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Evaluating the challenges encountered in the **white goods ındustry in the adaptation process to ındustry 4.0 via** a hybrid MCDM model

Endüstri 4.0'a uyum sürecinde beyaz eşya sektöründe karşılaşılan zorlukların hibrit bir ÇKKV modeli ile değerlendirilmesi

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Evaluating the Challenges Encountered in the White Goods Industry in the Adaptation Process to Industry 4.0 via a Hybrid MCDM Model

Highlights

- *This paper identifies and analyzes the adoption challenges of Industry 4.0 in the Turkish white goods industry*
- *The DEMATEL (Decision Making Trial and Evaluation Laboratory) approach quantifies the influence of the barriers amongst one another*
- *The Interpretive Structural Modelling (ISM) obtains hierarchical structure of the difficulties*
- *The research findings would help organizations in successful adoption to Industry 4.0 in the Turkish white goods industry*

Graphical Abstract

This study identifies and analyzes the challenges related to adoption of Industry 4.0 in the Turkish white goods industry.

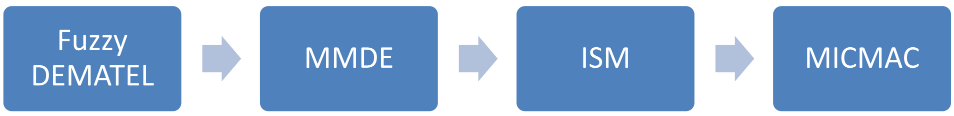

Figure. Methodology of the study

Aim

The aim of this study is to define and analyze the difficulties for the adoption of I4.0 in the white goods sector in Türkiye.

Design & Methodology

Firstly, difficulties of I4.0 adoption are determined and finalized by examining the literature. Then a hybrid MCDM approach consisting of the Fuzzy Decision Making Trial and Evaluation Laboratory (F-DEMATEL) method, the Maximum Mean De-Entropy (MMDE) technique, the interpretive structural modelling (ISM) technique and MICMAC analysis is used to evaluate relationships and interactions between difficulties.

Originality

When literature is investigated, we didn't find any study about industry 4.0 challenges performed in white goods industry. This study one of the first studies performed in white goods industry in Türkiye. Also, this study is one of the first studies in which the fuzzy DEMATEL and ISM with MICMAC analysis was combined together in evaluation of Industry 4.0 difficulties.

Findings

Findings show that "Lack of technological infrastructure and networks powered by the internet" and "Lack of integration of data and technology platforms" are the difficulties that have the strongest driving power, and they have direct or indirect effects on other difficulties.

Conclusion

The proposed approach can provide industrial practitioners and managers with a more realistic picture of the issues that will arise during the adoption of I4.0 in manufacturing industries, which will aid them in making decisions, and that can assist them in successfully integrating I4.0 practices in their organizations.

Declaration of Ethical Standards

The authors of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Evaluating the Challenges Encountered in the White Goods Industry in the Adaptation Process to Industry 4.0 via a Hybrid MCDM Model

Araştırma Makalesi / Research Article

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ABSTRACT

The aim of this study is to define and analyze the difficulties for the adoption of I4.0 in the white goods sector in Türkiye. Firstly, difficulties of I4.0 adoption are determined and finalized by examining the literature. Then a hybrid MCDM approach consisting of the Fuzzy Decision Making Trial and Evaluation Laboratory (F-DEMATEL) method, the Maximum Mean De-Entropy (MMDE) technique, the interpretive structural modelling (ISM) technique and MICMAC analysis is used to evaluate relationships and interactions between difficulties. Findings show that "Lack of technological infrastructure and networks powered by the internet" and "Lack of integration of data and technology platforms" are the difficulties that have the strongest driving power, and they have direct or indirect effects on other difficulties. These are the main difficulties for Industry 4.0 adoption in white good production industry. On the other hand, "Ineffective communication and cooperation amongst supply chain participants" is found out the most affected difficulty directly or indirectly from other difficulties.

Keywords: Industry 4.0, fuzzy DEMATEL, ISM, MICMAC, difficulties for Industry 4.0, white goods industry.

Endüstri 4.0'a Uyum Sürecinde Beyaz Eşya Sektöründe Karşılaşılan Zorlukların Hibrit bir ÇKKV Modeli ile Değerlendirilmesi

ÖZ

Bu çalışmanın amacı, Türkiye'de beyaz eşya sektöründe I4.0'ın benimsenmesindeki zorlukları tanımlamak ve analiz etmektir. Öncelikle literatür incelenerek I4.0'ın benimsenmesinin zorlukları belirlenir ve sonuçlandırılır. Daha sonra ilişkileri değerlendirmek için Bulanık Karar Verme Deneme ve Değerlendirme Laboratuvarı (F-DEMATEL) yöntemi, Maksimum Ortalama De-Entropi (MMDE) tekniği, yorumlayıcı yapısal modelleme (ISM) tekniği ve MICMAC analizinden oluşan hibrit bir MCDM yaklaşımı kullanılarak zorluklar arasındaki etkileşimler incelenmiştir. Bulgular, "İnternet destekli ağların ve teknolojik altyapının olmaması" ile "Veri ve teknoloji platformlarının entegrasyonunun olmaması"nın en güçlü itici güce sahip zorluklar olduğunu ve diğer zorluklar üzerinde doğrudan veya dolaylı etkileri olduğunu göstermektedir. Bunlar, beyaz eşya üretim endüstrisinde Endüstri 4.0'ın benimsenmesinin ana zorluklarıdır. Öte yandan, "Tedarik zinciri katılımcıları arasında etkin olmayan iletişim ve işbirliği", diğer zorluklardan doğrudan veya dolaylı olarak en çok etkilenen zorluk olarak bulunmuştur.

Anahtar Kelimeler: Endüstri 4.0, bulanık DEMATEL, ISM, MICMAC, Endüstri 4.0 için zorluklar, beyaz eşya sektörü.

1. INTRODUCTION

Industry 4.0 (I4.0) adverts the cross-organizational integration of physical objects, smart devices, human factors, manufacturing lines, and processes in order to initiate a system in which all operations are connected and communicate knowledge in real time [1]. I4.0 execution paves the way for manufacturing sectors to increase productivity, cost decrease, and efficiency. Manufacturing sectors can potentially set off these opportunities to meet the ever-increasing need for innovation and shorter product life cycles [2]. The core principles of I4.0 are thus the machines' interconnection, work items, and systems, and firms are developing smart networks that can control each other autonomously along the full value chain [3].

Numerous physical and digital technologies are combining through analytics, robotics, artificial intelligence, digitization, and the internet of things. By allowing to companies to be faster, more adaptable, and more effective processes, these technologies are enabling the development of digital businesses that will enable the production of high-quality items at lower costs. I4.0 will ultimately contribute strategically to increased productivity, significantly improve the economies of all industry segments, and lead to real and progressive growth as well as a complete shift in the competitive power of organizations globally [4].

Businesses are related with applying new technologies as I4.0 to assure their long-term competitiveness and give

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them the adaption ability to dynamically changing environmental status like shortened product life cycles, increased variety, and shifting costumer expectations in line with the anticipated changes [5]. I4.0 does bring about improvements and opportunities as mentioned above, but it also brings difficulties that can be seen as dangerous to enterprises [6]. Despite the mounting demand, there are a number of challenges that could prevent manufacturers from applying I4.0. Managers must have knowledge about the difficulties of I4.0 in order to appropriately build plans to overcome the challenges that have been identified [7].

Many studies about I4.0 difficulties were performed in both developed countries and emerging countries. When developing and developed countries are compared, one of the most important differences is the low rate of industrialization in emerging countries. Developed countries have the benefit of having been early to adopt industrialization. This situation results in a gap, or in some circumstances, or in a precipice between developing and developed countries [8]. Because emerging countries have a distinct economic viewpoint and may not have the similar accession to technical innovation as developed countries, they will not experience the I4.0 in the same manner that developed countries perform [10]. Therefore, analyzing I4.0 implementation difficulties is very important for emerging countries.

