completion of the project, this combination can be changed, and the company is ready to do another project. To conduct manufacturing projects, some human-to-human, human-to-object, and object-to-object interactions take place. With the development of the Internet of Things, these interactions can be integrated. This way, partners can focus on multiple decisions requiring integrated and compact information and high computing power rather than worrying about interactions. Manufacturing companies use multiple computer resources such as servers, databases, and decision units. It leads to waste investment, failure in utilizing production resources, low productivity, and improper information exchange among servers. Cloud computing provides a

vital solution to these problems. All data is stored on public or private cloud servers, and complex decisions can be supported using cloud computing (Bi et al., 2014). According to the stated cases above, IoT affects all parts of the production chain (communications, information, decision-making). Therefore, examining the challenges of implementing IoT in manufacturing companies can identify critical points and take necessary action measures.

2.3. Challenges of using IoMT in manufacturing

The development and application of IoMT affect various aspects of human life (such as security, healthcare, productivity, energy, and environmental sustainability). A literature review revealed that IoMT challenges were introduced in various fields, such as healthcare and treatment (Farahani et al., 2018) and blockchain (Kumar and Mallick, 2018; Makhdoom et al., 2019). Many studies have examined the conceptual study of this field (Afzal et al., 2019; Chen et al., 2014; Cooper and James, 2009; Farahani et al., 2018; Werlinger et al., 2009; Khan and Salah, 2018; Kumar and Mallick, 2018; Makhdoom et al., 2019; Reyna et al., 2018). Some studies have identified security challenges (Khan and Salah, 2018; Kumar and Mallick, 2018) and data management challenges (Cooper and James, 2009). The gap seen in the literature is the study of the challenges of the Internet of Things in the manufacturing industry. IoMT implementation and deployment in the manufacturing industry requires infrastructure associated with organizational, hardware, and software issues and challenges. By reviewing the literature on the application of IoMT in smart manufacturing, the challenges of Table (2) were identified.

Table 2. Challenges of using IoMT

Challenges		Definitions	References
Data management and integrity	C_1	Applying the IoMT approach creates a large amount of homogeneous and heterogeneous data; data analysis in different periods can produce practical results for the organization. Most data centers cannot process, integrate, and store this data on individual or organizational dimensions.	(Cooper and James, 2009; Farahani et al., 2018; Mohammadzadeh et al., 2018; Lee and Lee, 2015; Lim et al., 2018; Nasrollahi and Ramezani, 2020)
Sensitive data access control	C_2	With the deployment of the IoMT approach and the wide variety of data types, the level of user access to important and sensitive data is critical for the organization, and the lack of a coherent strategy for how users access disrupts the security of the information system.	(Werlinger et al. 2009; Mazhar et al., 2023)
Storage capacity and scalability	C_3	In IoMT, data and equipment integration is critical; therefore, all processes and devices need to be considered at maximum capacity so that in case of their development, there will be no disruption to their speed and utilization for stakeholders. It is possible by using tools such as smartphones.	(Farahani et al., 2018; Reyna et al., 2018)
User privacy	C_4	IoMT integrates and manages many issues related to individuals, including health and welfare services. All the information about people in one software package can affect user privacy.	(Afzal et al., 2019; Chen et al., 2014; Khan and Salah, 2018; Lee and Lee, 2015; Lim et al., 2018; Reyna et al., 2018)
Lack of security and trust management	C_5	The available hardware and software on the IoMT platform are extremely vulnerable due to a lack of encryption, insecure web interface, and other security issues, and consequently, hackers can access all the information on the platform, which creates insecurity for organizations and distrust for individuals.	(Afzal et al., 2019; Farahani et al., 2018; Mohammadzadeh et al., 2018; Khan and Salah, 2018; Khan and Turowski, 2016; Kumar and Mallick, 2018; Lee and Lee, 2015; Makhdoom et al., 2019; Nasrollahi and Ramezani, 2020; Reyna et al., 2018); Kaur et al., 2023)
Intra-organizational resistance (Labor)	C_6	The predominance of traditional approaches to processes, the feeling of job insecurity, and the organization's lack of acceptance of technology-based approaches cause their high resistance and challenge the dominance of the IoMT platform over the organization.	(Werlinger et al., 2009)
Integration of information system of external partners	C_7	Business cooperation of organizations together to achieve sustainable competitive advantage requires integration between their information systems. Business partners have information systems with different processes since data integration from different information systems with different programming languages requires an integrated data system.	(Cooper and James, 2009; Werlinger et al., 2009); Mazhar et al., 2023)

