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A case approach

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Published in:
Electronic Commerce Research and Applications

DOI:
10.1016/j.elerap.2023.101249

Publication date:
2023

Document version:
Final published version

Document license:
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Citation for pulished version (APA):
Govindan, K., & Arampatzis, G. (2023). A framework to measure readiness and barriers for the implementation of Industry 4.0: A case approach. *Electronic Commerce Research and Applications*, *59*, Article 101249. https://doi.org/10.1016/j.elerap.2023.101249

Electronic Commerce Research and Applications 59 (2023) 101249

Contents lists available at ScienceDirect

Electronic Commerce Research and Applications

journal homepage: www.elsevier.com/locate/elerap

A framework to measure readiness and barriers for the implementation of Industry 4.0: A case approach

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ARTICLE INFO

Keywords:
Industry 4.0
Readiness
Barriers
DEMATEL
MCDM
Denmark

ABSTRACT

Large businesses perceive the vital usefulness of Industry 4.0. They recognize how beneficial its implementation is to reinforce business competitiveness and to conserve, or even better, to increase their market share. Hence, top business management has embraced the challenge of the time: to evaluate the current level of digitization with the objective of proceeding to a full digitization phase in the future. With this concern, this paper proposes a framework to assist industries in promoting Industry 4.0 through two phases. In the initial phase, the case company's level of readiness is evaluated, and in the second phase, the barriers that exist within the implementation of Industry 4.0 (based on the company's readiness, obtained from the previous phase) are analyzed. Both phases have been carried out at a Danish case industry which is a third-tier supplier of anti-noise shims and back plates for manufacturers of disc brake linings. In the first phase, the assessment of readiness for Industry 4.0 demonstrates that the case industry is not fully ready; instead, they reside in the position of Industry 3.5 (in the middle of 3.0 and 4.0 revolutions). The limiting barriers to change for Industry 4.0 implementation are identified during the systematic literature review and analyzed using the DEMATEL method based on the industrial decision-makers' responses in the second phase. Moreover, the analysis demonstrates the most influential barrier category is the policy & organization category. The barrier "leadership" is considered the greater influencer of all since it responds in some way to almost all 21 barriers. Thus, leadership is the most significant barrier a company must overcome to adopt the Industry 4.0 concept. In addition, firms are challenged by the organizational changes that the adoption of Industry 4.0 will bring, and the tool of organizational change management will be handy.

1. Introduction

In the era of globalization, firms compete fiercely and aim to become the market leader by enhancing their competitiveness. The firms should stay competitive by embracing technological developments and, in this fashion, sustaining their competitive advantage against their rivals. Due to the fact that current business and manufacturing environments are more complex and dynamic and customers' requirements are more diverse, firms should become more flexible to provide customized goods that are of high quality and competitively priced (Fatorachian and Kazemi, 2018; Felsberger et al., 2022). Lately, technology, developed at a high point of sophistication, is implemented in manufacturing units. Industry 4.0 is the notion that every contemporary manufacturer must adopt in order not only to endure the tough rivalry but also to modernize itself and thrive. The concept of Industry 4.0 aims to redesign the manufacturing processes in order to transform the centralized model to a decentralized one by the use of ICT-based systems (Park, 2017; Kurniawan et al., 2022). Furthermore, Industry 4.0 assists to overcome modern challenges, such as volatility in markets and demands, intense competition, mass customization, and short product life cycles (Müller et al., 2018; Jain et al., 2022; Govindan et al., 2022).

Nevertheless, during the implementation of the Industry 4.0 concept, firms will experience technical and organizational changes in business culture, processes, and routines. Firms will face resistance and general barriers to the changes that should be confronted by experts. Accordingly, the drivers to change must be fostered (Lozano, et al., 2015; El Baz

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https://doi.org/10.1016/j.elerap.2023.101249
Received 16 July 2021; Received in revised form 20 February 2023; Accepted 28 February 2023
Available online 9 March 2023

et al., 2022). During organizational changes, the system will pass by a transitional period from the Status Quo (SQ) of the Industry 3.0 era to end up at the Status Quo Novo (SQN) in Industry 4.0. Implementation of the organizational change practices facilitates smoothness of this transition and it guarantees the stability of the system.

Moreover, national and international institutes worldwide have realized the value of the Industry 4.0 concept and the benefits it brings not only to the manufacturers but also to the rest of the stakeholders. There are several real life examples of the benefits of implementing Industry 4.0 that can be discovered in the literature. For an instance, BOSCHI automotive diesel system factor in China employs big data under the implementation of Industry 4.0 which benefits the production plant with various real time information sources, including machine conditions, cycle time, and schedules for maintenance operations. This information removes production bottlenecks and improves the productivity (Autonomous manufacturing, 2019). In addition to manufacturing/production benefits of Industry 4.0, implementation can be seen in various sectors. Hence, national institutes promote and, in some cases, subsidize the implementation of Industry 4.0 by local firms or they provide tax reliefs to the manufacturers. German government has announced in April of 2013 the "Industry 4.0" initiative and China, in response, announced the "Made-in-China 2025" (Li, 2016). Moreover, in late 2012, the concept of industrial internet was brought up in North America by General Electric covering a broader scope than Industry 4.0 such as power generation, manufacturing, healthcare, public sector, and mining (Rojko, 2017). Obviously, national governments in northwest countries, USA, and several Asian manufacturing countries acknowledge the worth of Industry 4.0; therefore, the Industry 4.0 Readiness levels are higher in those geographical regions compared with the rest of the world which are considered laggards (Danish Institute of Industry 4.0, n.d.). Governments perceive that the Industry 4.0 concept will empower the competitiveness of the national manufacturing firms meaning that they can earn more revenues after boosting their sales. Thus, with greater profits for the national firms, more profits are generated for the governments through business taxation. The objective of the governments is to earn the most money possible through taxation and, in this way, to fund the welfare of the state. Most industries are willing to move forward in the path of Industry 4.0; for instance, the European manufacturing sector expects to reach a growth of approximately 15% to 20% by 2030 if it accomplishes digital transformation on their value chains (Santos et al., 2017).

Despite the urge and opportunities of Industry 4.0, industries around the world face several challenges. An especially onerous challenge is the knowledge gap regarding expertise. In addition, industries are not fully aware whether they are capable of this digital transformation; it is not an easy task to transform all operations into digital because that involves significant resources of time, money, and labor. Without proper forecasting of capabilities, the firm may experience heavy financial losses since digitalization requires a large financial outlay. That risk ensures that some industries will be reluctant to pursue Industry 4.0 transformations. These preventing factors affect the decision makers negatively against Industry 4.0 adoption. The decision makers may doubt whether or not to invest the firm's resources to reap the benefits brought by Industry 4.0. The resolution of that dilemma tortures the leaders since the implications will be decisive for the future viability of the enterprise. For example, according to several studies (for instance, Vaidya et al., 2018; Sawik, 2022), the investment for all the key technologies of Industry 4.0 is vast and is considered an impediment. Hence, in order to promote the adoption and implementation of Industry 4.0 in the case context, this study proposes a research framework with two phases; each phase focuses on a specific research question.

RQ1: What is the current readiness level of the case industry to adopt Industry 4.0 in its organization?

RQ2: What barriers hinder the case industry from achieving an effective implementation of Industry 4.0?

The first phase will assist industrial managers to evaluate the readiness of their firm to implement Industry 4.0; industries can understand their capabilities in terms of digital transformation. This identified readiness projects the current capability level of the industry to adopt digitalization in their operations, but it does not provide solutions dedicated to improving their readiness for Industry 4.0 operations. The firm's readiness improvement can be achieved through identifying the barriers involved in the implementation of Industry 4.0. According to Lozano et al. (2015), the barriers that impede change must be overcome by the company since those barriers negatively affect different organizational levels and strategies. Furthermore, current research exhibits a gap in the exploration of the size of influence a barrier can have to the decision makers regarding a corporation's Industry 4.0 policies. Each of the barriers is rated differently by firm managers because the barriers' significance varies; no two barriers are considered precisely equal. Therefore, the second phase of this study is designed to help industrial managers identify the most influential barriers that hinder their adoption of Industry 4.0 practices. Once managers identify the influential barriers, they can take steps to eradicate those barriers and augment their readiness level.

Each phase utilizes different research approaches because each displays a different objective. Both phases combine theoretical and practitioner inputs from a systematic literature review and from experts' opinions, respectively. However, in the second phase, a numerical analysis has been included. Because the second phase includes several barriers, making the problem multi criteria, Decision-Making Trial and Evaluation Laboratory (DEMATEL), a multi-criteria decision-making approach, has been employed.

Although this study provides several scientific and social contributions, one of its key contributions is that this is the first study to combine an analysis of a firm's readiness level with its corresponding barriers to Industry 4.0 implementation. Secondly, this study proposes a series of sequential steps to be carried out for industries seeking to implement Industry 4.0 in their organization, particularly those in the European context. In addition, this study exemplifies the importance and urgency of Industry 4.0 in the current business context, so it may motivate top-level management to adopt the digital culture in their organization.

The remaining sections of the paper are as follows. Section 2 deals with the existing literature on the readiness model, barriers of Industry 4.0, and the DEMATEL application to identify the barriers. Section 3 outlines the problem and case description section; it deals with the formulation of the readiness framework and barriers of Industry 4.0 implementation along with information about the considered case industry. Next, the methodology is presented in section 4 and consists of the process explaining the questionnaire, interviews, and DEMATEL. The analysis and discussion of the results are presented in section 5. Finally, the conclusions of the chapter are gathered in section 6.

2. Literature review

This section unfolds the current state of the art on three different topics relevant to the proposed study. The first and second subsections deal with the readiness models and the barriers of Industry 4.0 respectively. The successful application of the DEMATEL methodology and an analysis of the barriers are reviewed in the third subsection. The final subsection collects inferences from the initial three subsections and details the existing literature gap.

2.1. Industry 4.0 readiness models

The necessity for evaluation of the current readiness status of firms with regard to the Industry 4.0 concept has led several researchers (for ex: Wankhede and Vinodh, 2022a; Wankhede and Vinodh, 2022b; Antony et al., 2021; Stentoft et al., 2021) to explore the area of readiness modeling as a basic toolbox to assess Industry 4.0 readiness within an enterprise. De Carolis et al. (2017) stress that the implementation of Industry 4.0 key technologies is a complex procedure; therefore, the introduction of those technologies depends on the maturity level of each firm's capabilities. For that reason, the transition to Industry 4.0 implementation requires a separate transformation roadmap according to each firm's readiness level. Several methodologies have been used to create maturity or readiness levels with respect to the Industry 4.0 concept. In the same paper, the maturity models of DREAMY (Digital REadiness Assessment MaturitY model), SMSRL (Smart manufacturing readiness level), and MOM (Manufacturing Operations Management) are presented (Carolis, Macchi, and Kulvatunyou, 2017). In addition, several other popular readiness-based business models for Industry 4.0 have been introduced, such as IMPULS (2015), Digital Operations Self-Assessment (2016), the Connected Enterprise Maturity Model (2016), and Industry 4.0 Maturity Model (2016). Table 1 shows the primary existing readiness/maturity business models for the implementation of Industry 4.0; this list includes current academic knowledge from only 2016 and forward. Moreover, further research conducted with grey literatures has erected few self-assessment Industry 4.0 readiness models, including one by the University of Warwick (University of Warwick, n. d.) and one by the consultant group PwC (PwC, n.d.).

Table 1
Existing Maturity Models for Industry 4.0 (2016–2020).