Many studies were performed about difficulties which companies meet when implementing I4.0. Most of these studies were generally performed in manufacturing industry. There is very little study which is performed sector specific about I4.0 difficulties [4, 10, 11, 12]. Despite the fact that previous studies have looked into I4.0 difficulties, none of them have particularly attempted to analyze I4.0 adoption difficulties in the scope of the white goods sector. Therefore, white goods sector is determined as the context of this study, and this study focuses on I4.0 difficulties in Turkish white goods sector. The aims of this study are as following;

1. To define the difficulties involved with the application of I4.0 in Turkish white goods sector.
2. To evaluate I4.0 difficulties and define the hierarchy and relationships between the determined difficulties for Turkish white goods sector.
3. To group these difficulties with regard to their importance in the adoption of I4.0.

To achieve the first goal, after a comprehensive literature review was performed about difficulties of I4.0 application in white goods industry, I4.0 difficulties for white goods sector have been defined theoretically as seen in Table 2 and, then evaluated by experts. To study the hierarchy or relationship between the difficulties mentioned in the literature, this paper used an integrated methodology consisting of DEMATEL, MMDE and ISM combined with MICMAC analysis as the research methodology.

This paper is construct as following. Section 2 includes a brief literature review on difficulties when adopting to I4.0 and define research gap in the literature. The applied methodology is extensively explained in Section 3, and it explains fuzzy DEMATEL, MMDE and ISM, MICMAC respectively. Section 4 demonstrates a detailed investigation of the difficulties to adopt the implementation of I4.0 in the Turkish white goods sector and its results with discussion. Conclusions is given in Section 5.

2. THEORETICAL BACKGROUND AND RESEARCH GAP

There is a large and fast developing body of literature about I4.0. Literature focusing on barriers, challenges, hurdles, difficulties and obstacles to adopt I4.0 has been taken into account for this study. When I4.0 literature is investigated, it can be seen that many studies performed about challenges/hurdles/ barriers/difficulties of I4.0 implementation. Table 1 presents a literature summary related with I4.0 challenges/difficulties/barriers/hurdles.

The majority of the studies in the literature are performed in the scope of larger businesses and developed countries. When Table 1 is investigated, many studies about I4.0 challenges were performed in developed countries such as Germany [13, 2, 14, 15, 16], UK [3], Norway [4], Denmark [17], Japan [5], United States, Central Europe, and Northern Thailand [18], USA, Italy, Austria, and Thailand [19], Romania [20]. When developing and developed countries are compared, one of the most important differences is the low rate of industrialization in developing countries. Developed countries have the benefit of having been early to adopt industrialization. This situation results in a gap, or in some circumstances, or in a precipice between developing and developed countries [8]. Because emerging countries have a distinct economic viewpoint and may not have the similar accession to technical innovation as developed countries, they will not experience the I4.0 in the same manner that developed countries perform [9]. Therefore, analyzing I4.0 implementation challenges is very important for emerging countries. Most of the studies among emerging countries were performed in India [21, 14, 22, 4, 23, 24, 25, 26] as seen in Table 1.

Researchers and practitioners have used different qualitative and quantitative techniques, containing analytic hierarchy process (AHP) [17, 27], AHP-analytic network process (ANP) [28], Best-Worst Method (BWM) [10, 11, 29], ISM [21, 23, 30], ISM-MICMAC [22, 24, 31, 26], delphi method-ISM [32, 26], ISM-ANP [33], TISM [34] and DEMATEL [23, 16, 25, 35, 36, 37], fuzyy AHP-Kmeans [36], Structural Equation Modelling (SEM) [38, 3] to model the challenges of I4.0

Many studies were performed about challenges which companies meet when implementing I4.0. Most of these studies were performed in general manufacturing industry [22, 16, 39, 28, 3, 29, 24, 40, 25, 12, 7, etc.]. Some studies for I4.0 challenges were done for SMEs for example Orzes et al. [19], Rauch et al. [18], Stentoft et al. [17], Prause [5].

As seen in literature review in Table 1, there is very little study which is performed sector specific about I4.0 challenges. For example, leather industry [10], oil and gas sector [4], palm oil sector [32], automobile sector [11], sports goods manufacturing industry [31], healthcare [34], textile and clothing [26]. As seen from literature review, the white goods industry still doesn't receive enough attention about adoption challenges of I4.0. When literature is investigated, we didn't find any study about industry 4.0 challenges performed in white goods industry. Therefore, white goods sector is determined as the context of the study. In order to fill above research gaps, efforts have been made in this study.

Table 1. Literature review about I4.0 challenges/barriers/difficulties

Study	Method(s)	Number of Difficulties	Country	Sector
Macurova et al. [41]	Survey	9	The Czech Republic	Industrial Sector
Moktadir et al. [10]	Best-Worst method (BWM). MCDM	10	Bangladeshi	leather industry
Kamble et al. [22]	ISM Fuzzy set theory Fuzzy MICMAC Analysis	12	India	Manufacturing
Schneider [15]	Literature review	18	Germany	-
Glass et al. [16]	Survey Statistical analysis Student's t-tests,	15	Germany	Manufacturing industry
Luthra and Mangla [42]	Questionnaire, Exploratory Factor Analysis, AHP	16	India	Various sectors
Türkeş et al. [20]	Survey	6	Romania	Various sectors
Horváth and Szabó [43]	a grounded theory approach and interviews.	9	Hungary	Mostly SME International companies
Orzes et al. [19]	Focus group methodology	19	USA, Italy, Austria, and Thailand	SMEs
Muller [13]	Survey Interview	15	Germany	Manufacturing plant
Vogelsang et al. [39]	In-depth interviews Literature review	17	Germany	Manufacturing
Sevinç et al. [28]	AHP, ANP	14	Türkiye	Manufacturing
Mogos et al. [4]	Questionnaire survey workshops	6	Norvay	Oil and gas companies, manufacturing industries
Rauch et al. [18]	Expert workshops	14	USA, Central Europe, Northern Thailand	SMEs
Stentoft et al. [17]	Survey Statistical analyses	11	Denmark	SMEs
Prause [5]	Questionnaire survey		Japan	SMEs
Rajput and Singh [23]	ISM	20	India	Manufacturing
Masood and Sonntag [3]	PLS-SEM questionnaire	3	UK	Manufacturing
Karadayi-Usta [44]	ISM	9	Türkiye	Manufacturing
Kumar et al. [29]	Questionnaire survey DEMATEL	15	India	Manufacturing
Raj et al. [35]	Grey- DEMATEL	15	French and Indian Companies	Manufacturing
Vigneshvaran and Vinodh [24]	Interpretive Structural Modelling (ISM), MICMAC	16	India	Manufacturing
Abdul-Hamid et al. [32]	fuzzy Delphi Method, ISM	18	Malaysia	Palm oil industry
Bakhtari et al. [30]	ISM Expert opinion	12	İndia	Manufacturing
Contador et al. [40]	Questionnaire Survey	28	Brazil	Manufacturing
Kumar et al. [25]	Best Worst Method (BWM)	16	India	Manufacturing
Chauhan et al. [38]	Survey, SEM	20	India	Manufacturing
Kumar et al. [31]	DEMATEL	11	India	Sports Goods Manufacturing Industry
Kumar et al. [36]	K means clustering, fuzzy AHP, PCA	16	India	Manufacturing

Ajmera and Jain [34]	Total interpretive structural modelling (TISM)	15	India	Healthcare
Kumar et al. [12]	ISM with MICMAC	10	India	Manufacturing
Kumar et al. [33]	ISM, ANP	11	India	Agriculture supply chain
Nimawat and Gidwani [37]	DEMATEL	15	India	Manufacturing
Aygün and Satı [27]	Fuzzy AHP	9	Türkiye	SMEs Manufacturing
Jankowska et al. [7]	Questionnaire survey	11	Poland	Manufacturing
Turkes et al. [20]	Questionnaire	7	Romania	Pharma, Oil and Gas, Automotive, Chemical
Senna et al. [45]	ISM MICMAC	14	Portuguese	Manufacturing
Surange et al. [46]	VIKOR	14	India	Manufacturing
Singh et al. [47]	Dominance-based Rough Set Analysis (DRS	25	India	Construction

3. MATERIAL AND METHOD

In the literature many words used like challenges, barriers, hurdles, obstacles and difficulties. In this study we have used I4.0 difficulties. The Turkish white goods industry is one of the locomotive sectors of the Turkish economy with its advanced technology, innovative structure, high export income and employment opportunities. Türkiye, which realizes half of the world's white good production, has an important place in the sector, and Turkish white goods industry is the second biggest production base in the world after China. It is the largest production base in Europe, and Europe's largest white goods producer [48].