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Cost	C_8	Implementing IoMT is a costly project that companies are reluctant to invest in due to the lack of transparency in the results and cost-benefit analysis.	(Afzal et al., 2019; Werlinger et al., 2009; Kumar and Mallick, 2018)
Technical and empirical knowledge of management and staff	C_9	Since IoMT is an emerging and novel phenomenon, management and staff may not have mastered the relevant technical knowledge, leading to disruption and sometimes resistance. Therefore, technical training of individuals is vital for the implementation of IoMT.	(Werlinger et al., 2009; Mohammadzadeh et al., 2018)
Top management Support	C_{10}	For organizations to participate in the implementation of IoMT, there is a need for support and understanding of IoMT and its applications by senior management to make the necessary changes to implement it.	(Werlinger et al., 2009; Luthra and Mangla, 2018)
Standardization	C_{11}	The IoMT is a network with many heterogeneous devices that meet different standards and must interact with each other. Standardization can improve interoperability and allow products and services to compete at higher levels. However, the rapid growth of the Internet of Things has made it difficult to establish standards, including interoperability, accessibility, and security.	(Choudhary et al., 2020; Mohammadzadeh et al., 2018; Kumar and Mallick, 2018; Kumar et al., 2021; Luthra and Mangla, 2018)
Legal Issue	C_{12}	In IoMT, there are no rules on how to use its data or fight against crimes that occur while using the data; therefore, the security of data and information and the investigation of crimes from a legal point of view must be considered.	(Kumar and Mallick, 2018; Luthra and Mangla, 2018; Reyna et al., 2018)
The rapid growth of device technology	C_{13}	With the rapid growth of technology, devices and equipment in the IoMT network are becoming more advanced and powerful daily. Therefore, it is necessary that these devices have high flexibility in development or updating so that their replacement and relocation do not impose much cost and time on the organization.	(Luthra and Mangla, 2018; Mazhar et al., 2023)

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3. Research methodology

The present research is applied in terms of purpose and a descriptive survey regarding data collection. This study used existing literature studies to identify the challenges of IoMT implementation in smart manufacturing. On the other hand, field studies were conducted to complete the questionnaire. Experts of the present study are manufacturing managers and consultants active in the automotive industry who have work experience in manufacturing and research and applied experience in the field of the Internet of Things. The questionnaires were sent to the experts by e-mail, and 6 questionnaires were completed and returned by the respondents.

In this study, to achieve the relationship between the challenges of IoMT and creating a hierarchical structure, after reviewing the literature in this area, the challenges were identified, and then, through a questionnaire, the opinions of experts were collected. The ISM technique was used to create a hierarchical structure. Finally, MICMAC analysis was conducted to investigate the challenges of driving and dependence on power (See Figure (3)).