S No	Maturity Model	Source
1	Smart Modern Construction Enterprise Maturity Model (SMCeMM)	Das et al., (2022)
2	Comparison of existing Industry 4.0 Maturity model	Elibal and Özceylan (2022)
3	SANOL	Ünal et al. (2022)
4	Industry 4.0 maturity model selection	Altan Koyuncu et al., (2021)
5	Proposed maturity model with four dimensions (production, logistics, maintenance and IT)	Zoubek et al., (2021)
6	Developed maturity model for OSCM4.0	Caiado et al., (2021)
7	13 Business model patterns with taxonomy	Weking et al. (2019)
8	Wallach's Model – Organizational culture	Ziaei Nafchi and Mohelská (2020)
9	Maturity assessment framework (no specific name)	Wagire et al. (2020)
10	Metamodel for Industry 4.0 readiness	Basl and Doucek (2019)
11	DRL 4.0 (Digital readiness level 4.0) - Comprehensive assessment model for SMEs	Pirola et al. (2019)
12	Business model with smart products and services, smart business processes and strategy & organization, No name	Akdil et al. (2018)
13	VDMA	Viharos et al. (2017)
14	Fraunhofer Survey	Viharos et al. (2017)
15	Capgemini	Viharos et al. (2017)
16	DREAMY	Carolis, Macchi, and Kulvatunyou (2017)
17	SMSRL	Carolis, Macchi, and Kulvatunyou (2017); Jung et al. (2016)
18	MOM	Carolis, Macchi, and Kulvatunyou (2017)
19	IMPULS – Industrie 4.0 Readiness (2015)	Schumacher, Erol, and Sihn (2016); Barafort and Shrestha (2017)
20	Empowered and Implementation Strategy for Industry 4.0 (2016)	Schumacher, Erol, and Sihn (2016); Barafort and Shrestha (2017)
21	Industry 4.0 / Digital Operations Self-Assessment (2016)	Schumacher, Erol, and Sihn (2016); Barafort and Shrestha (2017)
22	The Connected Enterprise Maturity Model (2014)	Schumacher, Erol, and Sihn (2016); Barafort and Shrestha (2017)
23	I 4.0 Reifegradmodell (2015)	Schumacher, Erol, and Sihn (2016)
24	A maturity model for Industry 4.0 Readiness	Schumacher, Erol, and Sihn (2016); Barafort and Shrestha (2017)
25	SIMMI 4.0	Barafort and Shrestha (2017); Leyh et al. (2017)
25	No Name	Zheng and Ming (2017)
26	Industry 4.0-MM	Barafort and Shrestha (2017)
27	Towards a maturity model for Industrial Internet	Barafort and Shrestha (2017)

Some studies (Nasrollahi and Ramezani, 2020; Pacchini et al., 2019; Maria et al., 2019; Terminanto et al., 2019) proposed the methods to evaluate the readiness of the organization with Industry 4.0. For instance, Lin et al. (2020) evaluate the existing business models of Industry 4.0 with a Taiwan case context through K-means cluster analysis.

2.2. Barriers of Industry 4.0 implementation

According to Marques et al. (2017), the World Economic Forum has conducted a survey and its findings have shown several barriers identified by companies that behave as obstacles in movement towards the Industry 4.0 epoch. Most of those barriers concern the lack of standardization and interoperability issues (Marques et al., 2017). Moreover, several challenges, such as the development of infrastructures to support real-time data exchange and the training of necessary skilled manpower, should be overcome (Kamali Saraji et al., 2021; Wankhede and Vinodh, 2021; Tay et al., 2021; Karatas et al., 2022). The impediments of the historical investment in IT and automation and regulatory and quality constraints affect decision makers against Industry 4.0 implementation (O'Donovan et al., 2015). Khan and Turowski (2016a) conducted their survey in collaboration with experts in companies by doing interviews and completing questionnaires, and they identified several challenges against Industry 4.0 adoption, such as data security, training, and skill development. Despite several challenges to address with the implementation of Industry 4.0, only a few researchers have surveyed the existence of barriers that prevent enterprises from implementing Industry 4.0 practices; this study collects and evaluates all of them.

Some studies analyze barriers that are more specific to the application of the organization's operations. For example, Ozkan-Ozen et al. (2020) and Ghadge et al. (2020) studied the barriers involved in the implementation of Industry 4.0 in the application of supply chains. Raj et al. (2019) studied the barriers of Industry 4.0 in manufacturing sectors through inter-country comparisons. Ajmera and Jain (2019) proposed a model for exploring the barriers of Health 4.0 in the Indian health care system. Horváth and Szabó (2019) discussed the drivers and barriers of Industry 4.0 with the comparison of multinational companies (MNCs) and small and medium scale enterprises (SMEs).

Some studies studied both the drivers and barriers of Industry 4.0 with contexts specific to a country. Stentoft and Rajkumar (2020) explored the drivers and barriers of Industry 4.0 in a Danish manufacturing context through a statistical approach. Herceg et al. (2020) studied the challenges and drivers of Industry 4.0 in a Serbian manufacturing sector. Kumar et al. (2020) ranked barriers of Industry 4.0 in an Indian context with Best-Worst method. Türkeș et al. (2019) studied Romanian SME's with factors driving and hindering the application of Industry 4.0. The challenges involved in Polish and Canadian supply chain services with the implementation of Industry 4.0 was studied by Slusarczyk and Haque (2019). Kamble et al. (2018) studied the drivers and barriers of Industry 4.0 in an Indian manufacturing context with a MCDM tool.

Few academic articles explore generic Industry 4.0 pursuits; instead, most consider a single technology under Industry 4.0 to study corresponding barriers. Singh and Bhanot (2020) analyzed the Internet of Things (IoT) barriers that were further examined through methodologies including DEMATEL. Yuan and Cheah (2019) explored the barriers of IoT in Malaysian health care systems, in which six major barriers were identified. Rauch et al. (2019) studied the requirements and barriers of smart manufacturing with the application of SMEs' perspective.

Some studies discussed the generic approaches of Industry 4.0 barriers, such as Agostini and Filippini (2019), who studied the organizational and managerial challenges in the implementation of Industry 4.0. Some state-of-the-art reviews (Obiso et al., 2019) exist with an analysis of drivers and barriers in Industry 4.0 adaptations. Few studies relate Industry 4.0 topics with strategies like circular economy, but Rajput and Singh (2019) offer one study with the assistance of MCDM tools that prioritizes the challenges of Industry 4.0 in circular economy perspective.

2.3. Application of DEMATEL in analyzing the barriers

The multi-criteria decision-making approaches are used to facilitate decision makers in reaching an optimal choice over several alternatives. Moreover, MCDM structures the problems by offering alternatives under multiple criteria (Aruldoss, 2013). Among such MCDM tools, DEMATEL is one that is used to identify the interrelationships among the considered alternatives/factors. Further, DEMATEL provides an overview of the most influential alternative/factors among considered common alternatives. Because of this ease of use, researchers utilize DEMATEL in several means of applications (Asadi et al., 2022; Mohandes et al., 2022; Liang et al., 2022; Mubarik et al., 2021). From the literature review it has been evident that DEMATEL is popular among researchers in terms of assessing barriers of any phenomenon. With this success acknowledged, this study adapts DEMATEL to identify the influential barriers of Industry 4.0. Note that unlike other applications, digital applications are new to the research; hence, it is necessary to validate the success of DEMATEL in digital applications. A systematic literature review has been done particularly to explore the applications of DEMATEL in digital related problems. Table 2 shows these recent successful applications of DEMATEL in digital applications.

The above table shows the success of DEMATEL with digital focused research; this project will proceed with the implementation of a specific MCDM approach (DEMATEL) with regards to Industry 4.0.

2.4. Literature gap

From the above literature review, several elements have been noted. At first, regarding readiness model, several models are found in the literature, but each model has its own flaws. As a result, considering a single model for the studying the readiness will be not enough. It is better and more useful to make a thorough literature review with these models and then identify the readiness factors that will provide an extra boost towards an effective analysis of industries' current level of adoption of Industry 4.0. With this concern, in phase I of this study, readiness factors were collected from the literature review and checked with field and industrial experts. Secondly, several papers study the barriers of Industry 4.0, and most of these works admit that these barriers may harbor different levels of influence depending on their geographical context. We propose an urgent need for a case study specific to Denmark that analyzes Industry 4.0 implementation barriers. The study by Stentoft and Rajkumar (2020) considers the barriers of Industry 4.0 in a Danish context, but that study explores the relationship of Industry 4.0 with moving manufacturing out, back, and staying at home. The current study does not provide any initial level of strategies to adopt Industry 4.0 in a Danish context. Keeping the gap in mind, this study proposes a two phase research framework. First, the readiness level of the Danish case industry is observed, and secondly, differences between the current level and that of an effective implementation of Industry 4.0 are discussed through an identification of corresponding barriers.

3. Problem and case description

3.1. Problem description

This study considers two phases of research problem with one specific objective of promoting the effective adoption and implementation of Industry 4.0. The problem focused here aims to solve the

Table 2
DEMATEL in Digital applications.

S. No	Source	Focus	Objective	Problem description
1	Elibal and Özceylan (2022)	Industry 4.0	Criteria evaluation	Explored the industry 4.0 mautrity models through proposed criteria in the perspective of TQM principles using DEMATEL.
2	James et al., (2022)	Industry 4.0	Challenges	Analyzed the human resource management challenges with the implementation of Industry 4.0 through DEMATEL
3	Durmaz and Budak (2022)	Industry 4.0 technologies	Barriers	Studied the barriers of Industry 4.0 in the application of sustaianble supply chain management with Grey-DEMATEL
4	Miao et al., (2022)	Industry 4.0 technologies	Success factors	Studied the success factors of knowledge management in Industry 4.0 in the aviation sector with Grey-DEMATEL
5	Zhang et al., (2021)	Industry 4.0	Drivers	Analyzed the interrelationships of drives of Industry 4.0 enables smart waste management system using DEMATEL.
6	Kumar et al. (2021a), Kumar et al. (2021b), Kumar et al. (2021c)	Industry 4.0	Critical success factors	Analyzed the critical success factors of Industry 4.0 integrated circular supply chain with DEMATEL.
7	Raj et al. (2019)	Industry 4.0 technologies	Barriers	Studied the barriers of Industry 4.0 technologies with DEMATEL
8	Singh and Bhanot (2020)	IoT implementation	Barriers	Explored the barriers involved in IoT implementation in manufacturing sector with the assistance of DEMATEL-MMDE (Maximum Mean De-Entropy)-ISM (Interpretive Structural Modelling)
9	Luthra et al. (2020)	Industry 4.0	Drivers	Studied the drivers of Industry 4.0 in supply chain considering sustainable perspective
10	Rajput and Singh (2019)	Industry 4.0 and circular economy (CE)	Factors linking Industry 4.0 and CE	DEMATEL has been applied along with principal component analysis (PCA) to evaluate the links between the CE and I4.0

(*continued on next page*)

Table 2 (*continued*)

S. No	Source	Focus	Objective	Problem description
11	Bhagawati et al. (2019)	Industry 4.0 and sustainable supply chain	Success factors	Analyzed the success factors involved in achieving sustainable supply chain under Industry 4.0 environment
12	Torbacki and Kijewska (2019)	Industry 4.0 and Logistics 4.0	Characteristics of both logistics and manufacturing processes	Studied the characteristics involved in the transformation of conventional logistics to logistics 4.0
13	Aggarwal et al. (2019)	Industry 4.0	Challenges	Studied the key challenges of Industry 4.0 in Indian manufacturing context
14	Kazancoglu and Ozkan-Ozen (2018)	Workforce 4.0	Personnel selection criteria	Studied the new criteria for personnel selection in Industry 4.0 to promote workforce 4.0
15	Yang (2018)	Building management	Management systems for smart factory	Evaluated the different management systems for smart factory implementation under the concern of intelligent building management
16	Gomes et al. (2018)	Industry 4.0	Components of the Industry 4.0 domain	Analyzed and prioritized the components of the Industry 4.0 domain within the application of automotive supply chain industry

practitioners' challenges in the digital transformation. However, in order to comprehend the challenge of the practitioner level, an in-depth problem analysis, along with their influencing criteria, is needed. This study proposes a case study approach to provide in-depth knowledge of the challenges that exist within Industry 4.0 implementation. According to Yin (2012), the case study methodology is used to understand the complex phenomena that exists in real-world scenarios. In addition, the case study approach not only provides information about the case but also it examines the context of a specific problem. This study utilizes the case study approach to understand the case industry along with the case context (Denmark, Europe). As discussed in previous section, this study divides the problem in two phases – readiness and barriers – and describes each problem as follows.

3.1.1. Phase I – Readiness

During the literature review, several evaluation maturity models have been identified. To further augment the framework for the evaluation of Industry 4.0 Readiness, we utilize inspiration from several models, including academic institutions such as the University of Warwick's[1] self-assessment tool and the consultant group PwC's[2] self-assessment model. The current framework consists of 36 questions representing 36 readiness items grouped into 6 readiness dimensions. Table 3 illustrates the six dimensions with the 36 readiness items. Subsequently, the readiness dimensions and items are presented and analyzed in the next sections. Finally, at the end of the current section the case company description is presented.

3.1.2. Phase II – Barriers

In the second phase of the research, the barriers that hinder industries are identified and analyzed. Acknowledging the benefits of Industry 4.0 implementation, case industry managers are motivated to move rapidly to total digitization. An identification of the barriers that obscure the digital transformation of the firm is an important task, and that objective serves as a key reason why the case industry is eager to collaborate in this study. The objective for this second phase is to confront the most important barriers to resolve so Industry 4.0 implementation can be effectively adopted.

The analysis has taken place in case industry facilities in Denmark. During the meeting, an interview occurred with case industry's production manager. The meeting lasted one hour, and the identified barriers of Industry 4.0 implementation were discussed and analyzed to explore potential alignment of the literature and business experts. The production manager agrees with the total of the literature identified barriers, and he also suggests adding the barrier of the "Industry 4.0 culture." The manager's definition of "Industry 4.0 culture" signifies that the curiosity and motivation to implement Industry 4.0 key technologies should be spread among all employees to simplify the implementation and to gain additional buy-in to the concepts. If a lack of this common culture for Industry 4.0 occurs, it serves to prevent the adoption of Industry 4.0 concepts. Table 4 demonstrates the dimensions and corresponding barriers that hinder the effective implementation of Industry 4.0.

