Uncertain Supply Chain Management 11 (2023) 299–306

Contents lists available at GrowingScience

Uncertain Supply Chain Management

homepage: www.GrowingScience.com/uscm

Barriers to adopt industry 4.0 in supply chains using interpretive structural modeling

Murad Salim Attiany[a], Sami Awwad Al-kharabsheh[a], lafie Saleh Al-Makhariz[b*], Mohd Ahmad Abed-Qader[a], Sulieman Ibraheem Shelash Al-Hawary[c], Anber Abraheem Mohammad[d] and Adeeb Ahmed AL Rahamneh[b]

[a]*Business Administration Department, Faculty of Business, Isra University -Jordan*
[b]*Business Administration Department, Amman University College for Financial and Administrative Sciences, Al-Balqa Applied University, Jordan*
[c]*Department of Business Administration, School of Business, Al al-Bayt University, Mafraq, Jordan*
[d]*Marketing Department, Faculty of Administrative and Financial Sciences, Petra University, Jordan*

A B S T R A C T

Article history:
Received May 12, 2022
Received in revised format June 24, 2022
Accepted September 24 2022
Available online
September 24 2022

Keywords:
Industry 4.0
Barriers
Supply chains
ISM
MICMAC

This research aims at exploring barriers of adopting Industry 4.0 in manufacturing supply chains. Data were collected based on a review of extant literature on barriers Industry 4.0 adoption, individual interviews with a panel consisted of academic and industry experts. Following numerous previous studies, interpretive structural modeling (ISM) and matrix multiplication applied to classification (MICMAC) analysis were conducted to order 10 barriers based on their importance and impacts. The results excluded one barrier "cyber security challenges", categorized another one as a dependent barrier "lack of digital strategy", and eight barriers as linkage barriers "lack of infrastructure", "personnel resistance to adopt new technologies", "high investment requirements", "data management and quality challenges", "uncertainty of economic benefits", "low maturity level of technology", "lack of adequate skills", and "job disruptions". Henceforward, it was concluded that mitigating these eight barriers is very critical to ensure a successful adoption of Industry 4.0 technologies in supply chains. Further studies are required to categorize these eight barriers based on their importance and relationships.

1. Introduction

The fourth industrial revolution is a result of integrating supply chains into information and telecommunication technologies (Al-Nawafah et al., 2022; Al-khawaldah et al., 2022; Ghadge et al., 2020; Sharma et al., 2021). Since digitization is an important component of the success of supply chains in the current business environment, companies seek to adopt and use industry 4.0 technologies. But before that, barriers of adopting Industry 4.0 technologies must be explored (Al-Alwan et al., 2022; Fernando et al., 2022). According to Raj et al. (2020), investigating the barriers of Industry 4.0 adoption and implementation is still uncultivated in the literature. Henceforth, more studies are required to fill such a gap in the literature, particularly, Industry 4.0 adoption in developing countries (Ozkan-Ozen et al., 2020). However, many studies were carried out to explore the importance of these barriers. Examples of such barriers as reported in the literature take account of lack of infrastructure, resistance to change, lack of financial support, uncertainty of economic benefits, lack of digital skills, high investment requirements, lack of digital strategy and scare resources, cyber security challenges, and data management and quality challenges(Karadayi-Usta, 2019; Halse & Jæger, 2019; Raj et al., 2020; Ghadge et al., 2020; Kumar et al., 2021; Goel et al., 2022; Vigneshvaran & Vinodh, 2022; Hughes et al., 2022). However, accepting, rejecting or rearranging these barriers may vary using data from another business environment according to views of other experts. Most of these studies were conducted using a methodology consisted of a review of literature to identify the barriers of adopting Industry 4.0, individual interviews with a panel of experts to discuss the pre-identified barriers, and evaluate relationships between barriers,

* Corresponding author
E-mail address dr.lafi@bau.edu.jo (I. Al-Makhariz)

doi: 10.5267/j.uscm.2022.9.013

interpretive structural modeling (ISM) and matrix multiplication applied to classification (MICMAC) analysis to determine the root causes of the problem under study. The aim of this research is to identify the barriers of Industry 4.0 in supply chains based on literature review and expert opinions using ISM and MICMAC analysis. The importance of the research is that it categorizes such barriers based on their importance for solving the problem under study, which is Industry 4.0 adoption. Both scholars and practitioners could benefit from the present results in conducting further studies on Industry 4.0 barriers and their effects on other variables such as supply chain performance as well as prioritizing efforts dedicated to encouraging Industry 4.0 adoption. This research is structured as follows. The next section introduces a literature review of Industry 4.0 and its related barriers. Section 3 highlights the methodology applied in this research, followed by section 4 for results and discussion, section 5 for conclusion, limitations, and future research directions.