The Turkish white goods sector achieved a production increase of 10.8% between 2016 and 2020, achieved a growth of 12% in exports in the same period, and exported 22.0 million white goods in 2020. This rate corresponds to 76% of the total Turkish white goods production. 95% of the white goods sold in Türkiye are manufactured within Türkiye and nearly 70% of the production is carried out with domestic production input [48]. The main export market is the European Union. Exports are made to more than 100 countries and the sector ranks 7th in the world in terms of exports. From all these information, it is clear that white goods manufacturing sector is very important for Turkish economy. Therefore, this study provides very important insights for this sector and Turkish manufacturing industry.

Difficulties, which impede the adoption of I4.0 in Turkish white goods sector, were identified based on an existing survey of related literature and subsequent discussion with industry and academia specialists as presented in Table 2 with their references.

In this study, an integrated approach consisting of fuzzy DEMATEL, MMDE and ISM with MICMAC are employed to determine critical difficulties for adoption of I4.0 in white goods sector in Türkiye. The research framework of the study is demonstrated in Fig. 1. Initially, potential difficulties to I4.0 implementations were defined with the support of expert opinions and in-depth literature review. Afterward, the data provided from the experts with the questionnaire were analyzed, and the results were evaluated.

The methodology of the study includes fuzzy DEMATEL, MMDE, ISM, MICMAC. DEMATEL is performed to define the intensity of the relationship and interaction between factors. ISM, on the other hand, is utilized to determine the effects of factors on each other and to prioritize the factors by levelling them in a system. Because DEMATEL and ISM methods complement each other, both methods are integrated in this study. While combining these two methods, the MMDE, which is a scientific method and based on entropy calculation, was used instead of expert opinions or trial and error to determine the threshold level, Thus, it is aimed to determine the threshold value more effectively [53, 54].

Fuzzy set theory is also utilized in an integrated manner with the DEMATEL method, as it is successful in modelling vagueness and imprecision in linguistic factors [55].

3.1. Fuzzy DEMATEL

DEMATEL is one of the MCDM techniques applied to define the causal and effect relationship between factors. It is often used in complex situations to reveal the effect of each one of the factors on the others [53, 56]. In this method, a causal diagram called diagraph is used to explain these complex cause-effect relationships. On the other hand, handling the ambiguity of experts' opinions and statements effectively is the disadvantage of DEMATEL and for this reason, it has been used by expanding it with fuzzy numbers in this study [57]. The steps for the fuzzy DEMATEL are in following [54]:

Step 1. Determine criteria and fuzzy rating scale: In this step, the criteria are determined with the support of expert opinions and literature review. Pairwise comparisons between these criteria are made to define the influencing and affected factors. In this study, the fuzzy rating scale given in Table 3 was used.

Table 2. Difficulties with their references

		Difficulties	References
STRATEGIC DIFFICULTIES	D1	Lack of awareness about I4.0 government policies	Kumar et al. [25]; Luthra and Mangla [42]; Rauch et al. [18]; Chauhan et al. [38]; Ghadge et al. [49]; Türkeş et al. [20]
	D2	Poor digital operation vision and strategy	Türkeş et al. [20]; Raj et al. [35]; Abdul-Hamid et al. [32]; Luthra and Mangla [42]; Chauhan et al. [38]; Ghadge et al. [49]; Muller [13]
	D3	Lack of clarity towards I4.0 benefits	Kumar et al. [25]; Luthra and Mangla [42]; Yadav et al [50]; Orzes et al. [19]; Abdul-Hamid et al. [32]; Chauhan et al. [38]
	D4	Poor research and development on I4.0 adoption	Luthra and Mangla [42]; Kumar et al. [25]; Kamble et al. [22]; Stentoft et al. [17]
	D5	Lack of digital culture	Muller [13]; Raj et al. [35]; Stentoft et al. [17]; Türkeş et al. [20]; Horváth and Szabó [43]; Luthra and Mangla [42]; Rauch et al. [18]; Ghadge et al. [49]; Wang et al., [51]
ORGANIZATIONAL DIFFICULTIES	D6	Ineffective communication and cooperation amongst supply chain participants	Kumar et al. [25]; Wang et al. [51]; Horváth and Szabó [43]; Raj et al. [35]; Abdul-Hamid et al. [32]; Luthra and Mangla [42]; Chauhan et al. [38]
	D7	Lack of management support and dedication	Kumar et al. [25]; Luthra and Mangla [42]; Horváth and Szabó [43]; Orzes et al. [19]; Abdul-Hamid et al. [32]; Chauhan et al. [38]; Ghadge et al. [49]; Muller [13]
	D8	Fear of job loss or a shrinking workforce (Employment disruptions)	Horváth and Szabó [43]; Abdul-Hamid et al. [32]; Raj et al. [35]; Muller [13]; Moktadir et al. [10]
	D9	Lack of skilled workforce for I4.0 technologies	Horváth and Szabó [43]; Türkeş et al. [20]; Raj et al. [35]; Orzes et al. [19]; Abdul-Hamid et al. [32]; Chauhan et al. [38]; Muller [13]; Stentoft et al. [17]
	D10	Lack of dedicated financial resources for I4.0 technologies	Kumar et al. [25]; Moktadir et al. [10]; Orzes et al. [19]; Abdul-Hamid et al. [32]; Luthra and Mangla [42]; Ghadge et al. [49]; Stentoft et al. [17]
	D11	The high starting costs of I4.0 technologies	Kumar et al. [25]; Yadav et al [50]; Moktadir et al. [10]; Orzes et al. [19]; Abdul-Hamid et al. [32]; Raj et al. [35]
	D12	Unable to effectively adapt and apply new business models	Luthra and Mangla [42]; Abdul-Hamid et al. [32]; Horváth and Szabó [43]; Rauch et al. (2019); Ghadge et al. [49]; Moktadir et al. [10]; Chauhan et al. [38]
TECHNOLOGICAL DIFFICULTIES	D13	Lack of technological infrastructure and networks powered by the internet	Kumar et al. [25]; Horváth and Szabó [43]; Raj et al. [35]; Orzes et al. [19]; Abdul-Hamid et al. [32]; Luthra and Mangla [42]; Chauhan et al. [38]; Ghadge et al. [49]; Wang et al. [51]
	D14	Lack of integration of data and technology platforms	Horváth and Szabó [43]; Abdul-Hamid et al. [32]; Raj et al. [35]; Luthra and Mangla [42]; Chauhan et al. [38]; Ghadge et al. [49]
	D15	Lack of global standards and data sharing procedures	Horváth and Szabó [43]; Türkeş et al. (2019); Raj et al. [35]; Orzes et al. [19]; Abdul-Hamid et al. [32]; Luthra and Mangla [42]; Chauhan et al. [38]; Stentoft et al. [17]
	D16	Failure fear of I4.0 technologies (reliability of systems)	Kumar et al. [25]; Moktadir et al. [10]; Kumar et al [52]; Orzes et al. [19]; Yadav et al [50]
	D17	Data security issues	Horváth and Szabó [43]; Raj et al. [35]; Orzes et al. [19]; Abdul-Hamid et al. [32]; Luthra and Mangla [42]; Chauhan et al. [38]; Wang et al. [51]; Moktadir et al. [10]
	D18	Lack of technical knowledge for I4.0	Stentoft et al. [17]; Luthra and Mangla [42]; Rauch et al. (2019); Ghadge et al. [49]; Moktadir et al. [10]; Muller [13]; Chauhan et al. [38]; Türkeş et al. [20]

Table 3. Fuzzy rating scale

Linguistic Term	Triangular fuzzy numbers (TFNs)
No effect (N)	(0, 0, 0.25)
Very low effect (VL)	(0, 0.25, 0.5)
Low effect (L)	(0.25, 0.5, 0.75)
High effect (H)	(0.5, 0.75, 1)
Very high effect (VH)	(0.75, 1, 1)

Step 2. Generate the fuzzy initial direct-relation matrix: In order to measure level of the relations between the criteria $\{C1, C2, \ldots, Cn\}$, a direct relation matrix is created by using linguistic expressions. A fuzzy initial direct-relation matrix $\tilde{Z}$ is presented in Eq. (1):

$$\tilde{Z} = \begin{bmatrix} \tilde{z}_{11} & \cdots & \tilde{z}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{z}_{n1} & \cdots & \tilde{z}_{nn} \end{bmatrix} \quad (1)$$

where $\tilde{z}_{ij} = (l_{ij}, m_{ij}, u_{ij})$ TFN is the impact of difficulty i on difficulty j.