3.2. Case description

The considered case industry is a Danish manufacturing firm which was established in 1953 in Odense, Denmark. It has facilities not only in Denmark but also in Germany, USA, India, and China. The company manufactures specific components for the automotive industry offering both original equipment and aftermarket products. In fact, it is a third-tier component supplier for car brakes. The case industry is specialized in development and production of anti-noise shims and back plates for manufacturers of disc brake linings. The workforce consists of approximately 150 employees, both white and blue collars. A few years ago, it was a medium manufacturer in anti-noise and back plates; today, it is considered a leader within this certain market. Customers believe that case industry produces products with high utility value and best quality; therefore, it holds a great market share with net revenues for 2019 of 453 million DKK. To stay competitive in the business environment and to be progressive, this industry intends to transform their operations to a digital platform. They are not naive in the industrial sector, but they are new to such technologies which makes them more cautious in their initial steps towards digital transformation. With the concern of addressing the case industry issues with digital transformations, this study proposed the two-phase research framework and validated results with the considered case industry.

4. Solution methodology and application

This section seeks to explain the methodology and its application to the concerned research phases. Each phase has its own solution methodology and application.

4.0.1. Phase I Readiness

During the case study, an assessment of Industry 4.0 Readiness of the

[1] https://warwick.ac.uk/fac/sci/wmg/research/scip/industry4report/.
[2] https://i40-self-assessment.pwc.de/i40/landing/.

Table 3
Readiness dimensions and their corresponding items of Industry 4.0.

S. No	Readiness		Explanation	Source
	Dimensions	Items		
1	Business Models & Products	RI1. Digital product features	Evaluates the contribution of digital features on the products and services of the firm's portfolio.	University of Warwick, n.d.; PwC, n.d.; Viharos et al., 2017; Carolis et al., 2017; Jung et al., 2016; Schumacher et al., 2016; Barafort and Shrestha, 2017; Leyh et al., 2017; Zheng and Ming, 2017; Ziaei Nafchi and Mohelská, 2020; Lin et al., 2020; Pacchini et al., 2019; Maria et al., 2019; Basl and Doucek, 2019; Pirola et al., 2019; Terminanto et al., 2019; Akdil et al., 2018; Alcácer et al., 2021; Mansour et al., 2021; Hajoary, 2022; Benešová et al., 2021; Rakic et al., 2021; Tripathi and Gupta, 2021; Wankhede and Vinodh, 2022; Khin and Kee, 2022; Ali and Johl, 2022; Ali et al., 2022; Zutin et al., 2022
		RI2. Customized products	Examines the possibility of customers customizing the products that they order.	
		RI3. Product life cycle phases digitization	Evaluates the digitization level of a product from design until services and recycling.	
		RI4. Data analysis	Examines the importance of usage and analysis for the firm's current business mode.	
		RI5. Horizontal Integration	Used to research the extent that firms collaborate with their suppliers and customers for the development of products and services.	
		RI6. Data Collection	Deals with the way that the data are collected and in which business areas.	
2	Market & Sales	RI7. Integrated Sales Channels	Researches if firm uses the various channels digitally or non-digitally such as store, web-store, and sales platforms to sell products to each customer.	
		RI8. Sales Force Digitization	Deals with the digital enablement of the sale force such as mobile devices utilization and ubiquitous access to the sales systems.	
		RI9. Customized pricing system	Refers to whether the pricing system is customer-tailored according to each customer's willingness to pay by providing offers or discounts.	
		RI10. Partners collaboration for customer approach	Evaluates the extent of collaboration among partners in order to approach new customers by exchange of customers' database or coordination of marketing activities.	
3	Value Chains & Operations	RI11.Vertical value Chain Digitization	Evaluates the degree of digitization from the product development phase to the production phase.	
		RI12. Self-optimising processes usage (AI-ML)	Examines the extent of implementation of artificial intelligence and machine learning in the company.	
		RI13. Real-time view on production	Evaluates the extent to which the firm has real time view in the production procedure, and it can dynamically react on changes in potential demand.	
		RI14. End-to-end IT system	Assesses the degree of an end-to-end IT enabled planning and steering process from sales forecasting to warehousing and logistics.	
		RI15. Production equipment digitization	Refers to sensors, IoT connection, digital monitoring, control, optimization and automation.	
		RI16. Horizontal value chain digitization	Assesses the degree of digitization in horizontal value chain from customer order over supplier, production and logistics to service.	
		RI17. Data-driven maintenance schedule	Examines the degree of predictive maintenance.	
		RI18. Real-time data management for inventory control	Evaluates the extent of digitization with regards to inventory control in the warehouses.	
		RI19. Automation in process equipment and system infrastructure	Evaluates the extent of automation in the processes and infrastructure.	
		RI20. Autonomously guided work-pieces usage	Examines the potential use of autonomously guided workpieces, such as autonomous guided vehicles and autonomous	

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Table 3 (*continued*)

S. No	Readiness Dimensions	Items	Explanation	Source
			material handling equipment.	
		RI21. Machines and operational systems integration	Examines the grade that the machines and systems within production are integrated; this fact is also known as machine to machine learning.	
4	IT infrastructure	RI22. IT Architecture meets I 4.0 technologies	Evaluates at what extent that the current IT infrastructure has the requirements to meet Industry 4.0 technologies such as IoT, Big Data analytics, software, and algorithms.	
		RI23. Manufacturing execution system (MES)	Assesses the use of manufacturing execution system to control the manufacturing procedure.	
		RI24. IT Infrastructure & data processing	Item examines the maturity of the current IT architecture to gather, aggregate, and interpret real-time manufacturing, product and client data.	
		RI25. Cloud solutions usage	Examines to which extent that cloud computing is used for data processing.	
		RI26. IT horizontal integration	Examines the level of IT systems integration with suppliers and customers.	
		RI27. Agility	Examines the firm's agility of supply chain in changes in market environment and individual customer requirements.	
5	Legal & Security	RI28. Intellectual property (IP) protection	Refers to the protection of the intellectual property of digital products and services of the firm; moreover, it protects the firm in order not to violate external intellectual property.	
		RI29. Risk management consideration	Refers to the fact whether the risk management considers the firm's digital product portfolio.	
		RI30. (IT) security concept for production	Evaluates to which extent that the firm applies IT security to protect production sensitive data.	
6	Organization & Strategy	RI31.Value creation from data	Assesses the firm's capability to create value from data.	
		RI32. Executive and senior management support for I 4.0	Examines the potential involvement, support, and expertise of the executive and senior management regarding Industry 4.0.	
		RI33. Collaboration with external partners towards I 4.0	The collaboration among firm and external partners, such as academia, industry, suppliers, and customers concerning Industry 4.0 is assessed.	
		RI34. Company's strategy to I 4.0	Evaluates the level of the company's strategy to implement Industry 4.0 technologies.	
		RI35. I 4.0 investments	Assesses the level of investments put into Industry 4.0 application.	
		RI36. Skilled employees	Evaluates the competencies of the current employees regarding Industry 4.0 core technologies.	

case industry takes place. The primary data can be gathered generally from observations, experiments, surveys (questionnaires), and interviews. In the present survey, an interview among the author, the production manager, and procurement manager has taken place, and a questionnaire (Appendix A) has been completed. The production and procurement managers have been interviewed to provide their perspectives to evaluating the company's current situation regarding Industry 4.0 Readiness. This survey is oriented towards Industry 4.0 Readiness assessment; therefore, a questionnaire contains grades for each completed answer. The sum of the grades will provide an average score assessing in this manner the readiness of the firm.

The interviewed persons are the case industry production manager and procurement manager. The collected data are considered valid and reliable since both have worked for the company for several years. The method used to evaluate the current readiness of Industry 4.0 in the case industry involved an interview combined with answering a questionnaire. This mode of assessment is through external auditor (Schumacher et al., 2016) and the author played that role. Nevertheless, to create the questionnaire for the evaluation of Industry 4.0 readiness, inspiration

Table 4
Identified barriers of Industry 4.0 implementation with dimensions and its corresponding items.

S. No	Dimension	Items	Explanation	Sources
1.	Policy and organization aspect	Leadership **(B1)**	Leadership plays a pivotal role towards Industry 4.0 era since the leaders of a firm determine the Industry 4.0 implementation and inspire the employees to skip their self-interest for the interest of the organization.	Palazzeschi, Bucci, & Di Fabio, 2018; de Sousa Jabbour, Jabbour, Foropon, & Godinho Filho, 2018; Ozkan-Ozen et al., 2020; Kumar et al., 2022; Nimawat and Gidwani, 2021; Agarwal et al., 2022; Chauhan et al., 2021;
		Organizational Change **(B2)**	The arrival of the Industry 4.0 concept in a company carries disruption and organizational change that might be unwelcome by the internal industrial actors.	de Sousa Jabbour et al., 2018; Park, 2017; G. Li et al., 2017; Leyh, Schaffer, Bley, & Forstenhausler, 2017; Altendorfer-Kaiser, 2017; A. C. Pereira & Romero, 2017; Shamim, Cang, Yu, & Li, 2016; Khan & Turowski, 2016a; Ajmera and Jain, 2019; Horváth, and Szabó, 2019; Sarkar et al., 2022;
		Legal Issues **(B3)**	Legal issues might emerge with the implementation of Industry 4.0. Problems can come up in conjunction with employees' supervision, product liability, and intellectual property rights.	Park, 2017; Maslarić, Nikoličić, & Mirčetić, 2016; Sommer, 2015; Singh and Bhanot, 2020; Senna et al., 2022; Nimawat and Gidwani, 2021;
		Government Regulations/ Incentives absence **(B4)**	Lack of government support and initiative is the key barrier for Industry 4.0. Some local governments provide incentives and enact regulations to promote the concept of Industry 4.0, but in most countries, the local governments have not taken such initiatives. Still, it is a fact that functions as an impediment for firms, especially for SMEs.	Basl, 2017; Raj et al., 2019; Rauch et al., 2019; Agostini and Fillippini, 2019; Nimawat and Gidwani, 2021; Agarwal et al., 2022; Chauhan et al., 2021; Vigneshvaran and Vinodh, 2021
		Weak vision and commitment **(B5)**	The existence of a weak vision and commitment among the top management and the employees for the total implementation of Industry 4.0 might lead to failure.	O'Donovan et al., 2015; Singh and Bhanot, 2020; Türkeş et al., 2019; Senna et al., 2022; Kumar et al., 2022; Nimawat and Gidwani, 2021; Agarwal et al., 2022; Jena and Patel, 2022
		Cooperation **(B6)**	For the success of the endeavor, cross-company cooperation and cooperation among the various value chain actors (firm, suppliers, and customers) is essential for adoption of digitalization.	Kiel, Müller, Arnold, & Voigt, 2017; Ozkan-Ozen et al., 2020; Obiso et al., 2019; Sarkar et al., 2022; Kumar et al., 2021a; 2021b;
		Industry 4.0 Culture **(B7)**	Culture plays a key role to assess the Industry 4.0 platforms.	Expert's opinion
		Little awareness **(B8)**	There are many firms which ignore the existence of Industry 4.0 which results in lack of awareness about Industry 4.0.	Basl, 2017; Sung, 2017; O'Donovan et al., 2015; Ozkan-Ozen et al., 2020; Rajput and Singh, 2019; Senna et al., 2022;
2	HR management aspect	Lack of skilled employees **(B9)**	The implementation of Industry 4.0 technologies requires personnel who have advanced competencies to adopt the digital transformation in a company. For most firms, there is a lack of such skilled manpower in cutting-edge technologies, and that fact acts as a preventing factor towards the implementation of Industry 4.0.	Marques et al., 2017; Ang, Goh, & Li, 2016; Shamim et al., 2016; D. Li, 2016; Maslarić et al., 2016; Khan & Turowski, 2016a; Sommer, 2015; Raj et al., 2019; Kamble et al., 2018; Singh and Bhanot, 2020; Senna et al., 2022; Kumar et al., 2022; Nimawat and Gidwani, 2021; Chauhan et al., 2021;
		Resistance to change by employees **(B10)**	There are workers, especially the old ones, who are unwilling to learn to handle new technologies and are not motivated to change their working routines.	de Sousa Jabbour et al., 2018; Maksimchuk & Pershina, 2017; G. Li et al., 2017; Trstenjak & Cosic, 2017; Khan & Turowski,

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Table 4 (*continued*)