2. Literature review

2.1 Industry 4.0

Industry 4.0 has been described as information technology driven changes in manufacturing systems (Lasi et al., 2014). It can be understood as an integration between information and communication technologies (ICT) and manufacturing processes, therefore, ICT and technologies of manufacturing are regarded as two pillars of Industry 4.0 (Alshawabkeh et al., 2022; Tariq et al., 2022; Alolayyan et al., 2022; Dalenogare et al., 2018). A key theme of Industry 4.0 is a cyber-physical production system, which is based on knowledge integration to achieve agility in production systems (Sony & Naik, 2019).There are many technologies of Industry 4.0 such as Internet of Things (IoT), big data, artificial intelligence, additive manufacturing (Ertz et al., 2022; Khalayleh & Al-Hawary, 2022; AL-Zyadat et al., 2022), enterprise resource planning (ERP), social product development, radio frequency identification (RFID), and cloud-based manufacturing (Mohammad et al., 2022; Al-Abbadi et al., 2022; Sony & Naik, 2019). In terms of its benefits, prior works (e.g., Dalenogare et al., 2018) cited 14 expected benefits of Industry 4.0 including improving product customization, enhancing product quality, reducing operational costs, increasing productivity, and elevating process control.

2.2 Barriers to adopt Industry 4.0

There are many barriers to adopt the technologies of Industry 4.0. Examples of these barriers as cited in the literature are reported in Table 1 involve lack of infrastructure such as Internet coverage and ICT technologies, employee resistance to adopt new technologies, lack of funds, uncertainty of Industry 4.0 economic benefits, and lack of adequate skills for Industry 4.0 (Kumar et al., 2021). Reviewing the literature, Raj et al. (2020) identified 15 barriers to Industry 4.0 such as lack of digital strategy and scare resources, lack of standards, regulations, and certifications, low maturity level of the desired technology, lack of internal digital training, lack of digital skills, high investment in Industry 4.0 implementation, and challenges in value-chain integration. Other barriers were mentioned in the literature such as lack of readiness for innovation, lack of cooperation with suppliers, and lack of training (Karadayi-Usta, 2019). In their study on the barriers of Industry 4.0 in small and medium enterprises, Goel et al. (2022) used 15 barriers including unskilled personnel, lack of stakeholders' enthusiasm, financial support and technical knowledge.

Table 1
Barriers to adopt Industry 4.0 in supply chains

No.	Barriers	References
1	Lack of infrastructure: no funds to build a digital infrastructure	Kumar et al. (2021); Raj et al. (2020); Karadayi-Usta (2019); Goel et al. (2022); Vigneshvaran and Vinodh (2022); Halse and Jæger (2019); Hughes et al. (2022); Chauhan et al., (2021); Ghadge et al. (2020); Shang et al. (2022), Ada et al. (2021); Raj et al. (2020); Machado et al. (2021).
2	Personnel resistance to adopt new technologies	
3	Cybersecurity challenges	
4	High investment requirements	
5	Data management and quality challenges such as big data	
6	Lack of digital strategy	
7	Uncertainty of economic benefits	
8	Low maturity level of technology	
9	Lack of adequate skills	
10	Job disruptions: Changing the structure of jobs through automation	

In a study on barriers to integrate lean with Industry 4.0, Vigneshvaran and Vinodh (2022) analyzed 16 barriers related to personnel resistance to change, lack of adequate digital skills, lack of financial support, risk of cyber security, lack of management support, absence of Industry 4.0 strategy, and lack of long-term vision as well as lack of standards. Examples of other barriers cover employee fair to lose jobs (Halse & Jæger, 2019), and lack of financial support (Hughes et al., 2022). Ghadge et al. (2020) categorized the barriers of Industry 4.0 into four classes: organizational barriers, legal and ethical barriers, strategic barriers, and technological barriers. Six barriers were categorized under organizational barriers, which are resistance to change, lack of management support, expertise, and digital vision, financial constraints, complex network systems. Legal and ethical barriers include legal and security issues, while strategic barriers comprise lack of digital culture and unclear economic benefits. Finally, technological barriers embrace lack of digital infrastructure and poor data management and quality. For the current study, 10 barriers to adopt Industry 4.0 were chosen as shown in Table 1.