If there are p experts in the decision group, p decision matrix is obtained. In this case, the opinions of experts can be aggregated using following Eq. (2);

$$\tilde{z}_{ij} = (\tilde{z}_{ij}^{1} + \tilde{z}_{ij}^{2} + \cdots + \tilde{z}_{ij}^{p})/p \quad (2)$$

where $\tilde{z}_{ij}^{p} = (l_{ij}, m_{ij}, u_{ij})$ TFN is the influence of difficulty i on difficulty j according to expert p.

Step 3. Generate a normalized fuzzy direct relationship matrix: The normalized fuzzy direct relationship matrix ($\tilde{X}$) is provided by Eq. (3), Eq. (4) and Eq. (5).

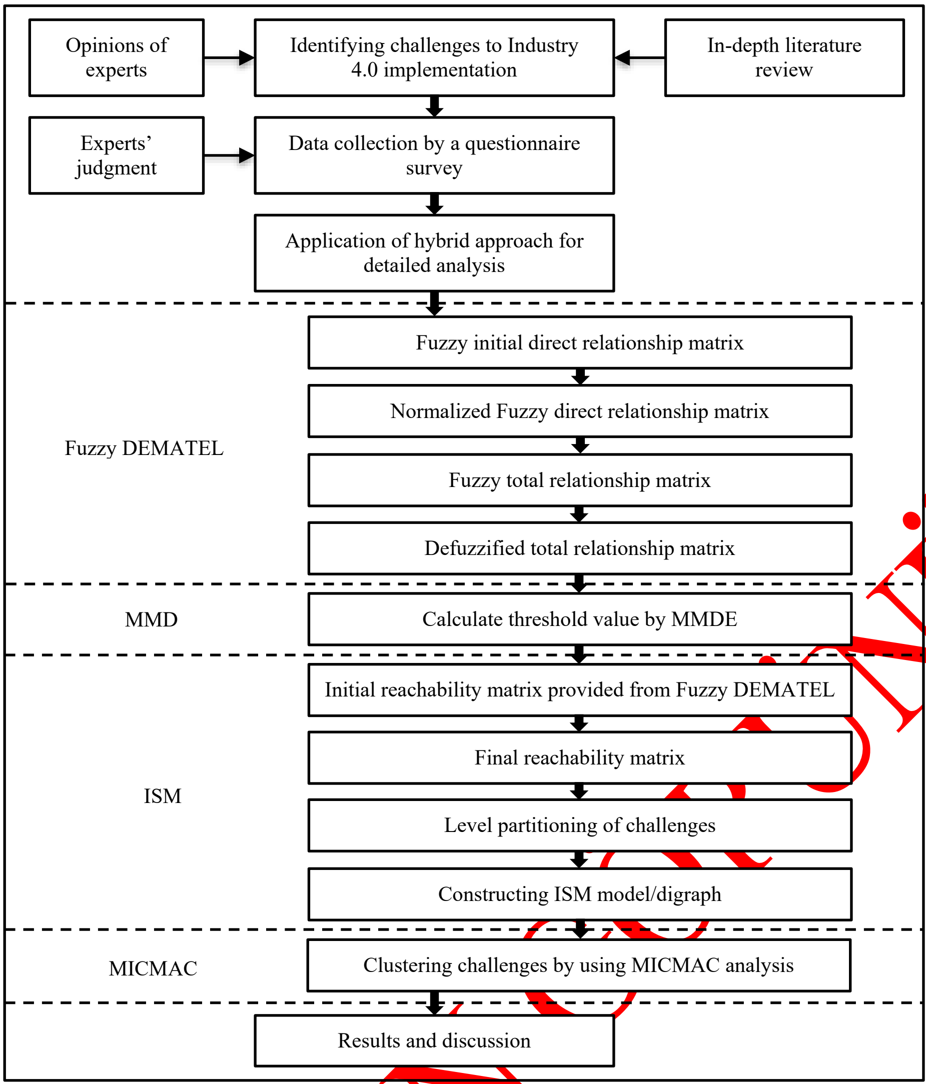

Figure 1. Research framework of the study

$$\tilde{x}_{ij} = \frac{\tilde{z}_{ij}}{r} = \left(\frac{l_{ij}}{r}, \frac{m_{ij}}{r}, \frac{u_{ij}}{r}\right) \quad (3)$$

$$r = \max_{1<i<n}\left(\sum_{j=1}^{n} u_{ij}\right) \quad (4)$$

$$\tilde{X} = \begin{bmatrix} \tilde{x}_{11} & \cdots & \tilde{x}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{x}_{n1} & \cdots & \tilde{x}_{nn} \end{bmatrix} \quad (5)$$

Step 4. Provide the fuzzy total-relation matrix: After providing the normalized fuzzy direct relationship matrix, the total relationship matrix ($\tilde{T}$) is obtained by Eq. (6).

$$\tilde{T} = \tilde{X} + \tilde{X} + \tilde{X} + \cdots = \sum_{i=1}^{\infty} \tilde{X}^{i} = \tilde{X}\,(I - \tilde{X}\,)^{-1} \quad (6)$$

where I refers the identity matrix.

Step 5. Defuzzification: Fuzzy total-relation matrix is defuzzified using Eq. (7) and total relation matrix (T) is obtained as presented in Eq. (8). The abbreviation "def" above the terms is an abbreviation of "defuzzifying".

$$t_{ij}^{def} = (u_{ij} + l_{ij} + 2 * m_{ij})/4 \quad (7)$$

$$T = \begin{bmatrix} t_{11}^{def} & \cdots & t_{1n}^{def} \\ \vdots & \ddots & \vdots \\ t_{n1}^{def} & \cdots & t_{nn}^{def} \end{bmatrix} \quad (8)$$

Step 6. Build cause–effect relation diagram: Lastly, the cause and effect relation diagram is presented by utilising the dataset of $(D_i + R_j)$ and $(D_i - R_j)$. D_i expresses the sum of rows while R_j expresses the sum of columns, and D_i and R_j are calculated by Eq. (9) and Eq. (10) respectively.

$$D_i = \sum_{i=1}^{n} t_{ij}^{def} \quad (i = 1, 2, \ldots, n) \quad (9)$$

$$R_j = \sum_{j=1}^{n} t_{ij}^{def} \quad (j = 1, 2, \ldots, n) \quad (10)$$

The impact-relation relation diagram is provided by presenting the points on a coordinate plane (D+R, D-R). D+R is its horizontal axis and D-R is its vertical axis, and the factors are evaluated with the help of this diagram [58]. The D+R value describes the importance of the i. factor in the whole system. The factor with a larger D+R value is more in relation with other factors and has a greater significance. That is, the D-R value denotes whether the factor has the cause or effect property. In other words, negative D-R means that factor is classified into causal group and positive D-R refers that factor is classified into effect group [59].