S. No	Dimension	Items	Explanation	Sources
		Training and implementation team **(B11)**	Several top managers consider it a heavy burden to plan training programs for employees regarding Industry 4.0 technologies; they are also hesitant to formulate and spend financial resources on an Industry 4.0 implementation team.	2016a; Kumar et al., 2022; Basl, 2017; Issa, Lucke, & Bauernhansl, 2017; Khan & Turowski, 2016a; Khan & Turowski, 2016b; Sommer, 2015; Raj et al., 2019; Kamble et al., 2018; Singh and Bhanot, 2020; Kumar et al., 2022; Sarkar et al., 2022; Agarwal et al., 2022; Chauhan et al., 2021; Kumar et al., 2021a; 2021b; Ghobakhloo et al., 2022; Majumdar et al., 2021
3	Economic aspect	High Investment/ Cost **(B12)**	The investment cost for Industry 4.0 is enormous and not all interested companies have it available at their disposal; therefore, it is considered as a serious barrier. Although the firm will spend a lot of funds in the beginning, they may need to spend additional funds in the future to support new technological developments.	Vaidya et al., 2018; Park, 2017; Kiel et al., 2017; Maksimchuk & Pershina, 2017; G. Li et al., 2017; Leyh et al., 2017; Trstenjak & Cosic, 2017; Altendorfer-Kaiser, 2017; Frolov, Kaminchenko, Kovylkin, Popova, & Pavlova, 2017; Papa, Kaselautzke, Radinger, & Stuja, 2017; Sanders, Elangeswaran, & Wulfsberg, 2016; Sommer, 2015; Basl, 2017; Ozkan-Ozen et al., 2020; Senna et al., 2022; Kumar et al., 2021a; 2021b; Jena and Patel, 2022; Ghobakhloo et al., 2022;
		Unclear Benefits/ Profitability (ROI) **(B13)**	Due to the Industry 4.0 newness, the benefits of implementation have not been measured clearly; therefore, the profitability is not clear.	Basl, 2017; Marques et al., 2017; Sung, 2017; Schumacher, Erol, & Sihn, 2016; Ang et al., 2016; Raj et al., 2019; Sarkar et al., 2022; Nimawat and Gidwani, 2021;
4	Technical aspect	Security/Privacy **(B14)**	The monitoring systems and sensors in manufacturing procedure handle a big mass of sensitive data and information which are vulnerable to cyber threats; therefore, security/privacy is considered a critical barrier against Industry 4.0 implementation.	Fatorachian & Kazemi, 2018; Park, 2017; Kiel et al., 2017; Feng, Bernstein, Hedberg, & Barnard Feeney, 2017; Basl, 2017; Marques et al., 2017; Preuveneers & Ilie-Zudor, 2017; T. Pereira, Barreto, & Amaral, 2017; Sung, 2017; Altendorfer-Kaiser, 2017; Nikolic, Ignjatic, Suzic, Stevanov, & Rikalovic, 2017; Papa et al., 2017; Ren, Wu, Zhang, Terpenny, & Liu, 2017; Oesterreich & Teuteberg, 2016; Yu et al., 2016; Asakura, 2016; Ang et al., 2016; Waidner & Kasper, 2016; Wittenberg, 2016; Khan & Turowski, 2016b; Hecklau, Galeitzke, Flachs, & Kohl, 2016; Lu, Morris, & Frechette, 2016; Weyer, Schmitt, Ohmer, & Gorecky, 2015; Sommer, 2015; Jazdi, 2014; Ozkan-Ozen et al., 2020; Kamble et al., 2018; Singh and Bhanot, 2020; Senna et al., 2022; Kumar et al., 2021a; 2021b; Ghobakhloo et al., 2022
		High complexity **(B15)**	Researchers believe that the interdisciplinary nature and the complexity of technological advancements of Industry 4.0 behave as obstacles for Industry 4.0 installment.	Müller, Kiel, & Voigt, 2018; Trappey et al., 2017a; Yan, Hua, Wang, Wei, & Imran, 2017; Ras et al., 2017; Thoben et al., 2017; Schumacher et al., 2016; Wittenberg, 2016; Raj et al., 2019; Sarkar et al., 2022; Vinodh and Shimray, 2022

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Table 4 (*continued*)

S. No	Dimension	Items	Explanation	Sources
		Interoperability/ Standards **(B16)**	So far, there is not adequate standardization to ascertain the seamless exchange of data among machines, devices, and products, and this fact is faced as a barrier against Industry 4.0 implementation. Thus, there is a need for international standard communication protocols, data formats, and interfaces to guarantee interoperability among various departments.	Fatorachian & Kazemi, 2018; Marques et al., 2017; Fernández-Miranda, Marcos, Peralta, & Aguayo, 2017; Peres et al., 2016; Park, 2017; Trappey et al., 2017a; Trappey et al., 2017b; Nikolic et al., 2017; Frolov et al., 2017; Rojko, 2017; Wan et al., 2016; Maslarić et al., 2016; Khan & Turowski, 2016a; Sanders et al., 2016; Weyer et al., 2015; Lu et al., 2016; Hecklau et al., 2016; Sommer, 2015; Ozkan-Ozen et al., 2020; Nimawat and Gidwani, 2021;
		Reluctance to change current technology/ legacy equipment **(B17)**	The reluctance of several firms to change their current technology/ legacy equipment since they have spent a lot of funds to invest in current technology which operates smoothly, and they are unwilling to invest in Industry 4.0 technologies.	O'Donovan et al., 2015; Marques et al., 2017; Ozkan-Ozen et al., 2020; Senna et al., 2022; Kumar et al., 2021a; 2021b
		Regulatory and quality constraints **(B18)**	There are some regulatory and quality constraints in some cases which obscure the procedure towards Industry 4.0. For instance, in pharmaceutical or medical devices sectors, there are some regulations and quality constraints that impede the adoption of Industry 4.0 core technologies.	O'Donovan et al., 2015; Raj et al., 2019; Kamble et al., 2018; Singh and Bhanot, 2020; Agarwal et al., 2022; Vinodh and Shimray, 2022; Majumdar et al., 2022
5	Competition aspect	Lack of leading companies in Industry 4.0 **(B19)**	There are only a few leading companies that have already implemented Industry 4.0 key technologies. This fact operates as a barrier since the competition and the action of rivals can draw attention for imitation. If there was a plethora of leading firms implementing the Industry 4.0 concepts, then more firms would mimic them.	Basl, 2017; Raj et al., 2019; Kumar et al., 2022; Vinodh and Shimray, 2022; Majumdar et al., 2022; Goswami and Daultani, 2022; Machado et al., 2021;
		Low application rates of Industry 4.0 **(B20)**	The low rates of firms which already adopted Industry 4.0 technological advancements do not motivate the rest of the enterprises to crave to implement the Industry 4.0 concept. On the contrary, it functions as an obstacle.	Basl, 2017; Ozkan-Ozen et al., 2020; Agarwal et al., 2022; Chauhan et al., 2021; Jena and Patel, 2022; Machado et al., 2021
6	Social aspect	Loss of many jobs **(B21)**	The implementation of Industry 4.0 technologies such as automation and IT systems will result in loss of jobs especially for the unskilled manpower.	Sung, 2017; Raj et al., 2019; Singh and Bhanot, 2020; Kamble et al., 2018; Singh and Bhanot, 2020

from several readiness models, including academic institutions such as University of Warwick's[3] self-assessment tool and consultant group PwC's[4] self-assessment model was taken. The current questionnaire consists of 36 questions representing 36 readiness items grouped into six readiness dimensions which were described in detail in the previous section.

The evaluation of Industry 4.0 Readiness consists of three stages: measuring the score for each question, calculating the average score for every dimension and the overall average score depicting the readiness situation, and presenting and illustrating the readiness report and radar charts. Fig. 1 shows the Industry 4.0 readiness evaluation procedure.

The answers to the questions are divided in four levels of maturity giving scores from 1 for the minimum level of digitization up to 4 for the maximum level of digitization. Afterwards, the scores for each answer are gathered and the average score for each dimension is calculated as is the overall score of Industry 4.0 Readiness. Equations (a) & (b) are used to calculate the average score per category and overall average score regarding Industry 4.0 Readiness of the firm.

Average score per category: $asc = \frac{a1+a2+\cdots+an}{n}$ (a)

where n = 1,2,….

Overall average score: $oas = \frac{asc1+asc2+\cdots+asc6}{6}$ (b)

since the readiness dimensions are 6.

[3] https://warwick.ac.uk/fac/sci/wmg/research/scip/industry4report/.

[4] https://i40-self-assessment.pwc.de/i40/landing/.

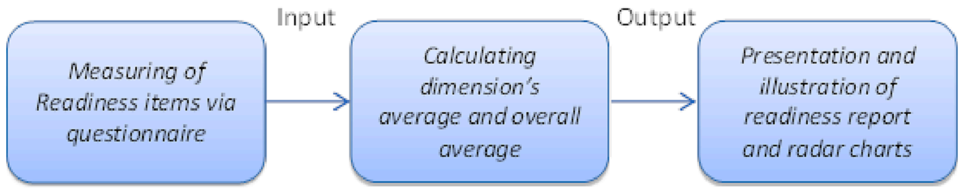

Fig. 1. Evaluation Procedure (Own Contribution).

In the last stage, a readiness report is represented and radar charts illustrating the dimensions' scores and the overall readiness score are developed. The format of the questions and answers is shown below in Table 5.

The questionnaire can be answered properly, if the interviewees are aware of the concept of Industry 4.0.

4.0.2. Phase II Barriers

This phase includes literature review and the opinions of expert and industrial decision makers to identify and analyze the influential barriers of Industry 4.0 implementation. This study introduces a MCDM tool, DEMATEL, to analyze the influence of barriers. The author chose DEMATEL in the analysis of interrelationship of factors because of DEMATEL's several advantages over other existing MCDM tools. For instance, specifically, for any complex problem, it clearly extracts the interdependencies and interrelationships among factors, which then can explore their interactions (Govindan and Chaudhuri (2016); Garg, 2021). In addition, DEMATEL assists the decision makers to formulate appropriate choices with insight into both short-term and long-term results, which may further improve an organization's performance (Mangla et al., 2016; Du and Li, 2021). The steps involved in DEMATEL are detailed in appendix and the outcome is given as follows.

STEP 1: Initial Direct-relationship (Average) matrix "A"

In this step, the identified barriers by the literature have been also validated by the expert and then a pairwise comparison occurs. The scores show how much a factor influences another factor. The scores vary among 0 and 4. For instance, Leadership (B1) provides "very high influence" (score = 4) to the Organizational change (B2). Below, Table 6 illustrates the initial direct relationship matrix "A."

STEP 2: Normalization – normalized direct-relation matrix "S"

In the second step, the initial direct-relation matrix is normalized by the aid of the Eqs. (2) & (3) returning the normalized direct-relation matrix "S." Table 7 illustrates the normalized direct influence matrix "S."

STEP 3: Calculation of total relation matrix "M"

In order to calculate the total relation matrix "M," combinations of the normalized matrix "S" with the aid of Eq. (4) are used. Table 8 below presents the total relation matrix "M."

STEP 4: Calculation of sum of rows and columns of Matrix M

In order to construct the total influence matrix, we need to calculate the sums of the rows and columns by using the Eqs. (5) & (6). Table 9 illustrates the influence matrix depicting the total influences given and received among the barriers.

Table 5
Question Example.

1. How would you evaluate the contribution of digital features over your products & services of your portfolio?
4: High contribution – Products exhibit mainly digital features and value from the licensing of Intellectual Property (e.g. cloud-based predictive maintenance solution, licenses for 3D-printing of products)
3: Medium Contribution - Products exhibit some digital features, and value from intellectual property licensing
2: Low Contribution - Products show value only from intellectual property licensing
1: No contribution - Value is generated solely with the sales of physical products and product-related services (e.g. traditional maintenance)

STEP 5: Calculation of threshold value (θ) for minor influences elimination

In order to find the threshold value θ, we use the formula to define the mean value $m = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}[aij]}{N}$ => $m = \frac{23{,}0973}{441}$ => m = 0,05237.

The standard deviation is equal to 0,01897. Therefore θ = 0,05237 + 0,01897 = 0,07134.

Afterwards, we construct the total influence matrix with threshold to eliminate the minor influences as shown in Table 10.

5. Results and discussion

As explained earlier, this section categorizes the two phases, and the results of phase I will provide the path forward for phase II.

5.1. Phase I

5.1.1. Business models and products

In this dimension, the case industry has concentrated the maximum average score compared to the rest of the dimensions. The average score was 3.2, meaning that the industry collaborates closely with its suppliers, partners, and customers achieving the horizontal integration. Moreover, case industry's products are completely customized according to clients' requirements and struggles to implement the complete mass-customization by using the assumption that the "batch size of 1" can be met at the same unit cost as a mass-produced product. The industry considers Big Data of great value to collect and analyze them for further actions in decision making. Especially, the industry needs to use Big Data to boost the uptime which is currently moderate and to decrease machine breakdowns. Improvements can be done regarding the digitization of the product life cycle phases since the core Industry 4.0 technologies are only implemented in a few phases. Fig. 2 demonstrates the radar graph of business models & products dimension.