3. Methodology

Six steps were followed to analyze Industry 4.0 barriers. First, barriers of Industry 4.0 adoption were identified based on a review of the literature. Second, significant barriers were determined based on opinions of a panel of industry and academic experts. Third, a structural self-interaction matrix (SSIM) was developed to establish relationships among barriers referring to the opinions of the experts' panel. Fourth, an initial reachability matrix (IRM) was advanced, on which a final reachability matrix (FRM) was extracted. Fifth, barriers of Industry 4.0 were partitioned to identify reachability, antecedent, and intersection sets. Finally, using interpretive structural modeling (ISM), a structural model of barriers to adopt Industry 4.0 was constructed. Such a methodology was applied in many prior works (e.g., Kamble et al., 2018; Karadayi-Usta, 2019; Raj et al., 2020; Kumar et al., 2021; Etemadi et al., 2021; Sarkar & Shankar, 2021; Gupta & Goyal, 2021; Goel et al., 2022; Godinho et al., 2022; Desingh, 2022, Verma et al., 2022).

3.1 Structural self-identification matrix (SSIM)

SSIM as shown in Table 2 was established based on opinions of an industry and academic panel of experts from industry sector using four symbols: "V" suggests that barrier *i* will affect barrier *j*, "A" suggests that barrier j will affect barrier i, "X" assumes that barriers i and j will affect each other, and "O" implies that barriers i and j are uncorrelated (Vigneshvaran & Vinodh, 2020). SSIM matrix was used to establish the initial reachability matrix (IRM). Results of SSIM in Table 2 indicate that solving barrier 1 affects barriers 2, 5, and 6 as shown in the first row. Furthermore, barriers 1 and 8 affect each other, while there are no relationships between barrier 1 and barriers 3, 7, 9, and 10. As well, the second row means that solving barrier 2 deals with barriers 6 and 7, barrier 8 exerts a direct effect on barrier 2, no relationships between barrier 2 and barriers 3, 4, and 5, barriers 2 and 9 affect each other, and no relationships between barrier 7 and barriers 8, 9, and 10. As well, barriers 2 and 10 affect each other. The other rows in the table are interpreted in a similar way. Interpreting the results based on the columns shows that barrier 4 will affect barrier 1, barrier 7 will affect barriers 4, 5, and 6, barrier 8 will affect barriers 2, 4, and 5, barrier 9 will affect barrier 4, and barrier 10 will affect barrier 6.

Table 2
Structural Self-Interaction Matrix

Barrie	Bj	Bj	Bj	Bj	Bj	Bj	Bj	Bj	Bj	Bj1
Bi1	-	V	O	A	V	V	O	X	O	O
Bi2		-	O	O	O	V	V	A	X	X
Bi3			-	O	O	O	O	O	O	O
Bi4				-	V	O	A	A	A	O
Bi5					-	O	A	A	V	V
Bi6						-	A	O	O	A
Bi7							-	O	O	O
Bi8								-	O	O
Bi9									-	X
Bi10										-

Table 3
Initial Reachability Matrix

Barrie	Bj	Bj	Bj	Bj	Bj	Bj	Bj	Bj	Bj	Bj1
Bi1	1	1	0	0	1	1	0	1	0	0
Bi2	0	1	0	0	0	1	1	0	1	1
Bi3	0	0	1	0	0	0	0	0	0	0
Bi4	1	0	0	1	1	0	0	0	0	0
Bi5	0	0	0	0	1	0	0	0	1	1
Bi6	0	0	0	0	0	1	0	0	0	0
Bi7	0	0	0	1	1	1	1	0	0	0
Bi8	1	1	0	1	1	0	0	1	0	0
Bi9	0	1	0	1	0	0	0	0	1	1
Bi10	0	1	0	0	0	1	0	0	1	1

3.1 Initial reachability matrix

SSIM is used to develop an initial reachability matrix (IRM) based on four rules (Karadayi-Usta, 2019; Kumar et al., 2021; Vigneshvaran & Vinodh, 2020), which are:

(1) V (i, j) entrance becomes "1" when barrier (i) exerts effect on barrier (j) and V (j, i) entrance becomes "0", when barrier (j) exerts effect on barrier (i).

(2) A (i, j) entrance becomes "0" when barrier (i) exerts effect on barrier (j) and V (j, i) entrance becomes "1" when barrier (j) exerts effect on barrier (i).

(3) Both X (i, j) entrance and X (j, i) entrance become "1" when barrier (i) affects barrier (j) and when barrier (j) affects barrier (i).

(4) Both O (i, j) entrance and X (j, i) entrance become "0".