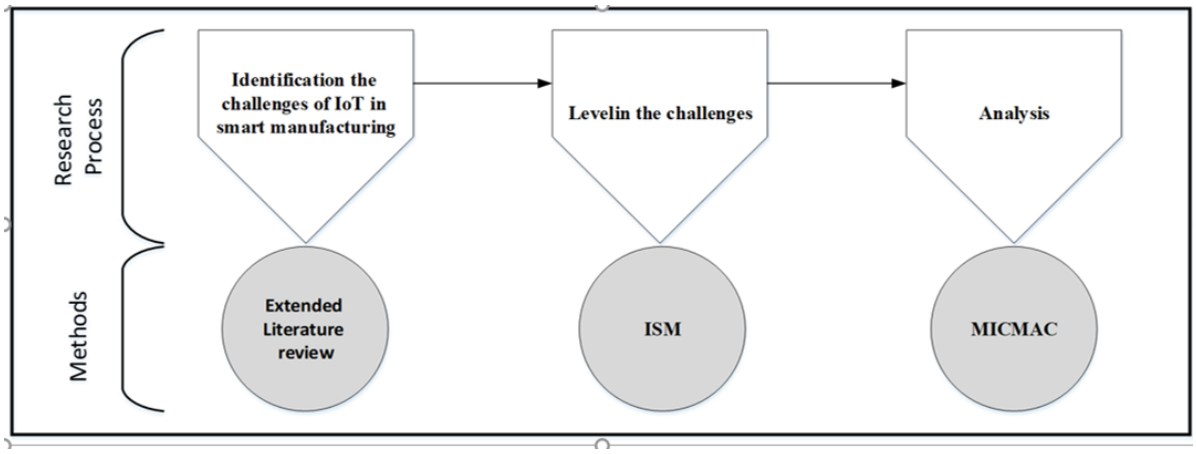

Figure 3. Research framework

3.1. Interpretive structural modeling (ISM)

Interpretive structural modeling is a systematic and structured method introduced by Warfield (1974). ISM is a powerful technique that breaks down a complex system into several subsystems and transforms it into a hierarchical model. This methodology combines three demonstrating languages of words, diagraphs, and discrete mathematics (Kaswan and Rathi, 2019). ISM is used to determine the interaction between factors and the impact of factors (Ali et al., 2022; Yang and Lin, 2020). One of the logics of this method is that the factors that have a greater impact on a system than other factors are more important. This technique helps to establish order in the complex relationships between the elements of the system (Agarwal et al.,

2007). It can also prioritize and level the elements of a system, which helps managers better execute the designed model. ISM technique in various fields such as lean Six Sigma enablers (Kaswan and Rathi, 2019), green building project risks (Guan et al. 2020), the study of supply chain sustainability (Chand et al., 2020), effective factors in green innovation performance (Yang and Lin, 2020) has been used.

Six stages must be taken to apply interpretive structural modeling techniques and determine the priorities and internal linkages of the system's constituents. First, the elements/dimensions are determined, and then a structural self-interaction matrix is obtained. The initial reachability matrix is then extracted, and in the next step, the reachability matrix is adapted. Leveling the elements of the reachability matrix is the next step, and finally, the model is drawn.

Step 1. Formation of structural self-interaction matrix

In this step, a pairwise comparison of the research elements is conducted. For this purpose, the scale presented by Bolaños et al. in 2005 is used, as shown in Table (3).

Table 3. The proposed scale for the structural self-interaction matrix formation (Bolaños et al. 2005)

Linguistic variables	**Number**
High influence	3
Meduim influence	2
Very low influence	1
No influence	0

Step 2. Creation of initial reachability matrix

At this point, the structural self-interaction matrix becomes a binary matrix. The reachability matrix is obtained by determining the relationships as zero and one from the matrix obtained from the total opinions of the respondents in two steps:

Sub-Step 1: First, a unit numerical scale (m) is considered, and the self-interaction matrix numbers are compared with it. Bolanos et al. (year?) Defined these relationships as follows:

$$M = \begin{cases} a_{ij} = 1 & if \quad a_{ij} \geq m \\ a_{ij} = 0 & if \quad a_{ij} < m \end{cases}$$

$$m = 2 \times n$$

Where n represents the number of respondents and m represents the scale value.

Sub-Step 2: In this step, the initial reachability matrix is obtained by adding the results of the first step to the unit matrix.

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Step 3. Creation of the final reachability matrix

The final reachability matrix is formed by applying transitivity relations among the variables in the next step.

Step 4. Determining relationships and leveling factors

The reachability matrix in Step 3 becomes a matrix with a standard framework by placing elements on its levels. In this step, the reachability matrix is categorized into different levels.

An antecedent set and a reachability set are identified for every variable to establish the variables' priority and level. The reachability set of each variable includes the variables that can be reached through this variable, and the antecedent set of each variable includes the variables through which this variable can be reached. It is conducted using the reachability matrix. After determining each variable reachability and antecedent sets, the intersection set, which includes the shared challenges between the reachability and the antecedent sets, is identified for each variable.

The level of variables is determined after determining reachability, antecedent, and intersection sets. In the first table, the variable with the same reachability set and intersection set occupies the highest level of the table. After determining these variables, they will be removed from the table, and the next table with the rest of the variables will be formed. In the second table, as in the first table, the second-level variable is specified, and this process is continued until the level of all variables is determined.