3.2. Maximum Mean De-Entropy (MMDE)

Although the cause-effect relations between the factors and the degrees of these relations are obtained with DEMATEL, the hierarchical structure between the factors will be obtained with the ISM by utilising the total relation matrix. However, a threshold value is needed to convert the total relation matrix to the binary matrix to be used in ISM, and there will be different hierarchical structures for different threshold values. At this point, a unique threshold value based on entropy calculation with the MMDE method will be obtained [53]. Entropy is a measurement the amount of uncertainty in information theory, and it can be interpreted by a probability distribution. For a given set $X = \{x_1, x_2, \dots x_n\}$ via a associated probability $P = \{p_1, p_2, \dots p_n\}$ the de-entropy of X defined as Eq. (11);

$$H^D = H\left(\frac{1}{n}, \frac{1}{n}, \dots, \frac{1}{n}\right) - H(p_1, p_2, \dots, p_n) \qquad (11)$$

where H^D denotes the de-entropy. This is because, the entropy ($H(p_1, p_2, \dots p_n)$) is the largest when $p_1 = p_2 = \dots = p_n$ and it is denoted as $H\left(\frac{1}{n}, \frac{1}{n}, \dots, \frac{1}{n}\right)$.

MMDE method adds the factors with the highest interaction value in the total relation matrix to the system one by one and calculates the de-entropy value. If the newly added factor increases the de-entropy value, it reduces the uncertainty, that is, it provides useful information. In this way, the most effective threshold value is determined [53, 60, 61].

3.3. ISM

ISM is utilised for analyzing and understanding complex systems. It constructs a multi-level structure and thus makes intricate systems easier to understand and interpret the interrelations of factors [62]. It is seen in the literature that the ISM technique is utilized effectively to analysis a wide variety of problems [63, 64, 65]. The steps of ISM technique are as follows.

Step 1. Total relation matrix provided by DEMATEL is transformed to a binary matrix by using threshold value determined by MMDE and thus initial reachability matrix is provided.

Step 2. The transitivity of the contextual relationship is a principal assumption of ISM so transitivity check is performed in the initial reachability matrix. If factor A impacts factor B and factor B impacts factor C, then it is concluded that factor A impacts factor C. As a result of transitivity control, final reachability (FR) matrix is provided.

Step 3. Factors are levelled into different hierarchical groups using FR matrix. The reachability set (R) contains the factor itself and the other factors which it affects. The antecedent set (A) contains the factor itself and other factors that may affect it. After the reachability and antecedent set are derived, their intersection sets ($R \cap A$) are obtained for all factors. Factors where the intersection set is the same as the reachability set $\left(R = (R \cap A)\right)$ are taken at first level. By taking away these factors and repeating these steps for other factors, the levels of all elements are defined [63, 66].

Step 4. A directed graph, called digraph is then constructed where factors are setting up according to the levels defined in the previous step and relationship links are plotted by using initial reachability matrix. However, some of the transitive relationships, which are very important to interpret, can be plotted.

3.4. MICMAC

ISM analysis is performed in many studies with MICMAC method. MICMAC is Matrics d'Impacts Croises-Multiplication Applique an Classment. MICMAC analysis is utilized to address dispersion of the factors, i.e. to determine the driving and dependence power of each factor. The driving power is the measure of the power of a factor to influence other factors, and the driving power of each factor is equal to the sum of the factors in the factor row in initial reachability matrix. The dependence power is the measure of the power of a factor to be influenced by others, and the dependence power of each factor is equal to the sum of the factors in the factor column in initial reachability matrix. MICMAC analysis classifies factors into four groups, called as (1) autonomous, (2) dependent, (3) linkage, (4) independent [52]. Autonomous factors have a weak influence and a weak dependence power, and these factors are comparatively cut off from the system. Dependent factors have a weak influence, but their dependency level is high. These factors can be handled by handling the factors on which they depend. Linkage factors have a very high influence as well as a high level of dependence power. These factors are unstable because any activity on these factors will have an influence on others and also a feedback influence on themselves. Independent factors have a powerful influence level, but a weak dependence power. They are regarded as crucial factors in the system [63, 67].

5. RESULTS AND DISCUSSION

Ten experts were selected to evaluate difficulties for adoption to I4.0 in Turkish white good industry. Some features of experts are presented in Table 4. Each of the experts performed pairwise comparison matrix by utilising the fuzzy rating scale shown in Table 3.

The matrix created with the opinions of Expert1 is presented in Table 5 as an example. Using the obtained pairwise comparison matrices and Eq. (2), the fuzzy initial direct-relation matrix was calculated as seen in Table 4.

Table 4. Features of experts

Decision Makers	Age	Sex	Experience in the company (years)	Position	Department	Education
Expert1	36	Male	10	Chief	Manufacturing	BSc
Expert2	30	Male	6	Chief	Supply chain	BSc
Expert3	28	Male	7	Engineer	R&D	MSc
Expert4	27	Female	3	Engineer	Manufacturing	BSc
Expert5	40	Male	10	Manager	Logistics	MSc
Expert6	45	Male	8	Manager	Manufacturing	PhD
Expert 7	32	Female	4	Engineer	Quality	BSc
Expert 8	30	Male	5	Chief	Manufacturing	MSc
Expert 9	41	Male	7	Manager	Engineering	BSc
Expert10	35	Female	3	Responsible	Purchasing	BSc

Table 5. Pairwise comparison matrix of Expert1

Difficulties	D1	D2	D3	D4	⋯	D15	D16	D17	D18
D1	-	H	VH	N	⋯	N	N	N	VL
D2	L	-	H	VH	⋯	L	L	VL	H
D3	L	L	-	VL	⋯	VL	L	N	N
D4	H	L	VH	-	⋯	L	N	VL	VH
⋮	⋮	⋮	⋮	⋮	⋱	⋮	⋮	⋮	⋮
D15	L	VL	N	N	⋯	-	H	L	N
D16	L	VH	VH	N	⋯	L	-	L	N
D17	H	L	VL	N	⋯	VL	L	-	N
D18	H	L	VH	L	⋯	L	VH	VL	-

Table 6. Fuzzy initial direct-relation matrix

Difficulties	D1	D2	D3	⋯	D17	D18
D1	(0, 0, 0)	(0.33, 0.58, 0.83)	(0.5, 0.75, 0.92)	⋯	(0.33, 0.5, 0.75)	(0.25, 0.5, 0.75)
D2	(0.08, 0.33, 0.58)	(0, 0, 0)	(0.42, 0.67, 0.92)	⋯	(0.25, 0.5, 0.75)	(0.33, 0.58, 0.83)
D3	(0.42, 0.67, 0.92)	(0.08, 0.33, 0.58)	(0, 0, 0)	⋯	(0.08, 0.25, 0.5)	(0.42, 0.58, 0.75)
⋮	⋮	⋮	⋮	⋱	⋮	⋮
D17	(0.17, 0.42, 0.67)	(0.25, 0.5, 0.75)	(0, 0.25, 0.5)	⋯	(0, 0, 0)	(0.17, 0.25, 0.5)
D18	(0.33, 0.58, 0.83)	(0.25, 0.5, 0.75)	(0.42, 0.67, 0.83)	⋯	(0, 0.25, 0.5)	(0, 0, 0)

By using Equation (3-8), normalized fuzzy direct relationship matrix, fuzzy total-relation matrix and defuzzied total relation matrix were calculated, respectively. The defuzzied total relation matrix presented in Table 7 gives information about the direct and indirect relationships between difficulties. That is, how each difficulty affects other difficulties and how it is affected by other difficulties. D values are calculated using Equation (9) as shown in the last column of the Table 7, and R values are computed by using Equation (10) as seen in the last row of the Table 7. It can be stated the larger D value for a difficulty, the greater impact of this difficulty on other difficulties. Also, we can say that the higher R value for a difficulty, the more affected by other difficulties [54].