Based on these rules, the initial reachability matrix as shown in Table 3 was created. Letters "V", "A", "X", and "O" are transformed into binary digits (0, 1) (Goel et al., 2022). For example, letter "V" in (1, 2) cell in Table 2 became "1" in the same cell and "0" in cell (2, 1), letter "A" in (1, 4) cell in Table 2 became "0" and became "1" in (4, 1) cell in Table 3, letter "O" in the fifth row become "0" in (5, 6) cell and became "0" in (6, 5) cell, and letter "X" in the ninth row in (9, 10) cell in Table 2 became "1" in the same cell in Table 2.

3.2 Final reachability matrix (FRM)

Final reachability matrix as shown in Table 4 contains essential transitive links (1*) between barriers of Industry 4.0. Transitive links are calculated based on the following rule: if barrier A is linked to barrier B and barrier B is linked to barrier C, then barriers A is linked to barrier C (Vigneshvaran & Vinodh, 2020). Examples: Bi2 (Personnel resistance to adopt new technologies) to Bj7 (Uncertainty of economic benefits) in the initial reachability matrix is "1" and Bj7 (Uncertainty of economic benefits) to Bj4 (high investment requirements) is 1, then,Bi2 (Personnel resistance to adopt new technologies) to Bj4 (High investment requirements) in the final reachability matrix should be (1*).Bi8 (Low maturity level of technology) to Bj3 (Cyber security challenges) in the initial reachability matrix is "0" and remains "0" in the final reachability matrix because Bi8 (Low maturity level of technology) to Bj1 (Lack of infrastructure) is "1" but Bj3 (Cyber security challenges) to Bi1 is "0", Bi8 (Low maturity level of technology) to Bj2 (Personnel resistance to adopt new technologies) is "1" but Bj3 to Bi2 is "0", Bi8 (Low maturity level of technology) to Bj4 (High investment requirements) is "1" but Bj3 to Bi4 is "0", and Bi8 (Low maturity level of technology) to Bj5 (Data management and quality challenges) is "1" but Bj3 to Bi5 is "0".

Table 4
Final Reachability Matrix(FRM)

Barriers	Bj1	Bj2	Bj3	Bj4	Bj5	Bj6	Bj7	Bj8	Bj9	Bj10	DRP	R
Bi1	1	1	0	1*	1	1	1*	1	1*	1*	9	1
Bi2	1*	1	0	1*	1*	1	1	1*	1	1	9	1
Bi3	0	0	1	0	0	0	0	0	0	0	1	2
Bi4	1	1*	0	1	1	1*	1*	1*	1*	1*	9	1
Bi5	1*	1*	0	1*	1	1*	1*	1*	1	1	9	1
Bi6	0	0	0	0	0	1	0	0	0	0	1	2
Bi7	1*	1*	0	1	1	1	1	1*	1*	1*	9	1
Bi8	1	1	0	1	1	1*	1*	1	1*	1*	9	1
Bi9	1*	1	0	1	1*	1*	1*	1*	1	1	9	1
Bi10	1*	1	0	1*	1*	1	1*	1*	1	1	9	1
DEP	8	8	1	8	8	9	8	8	8	8		
R	2	2	3	2	2	1	2	2	2	2		

DRP: Driving power; DEP: Dependency power; R: Rank.

3.3 Level Partitioning (LP)

Three sets were extracted; reachability set, antecedent set, and intersection set. The Reachability set was established bearing in mind a specific barrier and other barriers facilitating it. The antecedent set was initiated considering a particular barrier and other barriers enabling it (Goel et al., 2022). The intersection set was recognized based on identical barriers in both reachability and antecedent sets. The first iteration of barriers partitioning is finished after reaching level 1, which refers to similar reachability and intersection sets. A barrier that is assigned to a specific level is removed in the next iteration and so on to reach the final iteration. The results in Table 5 illustrate the final partitions pulled out from all iterations. It can be observed that two barriers (B3 & B6) were in level 1 and other barriers were in level 2.