Step 5. Drawing the initial and final interpretive structural model

A structural model is formed using the final reachability matrix. If there is a relationship between factors i and j, this relationship is indicated by an arrow going from *i* to *j*, and the ISM model diagram is formed. Finally, after eliminating transferability, the diagram becomes a model based on interpretive structural modeling.

Finally, interpretive structural modeling is created by placing factors according to their level in a directional graph. Factors classified in level one are placed in the lowest hierarchy of the interpretive structural modeling model, and higher-level factors are placed in the higher hierarchy of the model.

3.2. MICMAC Analysis

MICMAC has integrated with the ISM method to help analyze the findings. It is an analysis method that classifies factors into four categories according to their driving power and dependence power. Driving power and dependence power are determined using the ISM

method. The driving power of a factor is the total number of other factors that are influenced by it, whereas the dependence power of a factor includes the total number of factors that affect it. All factors can be classified into 4 categories (Xu and Zou, 2020):

Group 1. Autonomous factors: These factors have weak driving and dependence power. They need links to the system in which they are located. They cannot affect others or be affected by other factors.

Group 2. Dependent factors: These factors have weak driving and strong dependence power. These factors are deeply influenced by linkage and driving factors and are less likely to affect others.

Group 3. **Linkage factors:** These factors have intense driving and dependence power, and any change in them will significantly cause the reaction of other factors. In addition, system feedback affects these linkage factors.

Group 4. Driving factors: These factors have strong driving but weak dependence power. These factors greatly affect other factors.

4. Result

In the present study, by reviewing the literature in the field of using the Internet of Things in smart manufacturing, the challenges facing this new manufacturing system have been identified in Table (2). Due to the importance of examining the mentioned challenges in deploying smart manufacturing and determining the priority of the challenges to take appropriate measures, their leveling was conducted using ISM.

Based on the defined steps, from the aggregation of experts' opinions, the Structural Self-Interaction Matrix (SSIM) was formed and presented in Table (4).

Table 4. Structural self-interaction matrix

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}
C_1	0	1	16	3	2	3	3	16	2	1	2	18	3
C_2	18	0	0	16	3	1	2	3	0	0	1	2	1
C_3	17	17	0	2	1	3	2	17	1	2	1	1	1
C_4	17	2	0	0	17	2	1	1	1	2	2	1	2
C_5	0	1	3	3	0	16	1	1	0	1	1	1	3
C_6	2	3	1	1	16	0	2	0	18	16	0	15	1
C_7	3	2	3	0	2	1	0	18	1	3	13	18	2
C_8	14	1	13	0	0	0	1	0	0	18	0	0	1
C_9	0	1	0	2	1	18	3	0	0	17	2	2	1
C_{10}	2	0	3	1	1	17	1	1	1	0	2	1	1
C_{11}	18	2	1	1	2	0	18	1	1	0	0	2	14
C_{12}	1	2	1	0	17	1	3	3	0	18	3	0	0
C_{13}	3	17	17	2	2	16	1	2	17	0	16	1	0

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According to the structural self-interaction matrix and the scale number (m = 12), the initial reachability matrix was calculated (Table (5)).

Table 5. Initial reachability matrix

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}
C_1	1	1	1	0	1	0	0	1	0	1	0	1	0
C_2	1	1	1	1	1	0	0	1	0	0	0	1	0
C_3	1	1	1	1	0	0	0	1	0	1	0	1	0
C_4	1	0	1	1	1	1	0	1	0	0	0	1	0
C_5	0	0	0	0	1	1	0	0	1	1	0	1	0
C_6	0	0	0	0	1	1	0	0	1	1	0	1	0
C_7	1	0	1	0	1	0	1	1	0	1	1	1	1
C_8	1	1	1	0	0	1	0	1	0	1	0	1	0
C_9	0	0	0	0	1	1	0	0	1	1	0	1	0
C_{10}	0	0	0	0	1	1	0	0	1	1	0	1	0
C_{11}	1	1	1	0	0	1	1	1	1	0	1	1	1
C_{12}	0	0	0	0	1	1	0	0	0	1	0	1	0
C_{13}	1	1	1	1	1	1	1	1	1	1	1	1	1

The final reachability matrix was formed by applying transitivity relations among the challenges in the next step. The final reachability matrix is demonstrated in Table (6).