The impact-relation diagram created by using the (D+R) values in the X axis and the (D-R) values in the Y axis is presented in Fig. 2. (D+R) value represents the intensity of a difficulty both in terms of influencing and being influenced i.e. the larger this value, the more relationships a difficulty has with other difficulties. As can be seen from the diagram, the order of the difficulties in order of prominence from largest to smallest is D7, D16, D2, D18, D4, D6, D14, D12, D3, D5, D15, D1, D10, D8, D9, D11, D13 and D17. It is understood that D7 (Lack of management support and dedication) clearly has the highest prominence value, that is, it is a potential difficulty to adoption of I4.0 that should be addressed. (D-R) value indicates whether the difficulty has the cause or effect property. As it is clearly seen from the diagram, D13, D11, D1, D9, D10, D17, D2, D14, D15 and D3 difficulties are classified into causal group because they have a positive (D-R) value, and D8, D18, D5, D4, D7, D16, D12 and D6 difficulties are classified into effect group because they have a negative (D-R) value. In addition, it can be said that D13 (Lack of technological infrastructure and networks powered by the internet) and D11 (The high starting costs of I4.0 technologies) are difficulties that strongly affect other difficulties, and D6 (Ineffective communication and cooperation amongst supply chain participants) is the difficulty that is strongly affected by other difficulties.

After applying the DEMATEL, the ISM was applied to obtain the hierarchical structure between the difficulties in adoption of I4.0 in Turkish white goods sector. For this, the defuzzied total relation matrix calculated by the DEMATEL is transformed to the initial reachability matrix in ISM. This transformation a threshold value is required. Although the threshold value is chosen subjectively in many studies, the MMDE technique was preferred and used as a scientific method to specify the threshold value in this study. The threshold value was determined as 0.1434 by using the defuzzied total relation matrix and applying the steps of the method explained in detail in Section 3.2, respectively. A binary matrix is obtained by converting the values below the threshold to "0" and the values above it to "1". In this way, the initial reachability matrix required for the ISM application has been obtained as illustrated in Table 8.

Table 7. Defuzzied total relation matrix

Difficulties	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14	D15	D16	D17	D18	D
D1	0.09	0.14	0.15	0.15	0.16	0.14	0.15	0.12	0.12	0.14	0.10	0.16	0.10	0.13	0.14	0.14	0.11	0.14	**2.37**
D2	0.12	0.11	0.15	0.16	0.15	0.16	0.16	0.13	0.11	0.13	0.10	0.16	0.12	0.14	0.13	0.17	0.12	0.15	**2.48**
D3	0.13	0.12	0.10	0.14	0.12	0.16	0.16	0.11	0.12	0.14	0.09	0.15	0.10	0.12	0.12	0.15	0.09	0.14	**2.27**
D4	0.13	0.14	0.14	0.10	0.14	0.16	0.16	0.12	0.12	0.13	0.09	0.15	0.08	0.12	0.14	0.14	0.09	0.16	**2.30**
D5	0.11	0.14	0.14	0.14	0.09	0.13	0.17	0.12	0.10	0.10	0.10	0.14	0.09	0.13	0.13	0.14	0.09	0.13	**2.19**
D6	0.09	0.13	0.10	0.12	0.11	0.10	0.14	0.11	0.10	0.10	0.09	0.13	0.07	0.12	0.12	0.13	0.11	0.12	**2.00**
D7	0.13	0.15	0.14	0.16	0.15	0.17	0.13	0.13	0.14	0.14	0.09	0.16	0.10	0.14	0.13	0.17	0.09	0.15	**2.47**
D8	0.09	0.14	0.11	0.13	0.12	0.15	0.15	0.09	0.10	0.12	0.08	0.13	0.07	0.12	0.13	0.14	0.12	0.15	**2.14**
D9	0.11	0.12	0.13	0.15	0.13	0.16	0.16	0.11	0.08	0.10	0.09	0.16	0.07	0.11	0.11	0.16	0.10	0.16	**2.21**
D10	0.11	0.14	0.11	0.15	0.11	0.15	0.17	0.12	0.11	0.09	0.10	0.13	0.10	0.14	0.13	0.16	0.08	0.14	**2.26**
D11	0.11	0.14	0.11	0.13	0.11	0.15	0.17	0.11	0.11	0.13	0.07	0.13	0.10	0.12	0.10	0.16	0.08	0.12	**2.15**
D12	0.10	0.13	0.13	0.12	0.12	0.15	0.17	0.10	0.10	0.10	0.07	0.10	0.07	0.11	0.11	0.16	0.08	0.13	**2.04**
D13	0.10	0.13	0.12	0.13	0.12	0.16	0.13	0.14	0.09	0.10	0.11	0.13	0.07	0.15	0.12	0.13	0.12	0.12	**2.15**
D14	0.11	0.13	0.12	0.13	0.14	0.17	0.15	0.15	0.11	0.12	0.11	0.15	0.10	0.10	0.13	0.16	0.12	0.13	**2.34**
D15	0.13	0.13	0.14	0.13	0.13	0.16	0.15	0.13	0.10	0.11	0.09	0.13	0.09	0.13	0.09	0.15	0.12	0.13	**2.25**
D16	0.12	0.13	0.14	0.13	0.12	0.16	0.17	0.12	0.11	0.13	0.09	0.13	0.10	0.12	0.12	0.11	0.11	0.13	**2.23**
D17	0.10	0.12	0.10	0.11	0.10	0.14	0.13	0.11	0.08	0.10	0.07	0.12	0.08	0.11	0.10	0.14	0.06	0.10	**1.88**
D18	0.13	0.14	0.14	0.15	0.14	0.17	0.17	0.13	0.12	0.12	0.09	0.15	0.08	0.13	0.13	0.17	0.10	0.11	**2.38**
R	**2.02**	**2.40**	**2.26**	**2.44**	**2.27**	**2.73**	**2.79**	**2.15**	**1.90**	**2.10**	**1.61**	**2.53**	**1.59**	**2.27**	**2.17**	**2.69**	**1.77**	**2.42**	

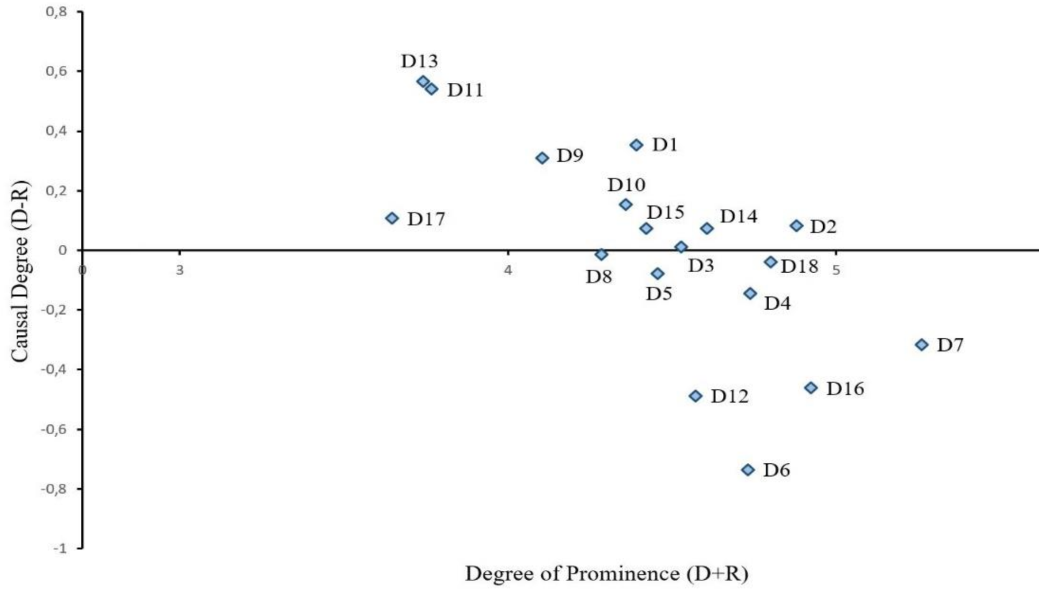

Figure 2. Impact-relation diagram for difficulties to I4.0 adoption in Turkish white goods sector