Table 5
Final results of level partitions

	Reachability set	Antecedent set	Intersection set	Level
B1	1, 2, 4, 5, 7, 8, 9, 10,	1, 2, 4, 5, 7, 8, 9, 10,	1, 2, 4, 5, 7, 8, 9, 10,	2
B2	1, 2, 4, 5, 7, 8, 9, 10,	1, 2, 4, 5, 7, 8, 9, 10,	1, 2, 4, 5, 7, 8, 9, 10,	2
B3	3,	3,	3,	1
B4	1, 2, 4, 5, 7, 8, 9, 10,	1, 2, 4, 5, 7, 8, 9, 10,	1, 2, 4, 5, 7, 8, 9, 10,	2
B5	1, 2, 4, 5, 7, 8, 9, 10,	1, 2, 4, 5, 7, 8, 9, 10,	1, 2, 4, 5, 7, 8, 9, 10,	2
B6	6,	1, 2, 4, 5, 6, 7, 8, 9, 10,	6,	1
B7	1, 2, 4, 5, 7, 8, 9, 10,	1, 2, 4, 5, 7, 8, 9, 10,	1, 2, 4, 5, 7, 8, 9, 10,	2
B8	1, 2, 4, 5, 7, 8, 9, 10,	1, 2, 4, 5, 7, 8, 9, 10,	1, 2, 4, 5, 7, 8, 9, 10,	2
B9	1, 2, 4, 5, 7, 8, 9, 10,	1, 2, 4, 5, 7, 8, 9, 10,	1, 2, 4, 5, 7, 8, 9, 10,	2
B10	1, 2, 4, 5, 7, 8, 9, 10,	1, 2, 4, 5, 7, 8, 9, 10,	1, 2, 4, 5, 7, 8, 9, 10,	2

3.4 ISM Model

ISM model in Fig. 1 was constructed based on the final results of level partitions. It was conducted following Ahmad and Qahmash (2021). It indicates that two barriers, i.e., barrier 3 and barrier 6 are at the top of the model in level 1, and the other barriers, i.e., 1, 2, 4, 5, 7, 8, 9, and 10, are in the second level. The figure shows that barrier 3 (Cyber security challenges) was excluded due its weak dependence power (DEP = 1) and driving power (DRP = 1). On the other side, barrier 6 (Lack of digital strategy) has a strong dependence power (DEP = 9) and weak driving power (DRP = 1).

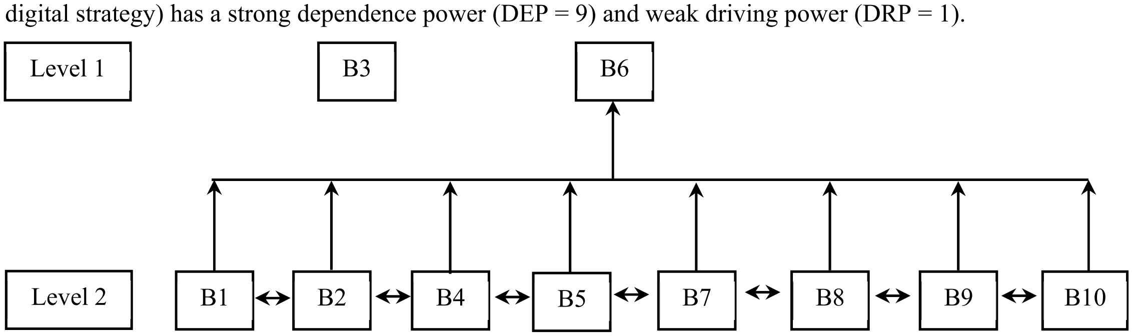

Fig. 1. ISM model of barriers to adopt Industry 4.0 in supply chains

3.5 *MICMAC analysis*

MICMAC analysis is carried out using both driving and dependency powers of the barriers (Karadayi-Usta, 2019). In such an analysis, barriers of adopting Industry 4.0 are categorized into autonomous variables (I), dependent variables (II), linkage variables (III), and independent variables (IV). Autonomous variables have weak driving power and dependence power, therefore, have no effect on other variables, while dependent variables show very weak driving power and very strong dependency power (Goel et al., 2022). Linkage variables have strong dependence power and strong driving power, which means that actions on these variables have effects on other variables in the higher level. Finally, independent variables have weak dependence power and high driving power, hence, such variables are called driving variables (Etemadi et al., 2021). The results of MICMAC analysis are shown in Fig. 2. It can be noted that barrier 3 is an autonomous variable, while barrier 6 is a dependent variable. The figure shows that there are no independent variables, whereas there are 8 linkage variables (i.e., 1, 2, 4, 5, 7, 8, 9, 10).