Table 6. The final reachability matrix

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	**Driving Power**
C_1	1	1	1	1	1	1	0	1	1	1	0	1	0	10
C_2	1	1	1	1	1	1	0	1	1	1	0	1	0	10
C_3	1	1	1	1	1	1	0	1	1	1	0	1	0	10
C_4	1	1	1	1	1	1	0	1	1	1	0	1	0	10
C_5	0	0	0	0	1	1	0	0	1	1	0	1	0	5
C_6	0	0	0	0	1	1	0	0	1	1	0	1	0	5
C_7	1	1	1	1	1	1	1	1	1	1	1	1	1	13
C_8	1	1	1	1	1	1	0	1	1	1	0	1	0	10
C_9	0	0	0	0	1	1	0	0	1	1	0	1	0	5
C_{10}	0	0	0	0	1	1	0	0	1	1	0	1	0	5
C_{11}	1	1	1	1	1	1	1	1	1	1	1	1	1	13
C_{12}	0	0	0	0	1	1	0	0	1	1	0	1	0	5
C_{13}	1	1	1	1	1	1	1	1	1	1	1	1	1	13
Dependence Power	8	8	8	8	13	13	3	8	13	13	3	13	3	

As mentioned, each level is identified when the intersection of the reachability set and the antecedent set equals the reachability set. Then, the leveled factors are removed, the intersections are re-examined, and the next-level factors are determined. This algorithm continues until the leveling is conducted completely. Table (7) provides the reachability set, antecedent set, and intersection set and the level related to each challenge.

Table 7. Level partitioning of drivers

Challenge	Reachability set	Antecedent set	Intersection set	Level
C_1	2,3,4,5,6,8,9,10,12	2,3,4,7,8,11,13	2,3,4,8	2
C_2	1,3,4,5,6,8,9,10,12	1,3,4,7,8,11,13	1,3,4,8	2
C_3	2,4,5,6,8,9,10,12	1,2,4,7,8,11,13	2,4,8	2
C_4	1,2, 5,6,8,9,10,12	1,2,3,7,8,11,13	1,2,8	2
C_5	6,9,10,12	1,2,3,4,6,7,8,9,10,11,12,13	6,9,10,11	1
C_6	5,9,10,12	1,2,3,4,5,7,8,9,10,11,12,13	6,9,10,11	1
C_7	1,2,3,4,5,6,8,9,10,11,12,13	11,13	11,13	3
C_8	1,2,3,4,5,6,9,10,12	1,2,3,4,7,11,13	1,2,3,4,	2
C_9	5,6,10,12	1,2,3,4,5,6,7,8,10,11,12,13	5,6,9,10,12	1
C_{10}	5,6,9,12	1,2,3,4,5,6,7,8,9, 11,12,13	5,6,9,12	1
C_{11}	1,2,3,4,5,6,7,8,9,10 ,12,13	7,13	7,13	3
C_{12}	5,6,9,10	1,2,3,4,5,6,7,8,9,10,11,13	5,6,9,10,12	2
C_{13}	1,2,3,4,5,6,7,8,9,10,11,12	7,11	7,11	3

According to the leveling performed in the previous step, a graph was formed as shown in figure (4).