Table 8. Initial reachability matrix

Difficulties	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14	D15	D16	D17	D18	Driving Power
D1	1	0	1	1	1	0	1	0	0	0	0	1	0	0	0	0	0	0	**6**
D2	0	1	1	1	1	1	1	0	0	0	0	1	0	0	0	1	0	1	**9**
D3	0	0	1	0	0	1	1	0	0	0	0	1	0	0	0	1	0	0	**5**
D4	0	0	0	1	0	1	1	0	0	0	0	1	0	0	0	0	0	1	**5**
D5	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	**2**
D6	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	**1**
D7	0	1	0	1	1	1	1	0	0	0	0	1	0	0	0	1	0	1	**8**
D8	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	1	**4**
D9	0	0	0	1	0	1	1	0	1	0	0	1	0	0	0	1	0	1	**7**
D10	0	0	0	1	0	1	1	0	0	1	0	0	0	0	0	1	0	1	**6**
D11	0	0	0	0	0	1	1	0	0	0	1	0	0	0	0	1	0	0	**4**
D12	0	0	0	0	0	1	1	0	0	0	0	1	0	0	0	1	0	0	**4**
D13	0	0	0	0	0	1	0	0	0	0	0	0	1	1	0	0	0	0	**3**
D14	0	0	0	0	0	1	1	1	0	0	0	1	0	1	0	1	0	0	**6**
D15	0	0	0	0	0	1	1	0	0	0	0	0	0	0	1	1	0	0	**4**
D16	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	1	0	0	**3**
D17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	**1**
D18	0	0	0	1	1	1	1	0	0	0	0	1	0	0	0	1	0	1	**7**
Dependence Power	**1**	**2**	**3**	**7**	**5**	**15**	**15**	**2**	**1**	**1**	**1**	**9**	**1**	**2**	**1**	**11**	**1**	**7**	

In the following step of ISM methodology, transitivity is checked in the initial reachability matrix. For example, if D1 is linked with D3 and D3 is linked with D6, then it is assumed that D1 will also be linked with D6. The final reachability matrix is presented in Table 9. In the last column of the matrix, there are driving power values computed by sum of the row and in the last row there are the dependence power values calculated by sun of the column. While the driving power value expresses the difficulty's effect level on other difficulties, the dependence power value expresses the difficulty's level of being affected by other difficulties. It is understood from Table 9 that the D13 (Lack of technological infrastructure and networks powered by the internet) is the difficulty that most affects the other difficulties in terms of adoption of I4.0 in Turkish white good sector, and the D6 (Ineffective communication and cooperation amongst supply chain participants) is the difficulty that is most affected by the other difficulties.

Table 9. Final reachability matrix

Difficulties	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14	D15	D16	D17	D18	Driving Power
D1	1	1	1	1	1	1	1	0	0	0	0	1	0	0	0	1	0	1	**10**
D2	0	1	1	1	1	1	1	0	0	0	0	1	0	0	0	1	0	1	**9**
D3	0	1	1	1	1	1	1	0	0	0	0	1	0	0	0	1	0	1	**9**
D4	0	1	1	1	1	1	1	0	0	0	0	1	0	0	0	1	0	1	**9**
D5	0	1	1	1	1	1	1	0	0	0	0	1	0	0	0	1	0	1	**9**
D6	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	**1**
D7	0	1	1	1	1	1	1	0	0	0	0	1	0	0	0	1	0	1	**9**
D8	0	1	1	1	1	1	1	1	0	0	0	1	0	0	0	1	0	1	**10**
D9	0	1	1	1	1	1	1	0	1	0	0	1	0	0	0	1	0	1	**10**
D10	0	1	1	1	1	1	1	0	0	1	0	1	0	0	0	1	0	1	**10**
D11	0	1	1	1	1	1	1	0	0	0	1	1	0	0	0	1	0	1	**10**
D12	0	1	1	1	1	1	1	0	0	0	0	1	0	0	0	1	0	1	**9**
D13	0	1	1	1	1	1	1	1	0	0	0	1	1	1	0	1	0	1	**12**
D14	0	1	1	1	1	1	1	1	0	0	0	1	0	1	0	1	0	1	**11**
D15	0	1	1	1	1	1	1	0	0	0	0	1	0	0	1	1	0	1	**10**
D16	0	1	1	1	1	1	1	0	0	0	0	1	0	0	0	1	0	1	**9**
D17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	**1**
D18	0	1	1	1	1	1	1	0	0	0	0	1	0	0	0	1	0	1	**9**
Dependence Power	**1**	**16**	**16**	**16**	**16**	**17**	**16**	**3**	**1**	**1**	**1**	**16**	**1**	**2**	**1**	**16**	**1**	**16**	

After obtaining the final reachability matrix, level partitioning of the difficulties should be conducted to provide the hierarchical structure of the difficulties. For this, first of all, reachability and antecedent sets of difficulties are provided by using the final reachability matrix as described in Table 9. Then, the difficulties with the same intersection set and reachability set are taken to the first level. Next, these difficulties are removed and the process is repeated. In the present study, this process was repeated 5 times and all difficulties were assigned to 5 different levels. Table 10 presents the summary of level partitioning of the difficulties to adoption of I4.0 in Turkish white goods sector.

Table 10. Level partitioning of the difficulties

Difficulties	Reachability set	Antecedent set	Intersection set	Level
D1	[D1]	[D1]	[D1]	III
D2	[D2 D3 D4 D5 D7 D12 D16 D18]	[D1 D2 D3 D4 D5 D7 D8 D9 D10 D11 D12 D13 D14 D15 D16 D18]	[D2 D3 D4 D5 D7 D12 D16 D18]	II
D3	[D2 D3 D4 D5 D7 D12 D16 D18]	[D1 D2 D3 D4 D5 D7 D8 D9 D10 D11 D12 D13 D14 D15 D16 D18]	[D2 D3 D4 D5 D7 D12 D16 D18]	II
D4	[D2 D3 D4 D5 D7 D12 D16 D18]	[D1 D2 D3 D4 D5 D7 D8 D9 D10 D11 D12 D13 D14 D15 D16 D18]	[D2 D3 D4 D5 D7 D12 D16 D18]	II
D5	[D2 D3 D4 D5 D7 D12 D16 D18]	[D1 D2 D3 D4 D5 D7 D8 D9 D10 D11 D12 D13 D14 “D15 D16 D18]	[D2 D3 D4 D5 D7 D12 D16 D18]	II
D6	[D6]	[D1 D2 D3 D4 D5 D6 D7 D8 D9 D10 D11 D12 D13 D14 D15 D16 D18]	[D6]	I
D7	[D2 D3 D4 D5 D7 D12 D16 D18]	[D1 D2 D3 D4 D5 D7 D8 D9 D10 D11 D12 D13 D14 D15 D16 D18]	[D2 D3 D4 D5 D7 D12 D16 D18]	II
D8	[D8]	[D8 D13 D14]	[D8]	III
D9	[D9]	[D9]	[D9]	III
D10	[D10]	[D10]	[D10]	III
D11	[D11]	[D11]	[D11]	III
D12	[D2 D3 D4 D5 D7 D12 D16 D18]	[D1 D2 D3 D4 D5 D7 D8 D9 D10 D11 D12 D13 D14 D15 D16 D18]	[D2 D3 D4 D5 D7 D12 D16 D18]	II
D13	[D13]	[D13]	[D13]	V
D14	[D14]	[D13 D14]	[D14]	IV
D15	[D15]	[D15]	[D15]	III
D16	[D2 D3 D4 D5 D7 D12 D16 D18]	[D1 D2 D3 D4 D5 D7 D8 D9 D10 D11 D12 D13 D14 D15 D16 D18]	[D2 D3 D4 D5 D7 D12 D16 D18]	II
D17	[D17]	[D17]	[D17]	I
D18	[D2 D3 D4 D5 D7 D12 D16 D18]	[D1 D2 D3 D4 D5 D7 D8 D9 D10 D11 D12 D13 D14 D15 D16 D18]	[D2 D3 D4 D5 D7 D12 D16 D18]	II

The interpretive structural model (ISM digraph) prepared using the initial reachability matrix and defined difficulty levels seen in Table 10 is presented in Figure 3. The ISM digraph illustrates the structural relationship between difficulties to adoption of I4.0. Relationship links in the digraph were plotted by using initial reachability matrix. In addition, some of the transitive relationships, which are very important to interpret, were plotted from final reachability matrix. As seen in the figure, D13 (Lack of technological infrastructure and networks powered by the internet) and D14 (Lack of integration of data and technology platforms) which are at the bottom two levels of the ISM digraph, are the difficulties with the strongest driving power and have direct or indirect effects on other difficulties. It can be said that they are the main difficulties for I4.0 adoption in white good sector.