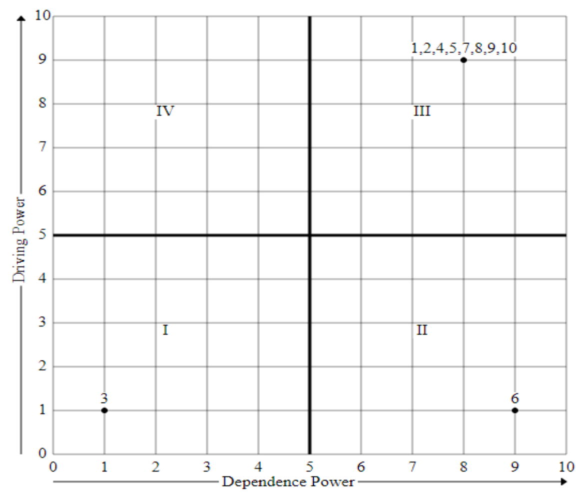

Fig. 2. Results of MICMAC analysis

4. Results and discussion

Exploring barriers to adopt Industry 4.0 in supply chains using interpretive structural modeling to analyze 10 barriers identified based on a review of literature and opinions of a panel of experts pointed out that one barriers (barrier 3: cyber security challenges) was an autonomous variables and therefore excluded, which means that this barrier had no effect itself on the adoption of Industry 4.0 or on the other nine variables. On top, one barrier (barrier 6: lack of digital strategy) was a dependent variable, which means it depends on actions on other barriers. Moreover, there were no independent variables in the current case. Independent variables are the most critical variables because they are driving variables. The remaining barriers were linkage variables, in other words, they have a direct impact on barrier 6. These variables are lack of infrastructure, personnel resistance to adopt new technologies, high investment requirements, data management and quality challenges, uncertainty of economic benefits, low maturity level of technology, lack of adequate skills, and job disruptions or changing the structure of jobs through different means such as automation. In total, the most important barriers of adopting Industry 4.0 are those regarded as linkage variables. They are required to develop an adequate digital strategy for Industry 4.0 adoption and to deal with scarce resources. A summary of research findings is reported in Table 6 in which the current barriers are categorized into three types.

Table 6
Summary of research results

Variables	No.	Description	Level
Autonomous variables	3	Cybersecurity challenges	1
Dependent variables	6	Lack of digital strategy	1
Independent variables	-	-	
Linkage variables	1	Lack of infrastructure: no funds to build a digital infrastructure	2
	2	Personnel resistance to adopt new technologies	2
	4	High investment requirements	2
	5	Data management and quality challenges such as big data	2
	7	Uncertainty of economic benefits	2
	8	Low maturity level of technology	2
	9	Lack of adequate skills	2
	10	Job disruptions: Changing the structure of jobs	2

In comparison with previous results, cyber security challenges, which was excluded in the current research, was a linkage barrier of adopting Industry 4.0 (Kumar et al., 2021). In agreement with the same authors, lack of infrastructure, high investment requirements, and data management and quality challenges were linkage variables. For Raj et al., 2020, barrier 6 (lack of digital strategy and scarce resources) was the most important variable in developing and developed economies. Generally, the current results are consistent with previous results reached by prior studies (Karadayi-Usta, 2019; Goel et al., 2022; Vigneshvaran & Vinodh, 2022; Halse & Jæger, 2019; Hughes et al., 2022; Ghadge et al., 2020).

5. Conclusion, limitations, and future research directions

Based on the current results, it was concluded that enhancing the adoption of Industry 4.0 requires considering 8 barriers, which are lack of infrastructure, personnel resistance to adopt new technologies, high investment requirements, data management and quality challenges, uncertainty of economic benefits, low maturity level of technology, lack of adequate skills, and job disruptions. Mitigating these barriers boosts companies' abilities to adopt industry 4.0 technologies. Therefore, companies are required to handle digital infrastructures, identify the economic benefits of adopting Industry 4.0, and train their employees to acquire more digital skills. This research is limited to exploring the importance of 10 barriers to adopt Industry 4.0, therefore, more studies are required to explore more barriers using additional expert opinions. The current results distributed Industry 4.0 barriers into two levels; level 1 (barriers 3 & 6) and level 2 (barriers 1, 2, 4, 5, 7, 8, 9, 10). In order to rank the barriers in the second level, a new study is required to analyze these eight barriers.

References

Ada, N., Kazancoglu, Y., Sezer, M. D., Ede-Senturk, C., Ozer, I., & Ram, M. (2021). Analyzing barriers of circular food supply chains and proposing industry 4.0 solutions. *Sustainability*, *13*(12), 6812.

Ahmad, N., & Qahmash, A. (2021). SmartISM: Implementation and assessment of Interpretive Structural Modeling. *Sustainability, 13*(16), 8801. https://doi.org/10.3390/su13168801.