5.1.2. Market & sales

In this dimension, the case industry scored an average of 2.3. Unfortunately, the industry still uses its traditional sales force and it does not exploit cutting-edge technologies such as web-shop, sales platforms, and social media to boost its sales. However, there is still room for improvement by adopting these technologies. Furthermore, the industry marches slowly to embrace digital era practices. Sales could provide high technology equipment such as digital devices to its sellers when meeting clients. Nevertheless, the industry can modernize its digital positioning in its sales force by providing mobile devices with real-time access to clients, by making product data available, and by offering the possibility to configure personalized products which would dynamically create and increase orders. In addition, the industry can cooperate with its partners for exchange of information for potential customers at a high level. Finally, the industry is currently using fixed offers to its customers, such as quantity discount while they could use dynamic pricing in real-time. Fig. 3 demonstrates the radar graph of the market & sales dimension.

5.1.3. Value chains & operations

The average score in the current dimension is 2.2. The case industry has highly digitized its vertical value chain from the product

Table 6
Initial direct relationship matrix "A".

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15	B16	B17	B18	B19	B20	B21
B1	0	4	4	2	4	2	4	2	4	3	4	4	4	4	3	3	3	3	4	4	4
B2	3	0	3	2	3	3	2	3	4	3	3	1	2	1	1	1	2	2	2	2	2
B3	3	2	0	4	1	1	1	1	1	1	1	2	2	4	1	2	2	2	1	1	2
B4	3	2	4	0	1	1	1	1	3	1	2	1	1	2	1	1	2	1	1	1	3
B5	3	2	1	0	0	1	2	1	3	3	3	3	2	2	1	2	3	3	3	3	3
B6	2	3	2	1	2	0	2	0	1	1	1	2	2	1	2	2	2	2	2	1	1
B7	2	1	1	2	2	1	0	1	1	2	2	2	1	0	2	1	0	0	2	1	3
B8	3	2	2	2	2	1	1	0	3	3	3	2	2	2	1	2	2	2	2	2	2
B9	3	2	2	2	2	1	1	1	0	3	3	2	2	1	2	1	1	3	1	1	2
B10	3	1	2	0	2	1	2	3	3	0	3	2	1	1	2	1	2	1	1	1	4
B11	3	2	1	0	2	1	2	2	3	2	0	2	1	1	1	1	1	1	1	1	2
B12	3	1	2	1	3	1	1	1	2	2	2	0	3	1	2	2	1	1	2	1	1
B13	3	1	1	1	3	1	2	2	3	2	2	3	0	1	2	1	2	2	2	1	2
B14	2	1	3	1	1	1	1	2	2	2	2	2	2	0	1	2	2	2	1	1	1
B15	2	2	2	1	2	1	3	2	3	3	3	2	1	1	0	2	2	1	1	1	1
B16	2	2	3	3	2	2	1	2	1	1	1	2	1	2	1	0	2	1	2	2	1
B17	2	1	1	1	2	1	1	2	2	2	2	2	1	1	3	2	0	1	1	1	1
B18	3	2	1	1	2	2	1	2	2	2	2	2	2	1	2	1	1	0	1	1	1
B19	3	2	1	1	3	2	2	2	2	2	2	1	1	1	1	1	1	1	0	2	1
B20	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1
B21	3	2	1	1	2	2	2	2	2	3	2	3	2	1	1	1	1	1	1	1	0

development to production. Additionally, the industry has implemented an end-to-end IT integrated system for planning and steering the procedure from sales forecasting to warehouse planning and logistics, which provides real time monitoring and makes the industry agile to changes. Likewise, the industry is using real-time data management through computer databases and smart devices to update the inventory levels. On the contrary, the industry has not applied key technologies of Industry 4.0 sufficiently such as sensors, Internet of Things connection, digital monitoring, optimization, and automation. Therefore, there is space for improvement if the appropriate investments on Industry 4.0 technologies are adopted promptly. Also, machines and operational systems are not integrated at all, which means that the so-called machine-to-machine integration is not achieved. Moreover, although the industry collaborates and works closely with customers regarding products customization, the digitization of the horizontal value chain is still at basic levels. Unfortunately, the industry does not use any kind of autonomously guided workpieces such as autonomous material handling equipment or autonomous guided vehicles that may become available in the future. Moreover, artificial intelligence and machine learning are not used at all but should be considered as essential future investments. All in all, in the dimension of value chains and operations, despite some progress the industry has achieved regarding the vertical value chain, there is still a vital lack of adoption of Industry 4.0 key technologies. These key technologies should be encountered with all necessary investments in the future since the industry wants to transform itself digitally. Fig. 4 illustrates the radar graph of value chains & operations.

5.1.4. IT infrastructure

In this dimension, the IT system's capabilities are examined. The average score for the case industry is 2.3. While the industry is far behind regarding the adoption of Industry 4.0 key technologies, such as Internet of Things, Big Data, and cloud solutions, leadership should spend funds to implement those technological advancements. Unfortunately, the firm schedules their production planning via SAP ERP by using SAP module for short term production planning; they do not utilize a manufacturing execution system (MES) to handle the manufacturing process (capacities, utilization schedules, etc). The IT & data architecture has enough advanced maturity to employ databases and smart devices to manipulate the generation of Big Data but there is still space for improvements. Furthermore, there is an adequate system integration with suppliers/customers happening after request and approval from IT department. Regarding the agility of the industry in terms of supply chains, they can immediately respond to any possible changes in market environment and individual customer requirements. Fig. 5 illustrates the radar graph of the IT infrastructure.

5.1.4.1. Legal & security. Regarding the dimension of legal & security concerns, the case industry has already taken measures to protect its intellectual property in products and services, but they still need to guarantee that the intellectual property is treated according to the appropriate regulatory framework. Moreover, the industry has already implemented a robust cyber security system for protection from cyberattacks. The risk of the exposure in industrial cyber spying is great in today's globalization epoch; therefore, the usage of cyber security systems is essential. The average score in legal & security is 2.3. Fig. 6 illustrates the radar graph of the legal & security dimension.

5.1.4.2. Organization & strategy. In this dimension, the case industry generates the lowest score compared to the other dimensions, with an average score of 1.5. It appears that the industry's leadership has moved hesitantly, marking only a few steps towards Industry 4.0 by searching the potential benefits of this implementation. Little or no funds have been invested to apply key technologies; that lack presented itself in the previous dimensions as well. Moreover, the low score reveals that the industry has not invested sufficient money in the Internet of Things, smart devices, Big Data analytics, software, and so forth. Furthermore, its manpower is not comprehensively skilled with respect to the Industry 4.0 toolbox. The most significant technological regret is that the concept of Industry 4.0 is apparently not considered in current business strategies. The industry has not collaborated on Industry 4.0 topics with their external partners, such as academicians, industry suppliers, or customers; these experts could assist the case industry regarding Industry 4.0 concepts. It seems that industry's leadership is not eager to adopt Industry 4.0 concepts; that hesitancy affects the low levels in Industry 4.0 in the remaining dimensions as well. It is highly recommended that top management of the industry should approach experts, including university professors, industry experts, suppliers, or customers who are knowledgeable regarding Industry 4.0 applications; industry leaders should augment their knowledge and acceptance of the value and benefits of Industry 4.0 concepts. Fig. 7 illustrates the radar graph of organization & strategy.

5.1.4.3. Overall readiness. The general analysis of the data gathered via the questionnaire has given an overall average score of 2.29. This means that the case industry does not belong to the lowest level of Industry 4.0

Table 7
Normalized direct influence matrix "S".

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15	B16	B17	B18	B19	B20	B21
B1	0,00	0,06	0,06	0,03	0,06	0,03	0,06	0,03	0,06	0,04	0,06	0,06	0,06	0,06	0,04	0,04	0,04	0,04	0,06	0,06	0,06
B2	0,04	0,00	0,04	0,03	0,04	0,04	0,03	0,04	0,06	0,04	0,04	0,01	0,03	0,01	0,01	0,01	0,03	0,03	0,03	0,03	0,03
B3	0,04	0,03	0,00	0,06	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,03	0,03	0,06	0,01	0,03	0,03	0,03	0,01	0,01	0,03
B4	0,04	0,03	0,06	0,00	0,01	0,01	0,01	0,01	0,04	0,01	0,03	0,01	0,01	0,03	0,01	0,01	0,03	0,01	0,01	0,01	0,04
B5	0,04	0,03	0,01	0,00	0,00	0,01	0,03	0,01	0,04	0,04	0,04	0,04	0,03	0,03	0,01	0,03	0,04	0,04	0,04	0,04	0,04
B6	0,03	0,04	0,03	0,01	0,03	0,00	0,03	0,00	0,01	0,01	0,01	0,03	0,03	0,01	0,03	0,03	0,03	0,03	0,03	0,01	0,01
B7	0,03	0,01	0,01	0,03	0,03	0,01	0,00	0,01	0,01	0,03	0,03	0,03	0,01	0,00	0,03	0,01	0,00	0,00	0,03	0,01	0,04
B8	0,04	0,03	0,03	0,03	0,03	0,01	0,01	0,00	0,04	0,04	0,04	0,03	0,03	0,03	0,01	0,03	0,03	0,03	0,03	0,03	0,03
B9	0,04	0,03	0,03	0,03	0,03	0,01	0,01	0,01	0,00	0,04	0,04	0,03	0,03	0,01	0,03	0,01	0,01	0,04	0,01	0,01	0,03
B10	0,04	0,01	0,03	0,00	0,03	0,01	0,03	0,04	0,04	0,00	0,04	0,03	0,01	0,01	0,03	0,01	0,03	0,01	0,01	0,01	0,06
B11	0,04	0,03	0,01	0,00	0,03	0,01	0,03	0,03	0,04	0,03	0,00	0,03	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,03
B12	0,04	0,01	0,03	0,01	0,04	0,01	0,01	0,01	0,03	0,03	0,03	0,00	0,04	0,01	0,03	0,03	0,01	0,01	0,03	0,01	0,01
B13	0,04	0,01	0,01	0,01	0,04	0,01	0,03	0,03	0,04	0,03	0,03	0,04	0,00	0,01	0,03	0,01	0,03	0,03	0,03	0,01	0,03
B14	0,03	0,01	0,04	0,01	0,01	0,01	0,01	0,03	0,03	0,03	0,03	0,03	0,03	0,00	0,01	0,03	0,03	0,03	0,01	0,01	0,01
B15	0,03	0,03	0,03	0,01	0,03	0,01	0,04	0,03	0,04	0,04	0,04	0,03	0,01	0,01	0,00	0,03	0,03	0,01	0,01	0,01	0,01
B16	0,03	0,03	0,04	0,04	0,03	0,03	0,01	0,03	0,01	0,01	0,01	0,03	0,01	0,03	0,01	0,00	0,03	0,01	0,03	0,03	0,01
B17	0,03	0,01	0,01	0,01	0,03	0,01	0,01	0,03	0,03	0,03	0,03	0,03	0,01	0,01	0,04	0,03	0,00	0,01	0,01	0,01	0,01
B18	0,04	0,03	0,01	0,01	0,03	0,03	0,01	0,03	0,03	0,03	0,03	0,03	0,03	0,01	0,03	0,01	0,01	0,00	0,01	0,01	0,01
B19	0,04	0,03	0,01	0,01	0,04	0,03	0,03	0,03	0,03	0,03	0,03	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,00	0,03	0,01
B20	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,00	0,01
B21	0,04	0,03	0,01	0,01	0,03	0,03	0,03	0,03	0,03	0,04	0,03	0,04	0,03	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,00

Table 8
Total relation matrix "M".