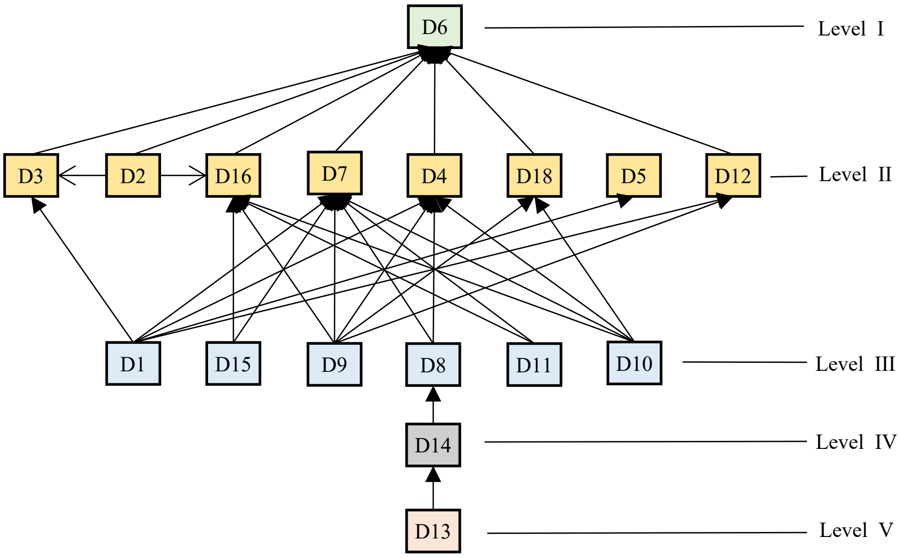

Figure 3. ISM model/digraph

On the other hand, it is understood that D6 (Ineffective communication and cooperation amongst supply chain participants) is the most affected difficulty directly or indirectly from other difficulties because it is located at the first level. D17 (Data security issues) is not included in this digraph because its driving and dependence powers are very low, and its relationship with other difficulties is very weak.

MICMAC analysis was also carried out to classify difficulties as autonomous, dependent, linkage, and independent. The MICMAC diagram obtained by using the driving and dependence power values in the initial reachability matrix given in Table 10 is presented in Figure 4.

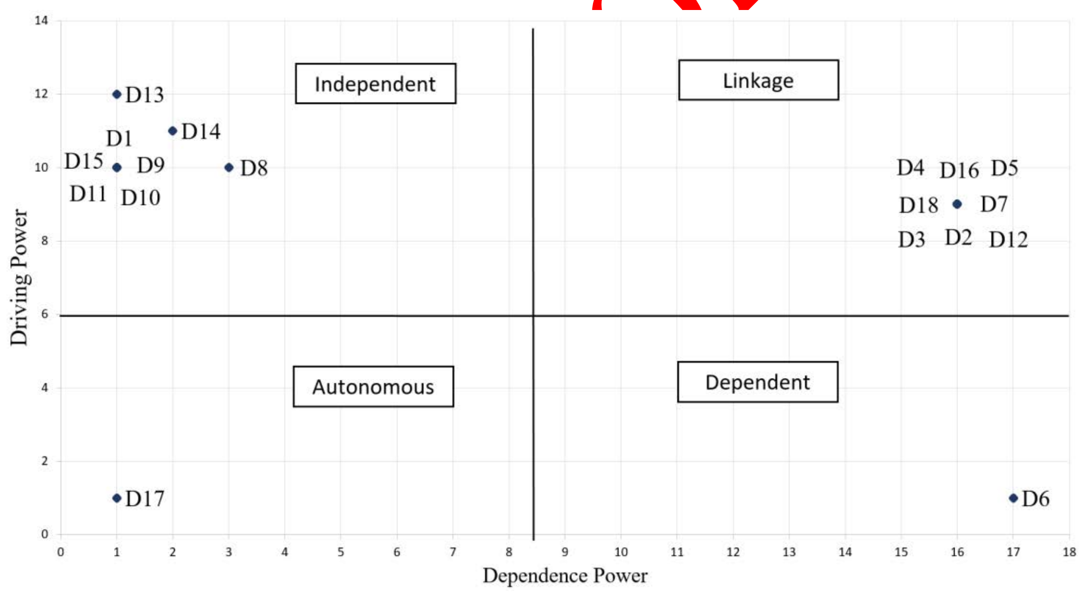

Figure 4. Clustering difficulties effecting I4.0 adoption in Turkish white goods sector by using MICMAC analysis

As can be seen from the Figure 4, there are eight difficulties in the independent class namely D1, D13, D14, D15, D9, D10, D11 and D8. Difficulties in this class, which have high level of driving power and low level of dependence power, must be considered as key factors in the system and should be focused primarily. These difficulties act as the main difficulties and are designated as the key challenges, and actions to be taken for these difficulties will have the effect on other difficulties.

There is only D6 (Ineffective communication and cooperation amongst supply chain participants) in the dependent class. Although D6 has high dependence power, its driving power is relatively low. Difficulty in this class is affected by difficulties in the independent and linkage classes.

In the autonomous class, there is only the D17 (Data security issues). Since this difficulty has weak driving power and dependence power, it is hardly related to the whole system.

There are eight difficulties in the linkage class namely D7, D2, D16, D3, D4, D18, D5, D12. These difficulties, which have high driving and dependence power, have instability in terms of relationships, and any action on these difficulties has a corresponding impact on other difficulties and feedback on themselves.

6. CONCLUSIONS

The Turkish white goods sector is one of the locomotive sectors of the Turkish economy with its advanced technology, innovative structure, high export income and employment opportunities. It is clear that white goods manufacturing sector is very important for Turkish economy. Therefore, this study provides very important insights for this sector and Turkish manufacturing industry.

This study has identified some of the most significant difficulties of adopting and implementing I4.0 in Turkish white goods manufacturing industry and has used a fuzzy DEMATEL-MMDE-ISM integrated model to examine, identify and visualize the relationships and interactions between the difficulties. The study identifies 18 potential difficulties grouped into three dimensions as strategic, organizational and technological. The proposed approach can provide industrial practitioners and managers with a more realistic picture of the issues that will arise during the adoption of I4.0 in manufacturing industries, which will aid them in making decisions, and that can assist them in successfully integrating I4.0 practices in their organizations. Future endeavours in the evolution of operations should be cautiously planned in order to rise up the global manufacturing ladder.

Despite there is growing attention in incorporating I4.0 into the Turkish manufacturing sector, there is a paucity of literature that suggests to systematically address the difficulties encountered in the actual world. The theoretical investigation developed in this paper can be summarized as follows:

(1) A large body of research was condensed into a list of eighteen major difficulties. An extensive literature review was performed to pick these difficulties, which were compared to their frequency in the occurrence list.

(2) Using the DEMATEL method, an interaction between these difficulties was discovered. The importance of each difficulty, i.e. its impact on the others, was measured and tabulated.

(3) Using MMDE technique obtained a specific threshold value which is further used in developing a hierarchical structure via ISM

(4) In addition, the most important difficulty was determined among these essential difficulties. The ISM technique was used to create a hierarchical framework for the difficulties.

(5) MICMAC analysis was also performed to classify difficulties as autonomous, dependent, linkage, and independent.

This study has significant limitations that could be exploited in future research. Other issues relating to diverse country contexts can be included in future studies. Furthermore, the study's conclusions are exclusive to the white-goods manufacturing sector the findings may differ for other industries such as automobile, textile, electronic, construction, and service. Besides, with small revisions, the study's findings could be advantageous to the white-good sectors of other emerging countries aiming for I4.0 difficulties. Moreover, hesitant fuzzy numbers can be used in methodology to overcome vagueness in linguistic variables more effectively.

DECLARATION OF ETHICAL STANDARDS

The authors of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

AUTHORS' CONTRIBUTIONS

Authors contributions are equal.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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