Al-Abbadi, L., Bader, D., Mohammad, A., Al-Quran, A., Aldaihani, F., Al-Hawary, S., & Alathamneh, F. (2022). The effect of online consumer reviews on purchasing intention through product mental image. *International Journal of Data and Network Science*, *6*(4), 1519-1530.

Al-Alwan, M., Al-Nawafah, S., Al-Shorman, H., Khrisat, F., Alathamneh, F., & Al-Hawary, S. (2022). The effect of big data on decision quality: Evidence from telecommunication industry. *International Journal of Data and Network Science*, *6*(3), 693-702.

Al-khawaldah, R., Al-zoubi, W., Alshaer, S., Almarshad, M., ALShalabi, F., Altahrawi, M., & Al-hawary, S. (2022). Green supply chain management and competitive advantage: The mediating role of organizational ambidexterity. *Uncertain Supply Chain Management*, *10*(3), 961-972.

Al-Nawafah, S., Al-Shorman, H., Aityassine, F., Khrisat, F., Hunitie, M., Mohammad, A., & Al-Hawary, S. (2022). The effect of supply chain management through social media on competitiveness of the private hospitals in Jordan. *Uncertain Supply Chain Management*, *10*(3), 737-746.

Alolayyan, M., Al-Rwaidan, R., Hamadneh, S., Ahmad, A., AlHamad, A., Al-Hawary, S., & Alshurideh, M. (2022b). The mediating role of operational Flexibility on the relationship between quality of health information technology and management capability. *Uncertain Supply Chain Management*, *10*(4), 1131-1140.

Alshawabkeh, R., AL-Awamleh, H., Alkhawaldeh, M., Kanaan, R., Al-Hawary, S., Mohammad, A., & Alkhawalda, R. (2022). The mediating role of supply chain management on the relationship between big data and supply chain performance using SCOR model. *Uncertain Supply Chain Management*, *10*(3), 729-736.

AL-Zyadat, A., Alsaraireh, J., Al-Husban, D., Al-Shorman, H., Mohammad, A., Alathamneh, F., & Al-Hawary, S. (2022). The effect of industry 4.0 on sustainability of industrial organizations in Jordan. *International Journal of Data and Network Science*, *6*(4), 1437-1446.

Chauhan, C., Singh, A., & Luthra, S. (2021). Barriers to industry 4.0 adoption and its performance implications: An empirical investigation of emerging economy. *Journal of Cleaner Production*, *285*, 124809.

Dalenogare, L. S., Benitez, G. B., Ayala, N. F., & Frank, A. G. (2018). The expected contribution of Industry 4.0 technologies for industrial performance. *International Journal of Production Economics*, *204*, 383-394.

Desingh, V. (2022). Internet of Things adoption barriers in the Indian healthcare supply chain: An ISM-fuzzy MICMAC approach. *The International Journal of Health Planning and Management*, *37*(1), 318-351.

Ertz, M., Sun, S., Boily, E., Kubiat, P., & Quenum, G. G. Y. (2022). How transitioning to Industry 4.0 promotes circular product lifetimes. *Industrial Marketing Management*, *101*, 125-140.

Etemadi, N., Van Gelder, P., & Strozzi, F. (2021). An ism modeling of barriers for blockchain/distributed ledger technology adoption in supply chains towards cybersecurity. *Sustainability*, *13*(9), 4672.

Fernando, Y., Wahyuni-TD, I. S., Gui, A., Ikhsan, R. B., Mergeresa, F., & Ganesan, Y. (2022). A mixed-method study on the barriers of industry 4.0 adoption in the Indonesian SMEs manufacturing supply chains. *Journal of Science and Technology Policy Management*.

Ghadge, A., Kara, M. E., Moradlou, H., & Goswami, M. (2020). The impact of Industry 4.0 implementation on supply chains. *Journal of Manufacturing Technology Management*, *31*(4), 669-686.

Godinho F. M., Monteiro, L., de Oliveira Mota, R., dos Santos Leite Gonella, J., & de Souza Campos, L. M. (2022). The Relationship between Circular Economy, Industry 4.0 and Supply Chain Performance: A Combined ISM/Fuzzy MICMAC Approach. *Sustainability*, *14*(5), 2772.

Goel, P., Kumar, R., Banga, H. K., Kaur, S., Kumar, R., Pimenov, D. Y., & Giasin, K. (2022). Deployment of Interpretive Structural Modeling in Barriers to Industry 4.0: A Case of Small and Medium Enterprises. *Journal of Risk and Financial Management*, *15*(4), 171.