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15	B16	B17	B18	B19	B20	B21
B1	0,08	0,11	0,11	0,07	0,12	0,07	0,10	0,08	0,12	0,10	0,12	0,12	0,11	0,10	0,09	0,09	0,09	0,09	0,10	0,10	0,11
B2	0,09	0,04	0,08	0,05	0,08	0,07	0,06	0,07	0,10	0,08	0,09	0,06	0,06	0,04	0,05	0,04	0,06	0,06	0,06	0,06	0,07
B3	0,08	0,06	0,03	0,08	0,05	0,04	0,04	0,04	0,05	0,05	0,05	0,06	0,06	0,08	0,04	0,05	0,05	0,05	0,04	0,04	0,06
B4	0,08	0,06	0,08	0,02	0,05	0,03	0,04	0,04	0,08	0,05	0,06	0,05	0,04	0,05	0,04	0,04	0,05	0,04	0,04	0,04	0,07
B5	0,09	0,06	0,05	0,02	0,04	0,04	0,06	0,05	0,09	0,08	0,08	0,08	0,06	0,06	0,04	0,06	0,07	0,07	0,07	0,07	0,08
B6	0,06	0,07	0,05	0,03	0,06	0,02	0,05	0,02	0,05	0,04	0,05	0,06	0,05	0,04	0,05	0,05	0,05	0,05	0,05	0,04	0,04
B7	0,06	0,04	0,04	0,04	0,05	0,03	0,02	0,03	0,04	0,05	0,06	0,05	0,04	0,02	0,05	0,03	0,02	0,02	0,05	0,03	0,07
B8	0,09	0,06	0,06	0,05	0,07	0,04	0,04	0,03	0,08	0,08	0,08	0,07	0,06	0,06	0,04	0,06	0,06	0,06	0,06	0,06	0,06
B9	0,08	0,06	0,06	0,05	0,06	0,04	0,04	0,04	0,04	0,08	0,08	0,06	0,06	0,04	0,05	0,04	0,04	0,07	0,04	0,04	0,06
B10	0,08	0,04	0,06	0,02	0,06	0,04	0,06	0,07	0,08	0,04	0,08	0,06	0,04	0,04	0,05	0,04	0,05	0,04	0,04	0,04	0,09
B11	0,08	0,05	0,04	0,02	0,06	0,03	0,05	0,05	0,07	0,06	0,03	0,06	0,04	0,03	0,04	0,03	0,04	0,04	0,04	0,04	0,06
B12	0,08	0,04	0,06	0,03	0,07	0,03	0,04	0,04	0,06	0,06	0,06	0,03	0,07	0,04	0,05	0,05	0,04	0,04	0,05	0,04	0,04
B13	0,08	0,04	0,04	0,04	0,08	0,04	0,06	0,06	0,08	0,06	0,07	0,08	0,03	0,04	0,05	0,04	0,06	0,05	0,06	0,04	0,06
B14	0,06	0,04	0,07	0,03	0,04	0,03	0,04	0,05	0,06	0,06	0,06	0,06	0,05	0,02	0,04	0,05	0,05	0,05	0,04	0,03	0,04
B15	0,07	0,06	0,06	0,04	0,06	0,04	0,07	0,05	0,08	0,08	0,08	0,06	0,04	0,04	0,02	0,05	0,05	0,04	0,04	0,04	0,05
B16	0,07	0,06	0,07	0,06	0,06	0,05	0,04	0,05	0,05	0,04	0,05	0,06	0,04	0,05	0,04	0,02	0,05	0,04	0,05	0,05	0,04
B17	0,06	0,04	0,04	0,03	0,06	0,03	0,04	0,05	0,06	0,06	0,06	0,06	0,04	0,03	0,06	0,05	0,02	0,04	0,04	0,03	0,04
B18	0,08	0,05	0,04	0,03	0,06	0,05	0,04	0,05	0,06	0,06	0,06	0,06	0,05	0,04	0,05	0,04	0,04	0,02	0,04	0,04	0,04
B19	0,08	0,05	0,04	0,03	0,07	0,05	0,05	0,05	0,06	0,06	0,06	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,02	0,05	0,04
B20	0,04	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,01	0,03
B21	0,08	0,06	0,04	0,03	0,06	0,05	0,05	0,05	0,06	0,07	0,06	0,07	0,06	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,03

Table 9
Sum of Influences.

Barriers	ri	si	ri + si	ri-si
B1. Leadership	2,049683	1,580861	3,630544	0,468822
B2. Organizational Change	1,38105	1,108538	2,489587	0,272512
B3. Legal Issues	1,083631	1,156694	2,240325	−0,07306
B4. Government Regulations/ Incentives absence	1,029539	0,822987	1,852526	0,206551
B5. Weak vision and commitment	1,332387	1,295749	2,628136	0,036638
B6. Cooperation	0,9883	0,828144	1,816444	0,160156
B7. Industry 4.0 Culture	0,841777	1,027045	1,868822	−0,18527
B8. Little awareness	1,260575	1,014796	2,275371	0,245779
B9. Lack of skilled employees	1,121913	1,416094	2,538007	−0,29418
B10. Resistance to change by employees	1,119362	1,297449	2,416811	−0,17809
B11. Training and implementation team	0,949254	1,36102	2,310275	−0,41177
B12. High Investment/Cost	1,036886	1,268552	2,305439	−0,23167
B13. Unclear Benefits/ Profitability (ROI)	1,149452	1,060817	2,210269	0,088634
B14. Security/Privacy	0,984772	0,904868	1,889641	0,079904
B15. High complexity	1,103991	0,959293	2,063284	0,144698
B16. Interoperability/ Standards	1,041524	0,924286	1,96581	0,117238
B17. Reluctance to change current technology/ legacy equipment	0,93167	1,012877	1,944547	−0,08121
B18. Regulatory and quality constraints	1,009141	0,967565	1,976706	0,041576
B19. Lack of leading companies in Industry 4.0	1,001991	0,995194	1,997186	0,006797
B20. Low application rates of Industry 4.0	0,615676	0,906775	1,522451	−0,2911
B21. Loss of many jobs	1,06477	1,18774	2,25251	−0,12297

implementation but it cannot be considered a digitization leader in the automotive industry. By examining the dimensions one by one, the investigation notes that the industry's strategy and vision towards the Fourth Industrial Revolution is weak; in other words, the firm's leadership does not value Industry 4.0 concepts enough to spend funds to establish available key technologies. Additionally, the absence of skilled workforce within the corporation appears as an obstacle to a smooth digital transformation. On the other hand, the case industry does cooperate closely with its partners and customers to achieve a partial horizontal integration. Cooperation with customers is considered intimate since the industry's products are entirely individualized to each customer's requirements. Specifically, the industry is using mass-customization to achieve the same unit cost that others offer through mass production. Nonetheless, the goal is still distant for the case industry to become a digital leader, and it will happen only if the industry's top management is convinced by academic and industrial experts to move forward with Industry 4.0 applications. Industry leadership must acknowledge the benefits that can ultimately boost their industry's performance from Industry 4.0 core technologies before they are convinced to invest their resources. Table 11 illustrates the overview of scores and average scores per readiness item and dimension. Fig. 8 below presents the Industry 4.0 readiness of the case industry for all the six readiness dimensions.

From Fig. 8, it is evident that the case industry is not ready for the Industry 4.0 adoption; their overall readiness shows with an average of 2.3 out of 4. This score shows the case industry is roughly midway of adopting Industry 4.0, a ranking that is often termed as Industry "3.5." According to Chien et al. (2017) and Chien et al. (2020), an organization is positioned in a transitional stage when it stands in between "Industry 3.0" and "Industry 4.0." The literature also refers to this point as a hybrid strategy, which may allow the industry to transform from traditional strategies to digital operations. With this concern, this study proposes a second research phase to identify the barriers that hinder the case industry from advancing from an Industry 3.5 position to Industry

Table 10
Total influence matrix with threshold.

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15	B16	B17	B18	B19	B20	B21
B1	**0,0753**	**0,1071**	**0,1090**	0,0670	**0,1170**	0,0675	**0,1041**	**0,0766**	**0,1222**	**0,1038**	**0,1198**	**0,1156**	**0,1058**	**0,0978**	**0,0869**	**0,0851**	**0,0891**	**0,0877**	**0,1024**	**0,0983**	**0,1115**
B2	**0,0931**	0,0365	**0,0786**	0,0545	**0,0835**	0,0683	0,0614	**0,0740**	**0,1014**	**0,0840**	**0,0863**	0,0557	0,0627	0,0442	0,0455	0,0440	0,0609	0,0606	0,0604	0,0577	0,0679
B3	**0,0816**	0,0562	0,0315	**0,0773**	0,0467	0,0354	0,0399	0,0402	0,0507	0,0466	0,0486	0,0603	0,0557	**0,0800**	0,0385	0,0519	0,0545	0,0529	0,0395	0,0373	0,0583
B4	**0,0801**	0,0555	**0,0843**	0,0213	0,0451	0,0344	0,0391	0,0387	**0,0759**	0,0458	0,0609	0,0454	0,0408	0,0518	0,0374	0,0368	0,0527	0,0385	0,0379	0,0361	0,0711
B5	**0,0907**	0,0620	0,0487	0,0247	0,0412	0,0404	0,0603	0,0467	**0,0856**	**0,0827**	**0,0844**	**0,0817**	0,0614	0,0551	0,0449	0,0564	**0,0723**	**0,0717**	**0,0728**	0,0704	**0,0785**
B6	0,0644	0,0676	0,0547	0,0337	0,0588	0,0197	0,0523	0,0241	0,0470	0,0442	0,0456	**0,0573**	**0,0528**	0,0351	0,0506	0,0496	0,0516	0,0504	0,0517	0,0356	0,0414
B7	0,0596	0,0366	0,0370	0,0435	0,0542	0,0306	0,0214	0,0342	0,0429	0,0542	0,0555	0,0535	0,0352	0,0182	0,0465	0,0322	0,0202	0,0189	0,0482	0,0326	0,0666
B8	**0,0886**	0,0608	0,0624	0,0520	0,0664	0,0386	0,0446	0,0303	**0,0842**	**0,0802**	**0,0824**	0,0657	0,0597	0,0553	0,0426	0,0551	0,0580	0,0572	0,0573	0,0552	0,0639
B9	**0,0839**	0,0576	0,0585	0,0489	0,0626	0,0361	0,0421	0,0416	0,0385	**0,0764**	**0,0785**	0,0621	0,0566	0,0385	0,0536	0,0383	0,0411	0,0677	0,0405	0,0382	0,0606
B10	**0,0834**	0,0439	0,0573	0,0218	0,0625	0,0357	0,0558	0,0686	**0,0793**	0,0356	**0,0786**	0,0627	0,0430	0,0382	0,0535	0,0388	0,0542	0,0400	0,0406	0,0384	**0,0875**
B11	**0,0771**	0,0531	0,0399	0,0185	0,0579	0,0328	0,0517	0,0508	**0,0740**	0,0583	0,0315	0,0572	0,0390	0,0344	0,0361	0,0350	0,0367	0,0367	0,0374	0,0353	0,0557
B12	**0,0803**	0,0416	0,0560	0,0339	**0,0742**	0,0341	0,0403	0,0390	0,0632	0,0599	0,0618	0,0318	0,0681	0,0372	0,0516	0,0509	0,0397	0,0387	0,0533	0,0373	0,0441
B13	**0,0846**	0,0443	0,0446	0,0354	0,0777	0,0362	0,0564	0,0553	**0,0806**	0,0643	0,0660	**0,0769**	0,0293	0,0384	0,0547	0,0394	0,0551	0,0547	0,0557	0,0393	0,0608
B14	0,0646	0,0397	0,0686	0,0340	0,0440	0,0330	0,0374	0,0516	0,0604	0,0576	0,0592	0,0576	0,0529	0,0218	0,0367	0,0497	0,0516	0,0508	0,0370	0,0349	0,0416
B15	0,0690	0,0564	0,0577	0,0356	0,0616	0,0352	0,0685	0,0545	**0,0786**	**0,0758**	**0,0777**	0,0609	0,0414	0,0374	0,0250	0,0518	0,0538	0,0391	0,0400	0,0377	0,0462
B16	0,0663	0,0553	0,0711	0,0630	0,0590	0,0482	0,0386	0,0521	0,0484	0,0449	0,0468	0,0583	0,0403	0,0516	0,0371	0,0229	0,0534	0,0381	0,0525	0,0506	0,0430
B17	0,0623	0,0386	0,0396	0,0318	0,0566	0,0319	0,0372	0,0504	0,0596	0,0570	0,0586	0,0561	0,0374	0,0341	0,0631	0,0487	0,0224	0,0355	0,0362	0,0344	0,0404
B18	**0,0792**	0,0550	0,0419	0,0331	0,0597	0,0477	0,0396	0,0522	0,0628	0,0595	0,0613	0,0587	0,0541	0,0359	0,0513	0,0365	0,0388	0,0237	0,0387	0,0364	0,0431
B19	**0,0786**	0,0548	0,0413	0,0329	**0,0727**	0,0476	0,0531	0,0516	0,0619	0,0591	0,0609	0,0444	0,0396	0,0357	0,0368	0,0361	0,0384	0,0378	0,0244	0,0507	0,0435
B20	0,0369	0,0301	0,0308	0,0260	0,0328	0,0261	0,0290	0,0288	0,0345	0,0328	0,0337	0,0324	0,0294	0,0272	0,0280	0,0275	0,0288	0,0281	0,0285	0,0130	0,0313
B21	**0,0814**	0,0559	0,0432	0,0340	0,0615	0,0486	0,0545	0,0534	0,0643	**0,0749**	0,0630	**0,0743**	0,0556	0,0367	0,0388	0,0375	0,0396	0,0388	0,0402	0,0374	0,0310

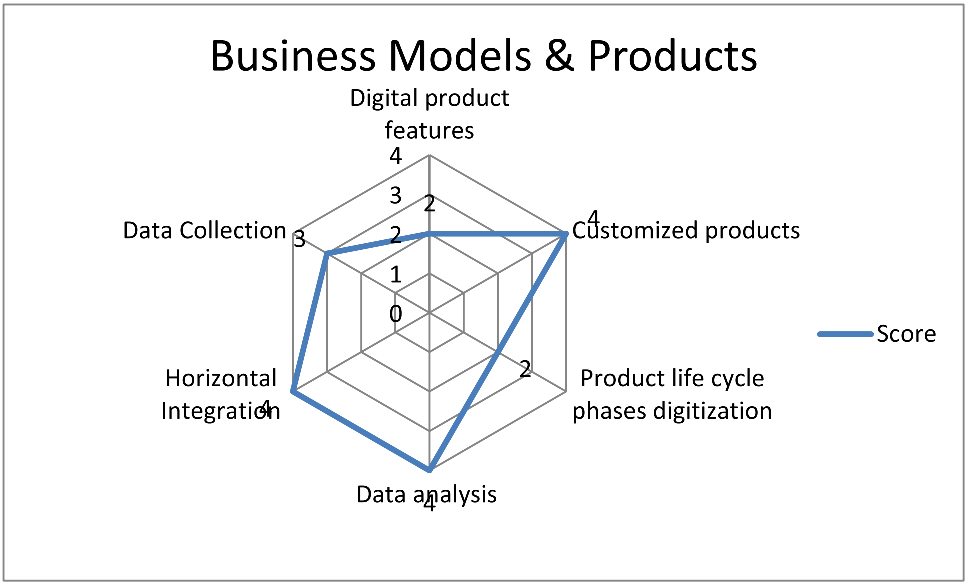

Fig. 2. Detailed Results for Business Models & Product (Own Contribution).