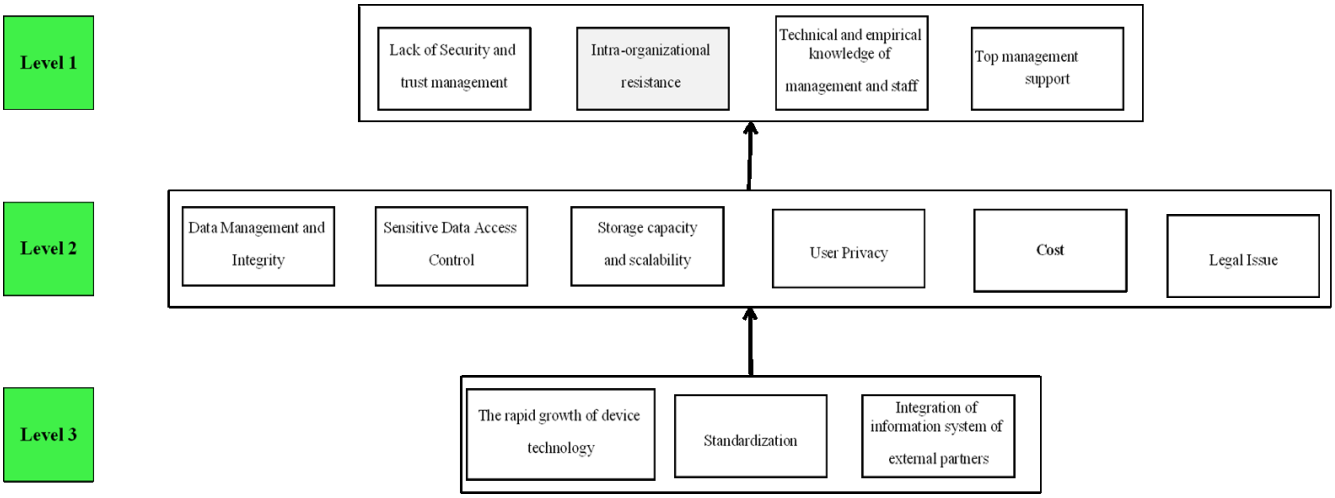

Figure 4. ISM model for challenges of internet of thing in smart manufacturing

Conducting MICMAC analysis requires calculating each factor's driving power and dependence power, which should be obtained from each row's summation and each column's summation in the final reachability matrix. After calculating these values given in Table (7), the coordinate figure is illustrated in Figure (5), where the position of the factors is specified.