Gupta, A. K., & Goyal, H. (2021). Framework for implementing big data analytics in Indian manufacturing: ISM-MICMAC and Fuzzy-AHP approach. *Information Technology and Management*, *22*(3), 207-229.

Halse, L. L., & Jæger, B. (2019). *Operationalizing industry 4.0: Understanding barriers of industry 4.0 and circular economy. In Proceedings of the Advances in Production Management Systems: Towards Smart Production Management System, Berlin*, Germany, 1–9 September 2019; pp. 135–142.

Hughes, L., Dwivedi, Y. K., Rana, N. P., Williams, M. D., & Raghavan, V. (2022). Perspectives on the future of manufacturing within the Industry 4.0 era. *Production Planning & Control*, *33(*2-3), 138-158.

Kamble, S. S., Gunasekaran, A., & Sharma, R. (2018). Analysis of the driving and dependence power of barriers to adopt industry 4.0 in Indian manufacturing industry. *Computers in Industry, 101*, 107-119.

Karadayi-Usta, S. (2019). An interpretive structural analysis for industry 4.0 adoption challenges. *IEEE Transactions on Engineering Management*, *67*(3), 973-978.

Khalayleh, M., & Al-Hawary, S. (2022). The impact of digital content of marketing mix on marketing performance: An experimental study at five-star hotels in Jordan. *International Journal of Data and Network Science*, *6*(4), 1023-1032.

Kumar, P., Bhamu, J., & Sangwan, K. S. (2021). Analysis of barriers to Industry 4.0 adoption in manufacturing organizations: An ISM approach. *Procedia CIRP*, 98, 85-90.

Lasi, H., Fettke, P., Kemper, H. G., Feld, T., & Hoffmann, M. (2014). Industry 4.0. *Business & Information Systems Engineering*, 6(4), 239-242.

Machado, E., Scavarda, L. F., Caiado, R. G. G., & Thomé, A. M. T. (2021). Barriers and enablers for the integration of industry 4.0 and sustainability in supply chains of MSMEs. *Sustainability*, *13*(21), 11664.

Mohammad, A., Aldmour, R., & Al-Hawary, S. (2022). Drivers of online food delivery orientation. *International Journal of Data and Network Science*, *6*(4), 1619-1624.

Ozkan-Ozen, Y. D., Kazancoglu, Y., & Mangla, S. K. (2020). Synchronized barriers for circular supply chains in industry 3.5/industry 4.0 transition for sustainable resource management. *Resources, Conservation and Recycling*, *161*, 104986.

Raj, A., Dwivedi, G., Sharma, A., de Sousa Jabbour, A. B. L., & Rajak, S. (2020). Barriers to the adoption of industry 4.0 technologies in the manufacturing sector: An inter-country comparative perspective. *International Journal of Production Economics*, *224*, 107546.

Sarkar, B. D., & Shankar, R. (2021). Understanding the barriers of port logistics for effective operation in the Industry 4.0 era: Data-driven decision making. *International Journal of Information Management Data Insights*, *1*(2), 100031.

Shang, C., Saeidi, P., & Goh, C. F. (2022). Evaluation of circular supply chains barriers in the era of Industry 4.0 transition using an extended decision-making approach. *Journal of Enterprise Information Management*, *35*(4/5), 1100-1128.

Sharma, M., Kamble, S., Mani, V., Sehrawat, R., Belhadi, A., & Sharma, V. (2021). Industry 4.0 adoption for sustainability in multi-tier manufacturing supply chain in emerging economies. *Journal of cleaner production*, *281*, 125013.

Sony, M., & Naik, S. (2019). Key ingredients for evaluating Industry 4.0 readiness for organizations: A literature review. *Benchmarking: An International Journal*. http://doi:10.1108/BIJ-09-2018-0284.

Tariq, E., Alshurideh, M., Akour, I., & Al-Hawary, S. (2022). The effect of digital marketing capabilities on organizational ambidexterity of the information technology sector. *International Journal of Data and Network Science*, *6*(2), 401-408.

Verma, P., Kumar, V., Daim, T., Sharma, N. K. and Mittal, A. (2022). Identifying and prioritizing impediments of industry 4.0 to sustainable digital manufacturing: A mixed method approach. *Journal of Cleaner Production*, *356*, 131639.

Vigneshvaran, R., & Vinodh, S. (2020). Development of a structural model based on ISM for analysis of barriers to integration of lean with industry 4.0. *The TQM Journal*, *33*(6), 1201-1221. DOI 10.1108/TQM-07-2020-0151.