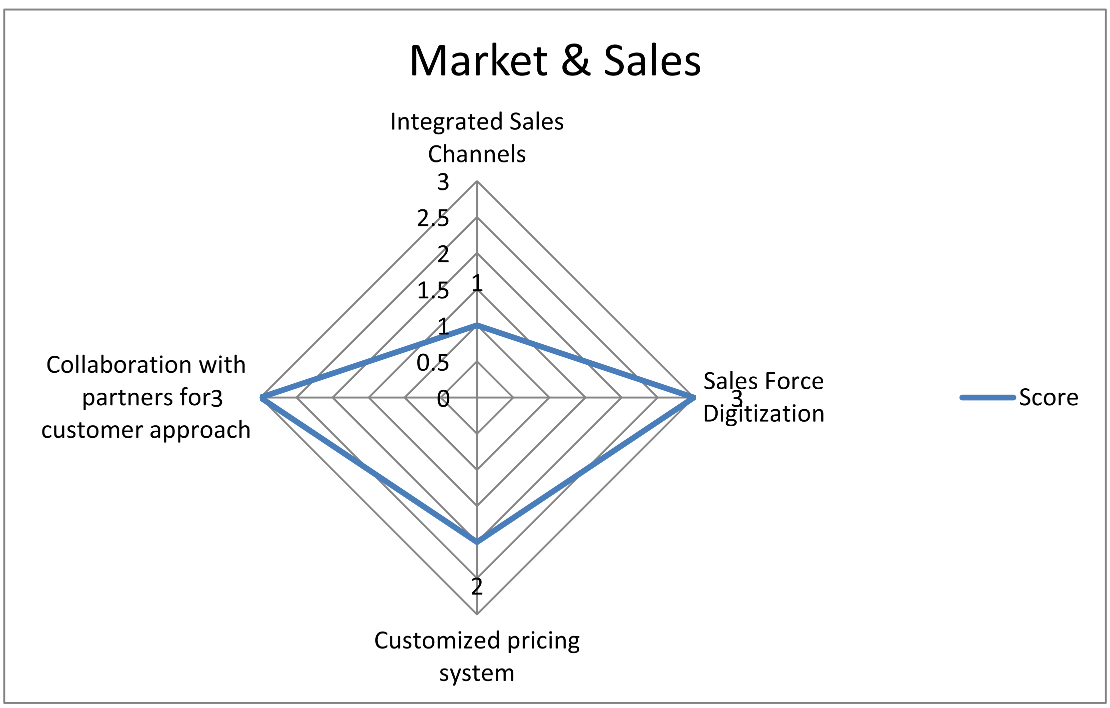

Fig. 3. Detailed Results for Market & Sales Dimension (Own Contribution).

4.0. Barriers were collected from the existing literature, validated with field experts, and further analyzed based on the replies of case decision makers through DEMATEL.

5.2. Phase II barriers

In this section, the cause and effects diagrams will be illustrated per barriers category according to **Step 6** of the DEMATEL method, and a discussion about the results will be presented. Additionally, the prominence-causal DEMATEL graph will be depicted with coordinated discussion.

5.2.1. Cause and effect analysis

Fig. 9 illustrates that the causal barriers order in Policy & Organization (P&O) aspect is B1 > B2 > B8 > B4 > B6 > B5. Apparently, B1 (Leadership) lies at the top of the causal barriers, which means that it is the most influential barrier in the P&O aspect regarding Industry 4.0 implementation. In the second position, B2 (Organizational Change) is the second causal barrier among the P&O barriers. The organizational change is considered very undesirable from most of the employees because it can bring turbulence in their everyday working routines. The production manager of the case industry also validated that B1 and B2, Leadership and Organizational Change, are the top influential barriers in this category. Leadership explores the benefits of the Industry 4.0 implementation but they are not completely convinced because they are

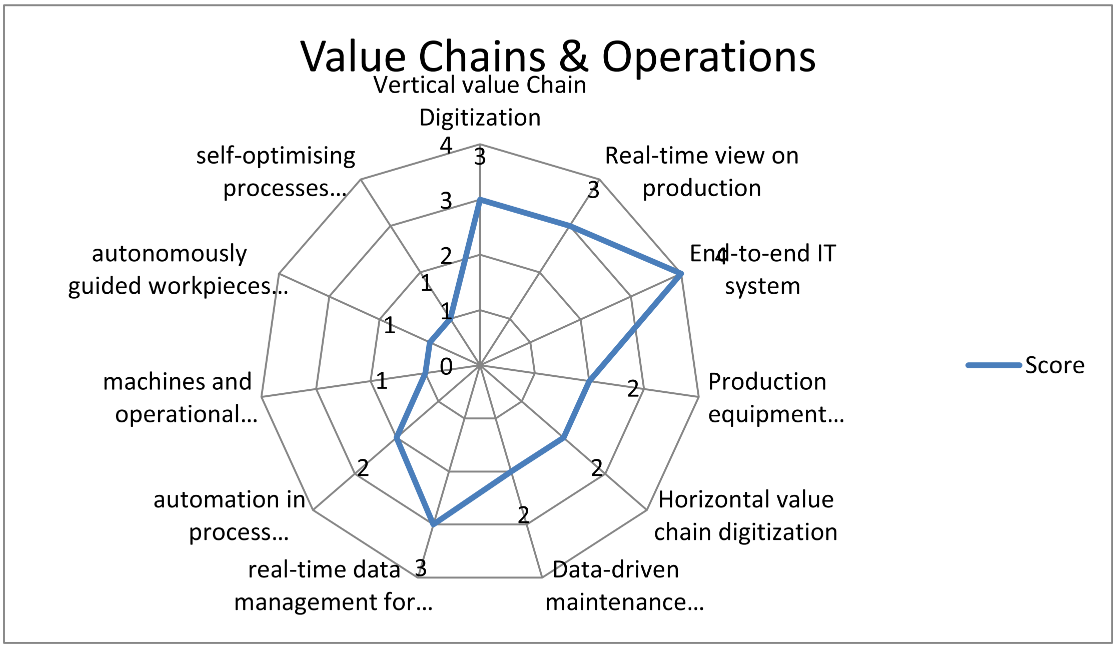

Fig. 4. Detailed Results for Value Chains & Operations (Own Contribution).

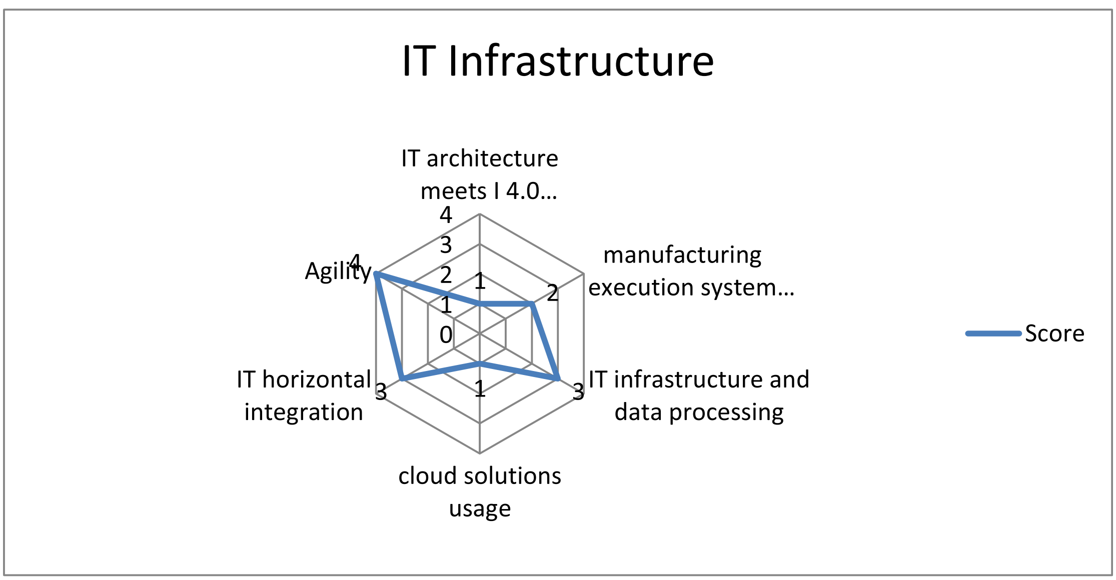

Fig. 5. Detailed Results for IT Infrastructure.

concerned about the organizational disruption the Industry 4.0 implementation can bring. The latter statement is also enhanced by the results of the Industry 4.0 Readiness evaluation in section 3, where the industry has the lowest average score (1.5) in the organization and strategy category. Specifically, the analysis has shown that there is a weak vision towards Industry 4.0 era since the investment for Industry 4.0 technologies was low so far. Factor B8 (Little Awareness) occupies third position since many firms and their managers are still not informed about the advent of Industry 4.0 revolution. Basl (2017) has conducted research showing that the primary barrier among Czech firms is their little awareness. The fourth position is occupied by B4 (Government Regulations/Incentives absence). In some cases, local governments have not yet planned a campaign to promote Industry 4.0 implementation by enacting regulations or by providing motivation to local companies. In the fifth position, B6 (cooperation) resides among the P&O barriers, since the lack of cross-divisional cooperation within the firm as well as the lack of cooperation with suppliers and customers impede the implementation of Industry 4.0 key technologies. In the last position, B5 (Weak vision and commitment) lies among the causal barriers. If the top management and the rest of employees have a weak vision and commitment to the endeavor, the entire firm struggles towards the Industry 4.0 era, then the goal of Industry 4.0 implementation will fail.

The effect group barriers are denoted as influenced barriers. The effect group sequence is B3 > B7. The B3 (Legal Issues) is less influenced by the causal barriers when compared to B7 (Industry 4.0 culture) which is the most influenced. The legal issues a firm might face, such as product liability and intellectual property protection, can be overcome by collaboration among companies and law firms. About the Industry 4.0 culture, it is clearly highly influenced by the causal group since, for example, leadership will transmit the Industry 4.0 culture to the manpower if the former is willing to implement Industry 4.0.

According to Fig. 10, there are only effect barriers in HR

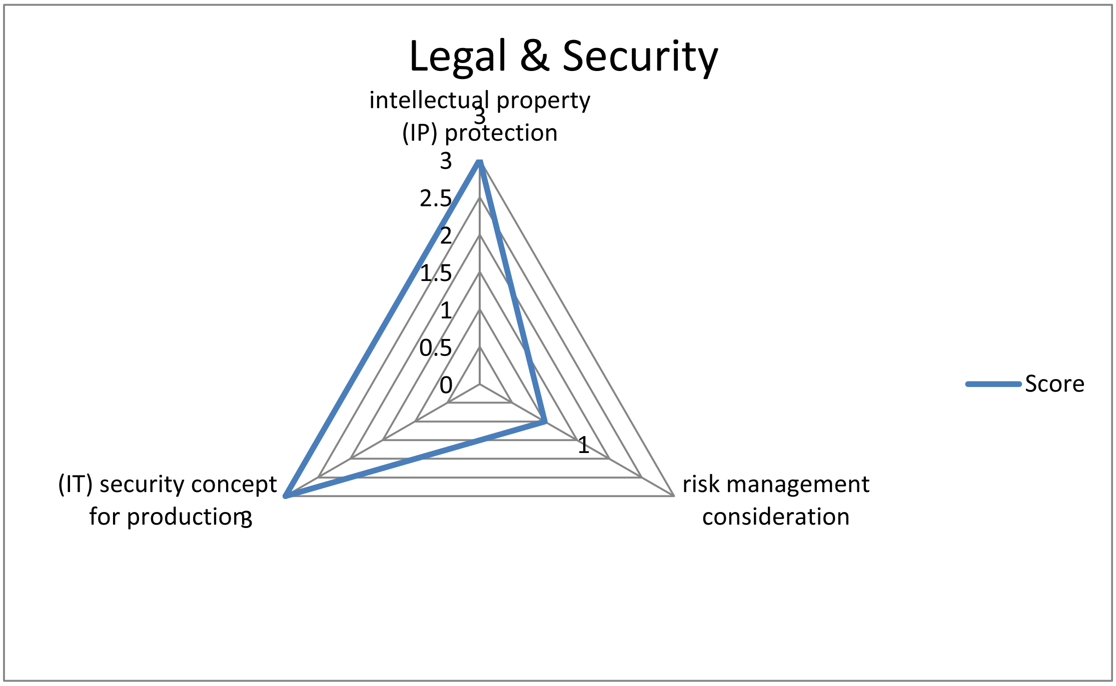

Fig. 6. Detailed Results for Legal & Security.