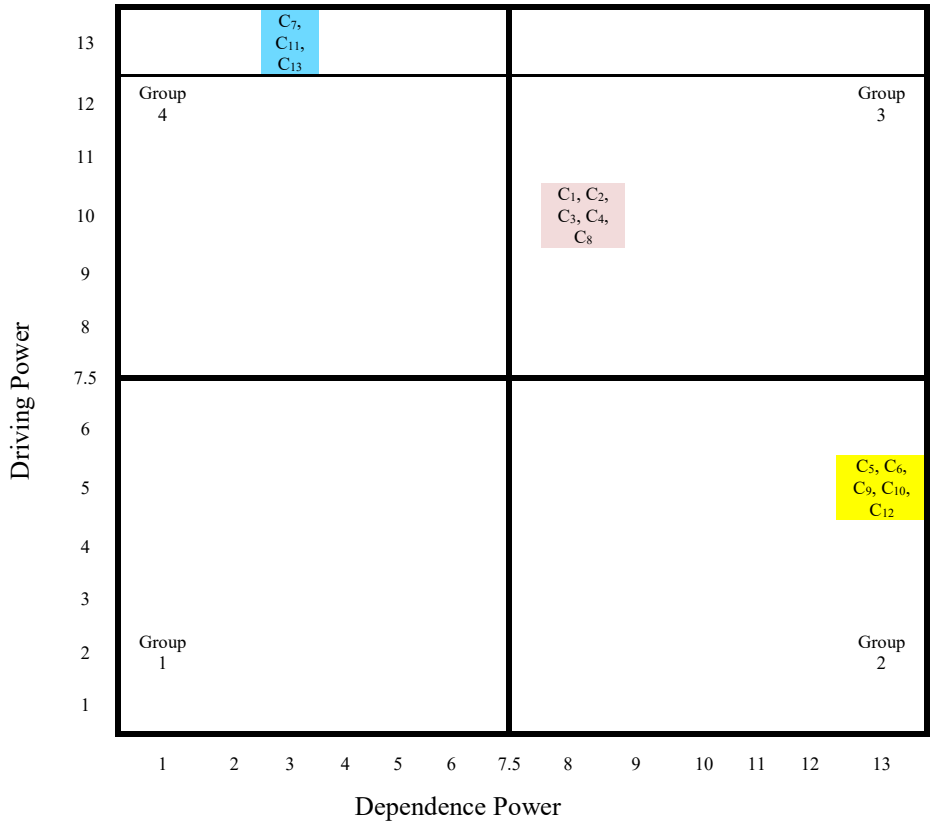

Figure 5. MICMAC analysis

According to the MICMAC analysis, none of the identified challenges are placed in the group of autonomous factors (group 1), which means that all the challenges introduced are related to the system and affect it. Challenges categorized in Group 2 include lack of security and trust management, Intra-organizational resistance, Technical and empirical knowledge of management and staff, top management support, and legal issues, which have the potential to be highly influenced (are being influenced). In group 3, there are challenges with data management and integrity, lack of sensitive data access control, storage capacity and scalability, control of access to sensitive data, storage capacity and scalability, privacy, and cost, which highly interact with the system. These challenges are highly influential and highly influenced; consequently, much more attention should be focused on them. Integration of information systems of external partners, standardization, and rapid growth of technology are challenges that have strong driving power located in the group of linkage factors (group 4).

5. Discussion

Business relationships with other organizations are recognized as a challenge when they do not have similar information and security systems. In addition, this challenge can occur when multiple organizations with different security and information systems merge (Werlinger et al.,

2009). Given this challenge, developing IoMT in smart manufacturing requires a common platform for global standardization. Common standards worldwide can enable relationships between organizations and other organizations and the integration of organizations. Addressing these two challenges can help remove the next-level challenges, including data management and integration. Another challenge at the third level is that technology is evolving rapidly, which is too costly. Therefore, this issue will lead to a cost challenge, which will be addressed later.

The data collected in the system are different, which makes them difficult to manage and integrate. On the other hand, due to the sharing of sensitive data related to inventories, bottlenecks, and various incidents, implementing IoMT requires updated approaches in the ethical, technical, and legal fields. Considering these issues is essential in preventing cyber criminalities because companies are responsible for not only their data but also the data security of supply chain partners (Luthra and Mangla, 2018). Another challenge at the second level, privacy, will be addressed mainly by considering legal issues. Another critical issue in implementing IoMT is that all new systems cost money due to the transformation of all aspects of existing systems. Therefore, investing in new projects requires the acceptance and support given by top management, and this is a challenge that will be addressed at level one.

In implementing and deploying any new system, top management support is one of the primary key factors, and not addressing this organizational factor will create a major challenge in its acceptance and implementation (Luthra and Mangla, 2018) because other factors required to implement a new project such as capital, human resource, and equipment are under the control of senior management in the organization. Since people can share their expertise and experience with others, the technical and empirical knowledge of management and staff will help them win support for accepting the deployment of a smart system. However, this will reinforce the implementation process (Werlinger et al., 2009). Since human resources play an essential role in implementing and advancing a new project in the organization, addressing this factor in using IoMT is vital as it can prevent other challenges. Perhaps the lack of a culture of using new information systems can be considered one of the main reasons for intra-organizational resistance within the organization. Using the same user account is unacceptable for employees (Werlinger et al., 2009) and will lead to mistrust, another level-one challenge. The resulting insecurity and mistrust prevent employees from cooperating in implementing IoMT in production systems (Afzal et al., 2019).

6. Conclusion

In recent years, the Internet of Things in various aspects of business has attracted the attention of many researchers and industrialists. One of the applications of the Internet of Things is in smart manufacturing. Implementing IoT in manufacturing, like all new and emerging technologies, will be associated with challenges that are critical to be identified. Furthermore, knowing which challenges come first and have the most significantimpact on implementing the smart manufacturing system is important. In other words, due to companies' limited resources and capabilities, it is impossible to overcome all these challenges simultaneously.

Therefore, in this study, by reviewing the literature, the challenges of IoMT were identified, and the ISM technique was used to determine their importance and level in the automotive industry. According to the opinions of experts in the automotive industry and ISM, the challenges were classified into three levels. Afterward, using MICMAC analysis, it was found that among the challenges introduced, the integration of information systems of external partners, standardization, and the rapid growth of technology has strong driving power, and on the other hand, lack of security and trust management and top management support are highly influenced compared with other challenges.

After identifying and prioritizing IoMT implementation challenges, the next step is to decide whether to remove them. Doing this step requires preparing and analyzing two fields. The former is determining the relevant component of technology with each challenge. The latter is identifying the related stakeholders for each challenge. These points help managers choose the most effective actions to overcome these challenges. Therefore, it can be suggested to researchers to analyze them.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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