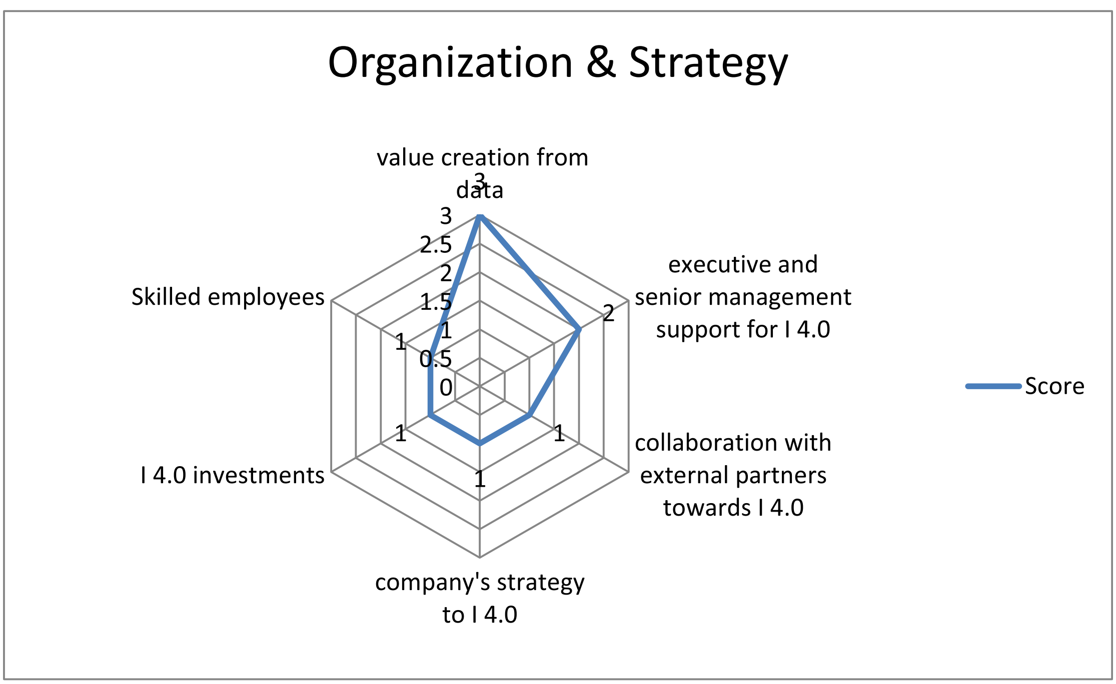

Fig. 7. Detailed Results for Organization & Strategy.

management aspect category and the effect group order is B10 > B9 > B11. Those are B9 (Lack of skilled employees), B10 (Resistance to change by employees), and B11 (Training and implementation team). Ang et al. (2016) consider that the application of Industry 4.0 requires highly skilled employees such as IT professionals, designers, and CFD engineers. However, those barriers might influence barriers in the other groups.

Fig. 11 shows that B13 (Unclear Benefits/Profitability (ROI)) is the only causal barrier and B12 (High Investment/Cost) is the only effect barrier. Vaydia et al. (2018) claims that the full adoption of all pillars of Industry 4.0 requires a huge investment. Obviously, the B13 barrier strongly influences the B12 barrier. The reason is that in order to invest high funds to Industry 4.0 projects, leadership first needs to be convinced by the ROI (profitability) that Industry 4.0 implementation will return benefits to the company.

Fig. 12 illustrates that, in technical aspect, the causal barriers order is B15 > B16 > B14 > B18. Apparently, the B15 (High complexity) is positioned at the top, which means that it is the dominant influencer barrier in the technical aspect regarding implementation of the Industry 4.0 concept. The MAST production manager claims that the high

Table 11
Overview of scores and average score.

Dimensions	Readiness Items	Score	Average Score
D 1	RI 1	2	3.2
	RI 2	4	
	RI 3	2	
	RI 4	4	
	RI 5	4	
	RI 6	3	
D 2	RI 7	1	2.3
	RI 8	3	
	RI 9	2	
	RI 10	3	
D 3	RI 11	3	2.2
	RI 12	3	
	RI 13	4	
	RI 14	2	
	RI 15	2	
	RI 16	2	
	RI 17	3	
	RI 18	2	
	RI 19	1	
	RI 20	1	
	RI 21	1	2.3
D 4	RI 22	1	
	RI 23	2	
	RI 24	3	
	RI 25	1	
	RI 26	3	
	RI 27	4	
D 5	RI 28	3	2.3
	RI 29	1	
	RI 30	3	
D 6	RI 31	3	1.5
	RI 32	2	
	RI 33	1	
	RI 34	1	
	RI 35	1	
	RI 36	1	

complexity (B15) is an important barrier in his opinion since it can provide disruption in the production procedure and it can generate a chaotic situation. In the second position, B16 (Interoperability/Standards) is the second causal barrier among the causal group. The problematic interoperability and the lack of standards among Industry 4.0 key technologies is considered very undesirable for most firms since it can bring turbulence in their production along with non-functionality. The B14 (Security/Privacy) resides in the third position since managers are concerned about cyber-attacks against sensitive databases within the company. Kiel et al. (2017) say that the insecure data access makes companies vulnerable to cyber-crime and industrial spying. The fourth position is occupied by B18 (Regulatory and quality constraints). There are several constraints for firms that prevent Industry 4.0 adoption; for example, medical firms have signed agreements to produce medicines under certain technological infrastructures that guarantee high quality.

The effect group consists only of one barrier, B17 (Reluctance to change current technology/legacy equipment). The barrier B17 is highly influenced by the causal group of barriers.

In Fig. 13, we see that B19 (Lack of leading companies in Industry 4.0) is the only causal barrier and B20 (Low application rates of Industry 4.0) is the only effect barrier. Obviously, B19 barrier influences the B20 barrier. The lack of leading companies that have already applied the concept of Industry 4.0 acts as a hindering factor for the remaining firms; therefore, the rates of firms implementing Industry 4.0 technologies stays low.

5.2.2. Prioritization of barriers

During step 5 of the DEMATEL method, the threshold value $\theta = 0.07134$ was identified in order to eliminate the minor influences among the barriers and to highlight the most important interrelationships among them. All the relationships meeting or surpassing the threshold value θ are underlined in the total influence matrix (Table 10). Afterwards, we have drawn these strongest dyadic relationships (Fig. 14). Two-way significant relationships are represented by two-arrow lines, whereas one-way relationships are represented by one-arrow curved lines.

Interesting insights are yielded by the results. Among the Policy & Organization category barriers, B1 (Leadership), B2 (Organizational Change), B5 (Weak vision and commitment), and B8 (Little Awareness) have influenced all the barriers of the HR management category. The barrier B4 (Government Regulations/Incentives absence) influences

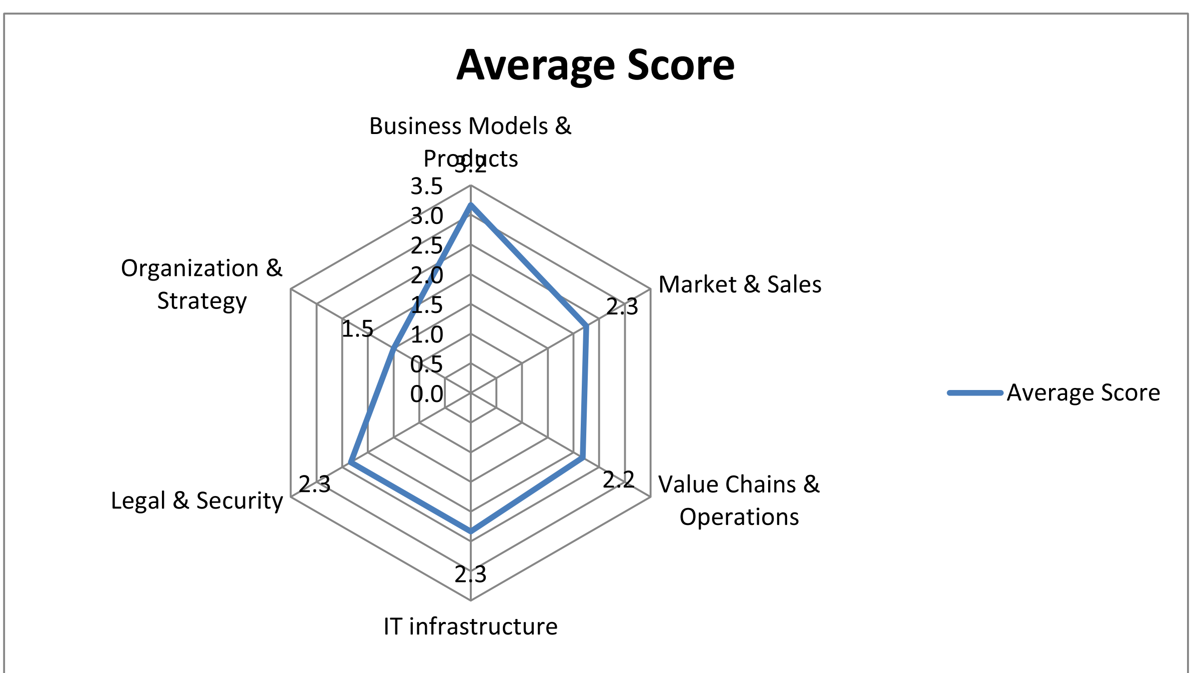

Fig. 8. Radar chart visualizing Industry 4.0 readiness in six dimensions.

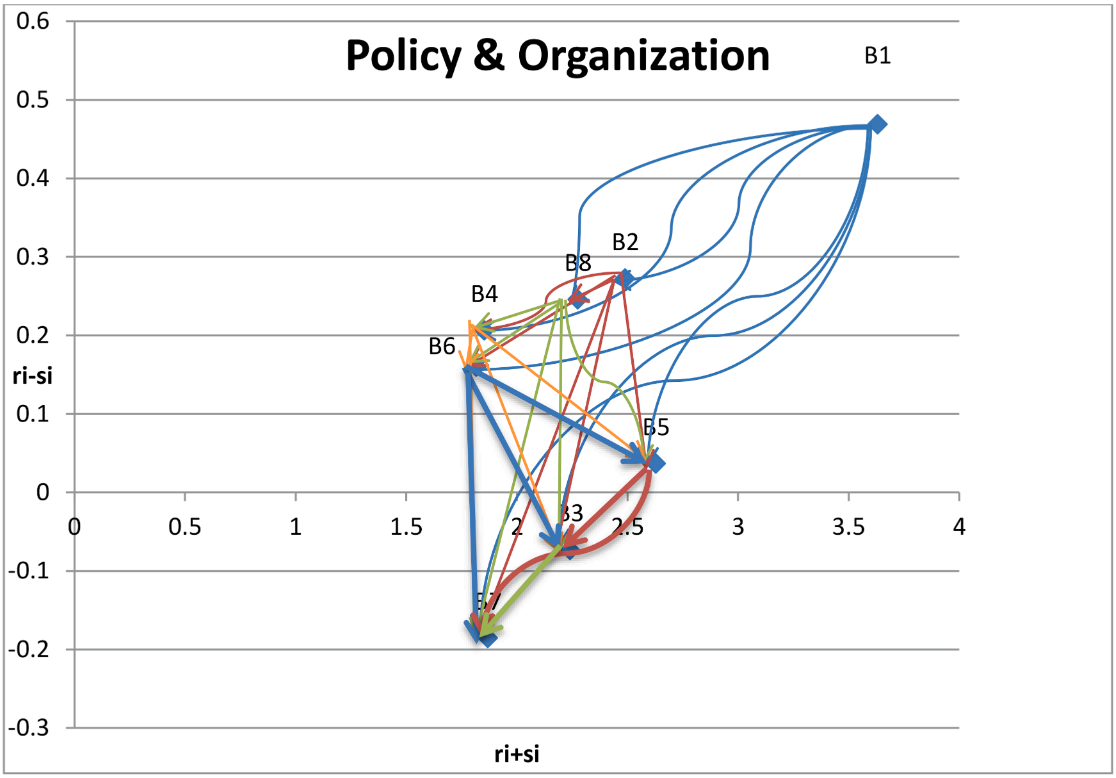

Fig. 9. Causal diagram with degree of central role and degree of relation of Policy & Organization Aspect's Barriers.

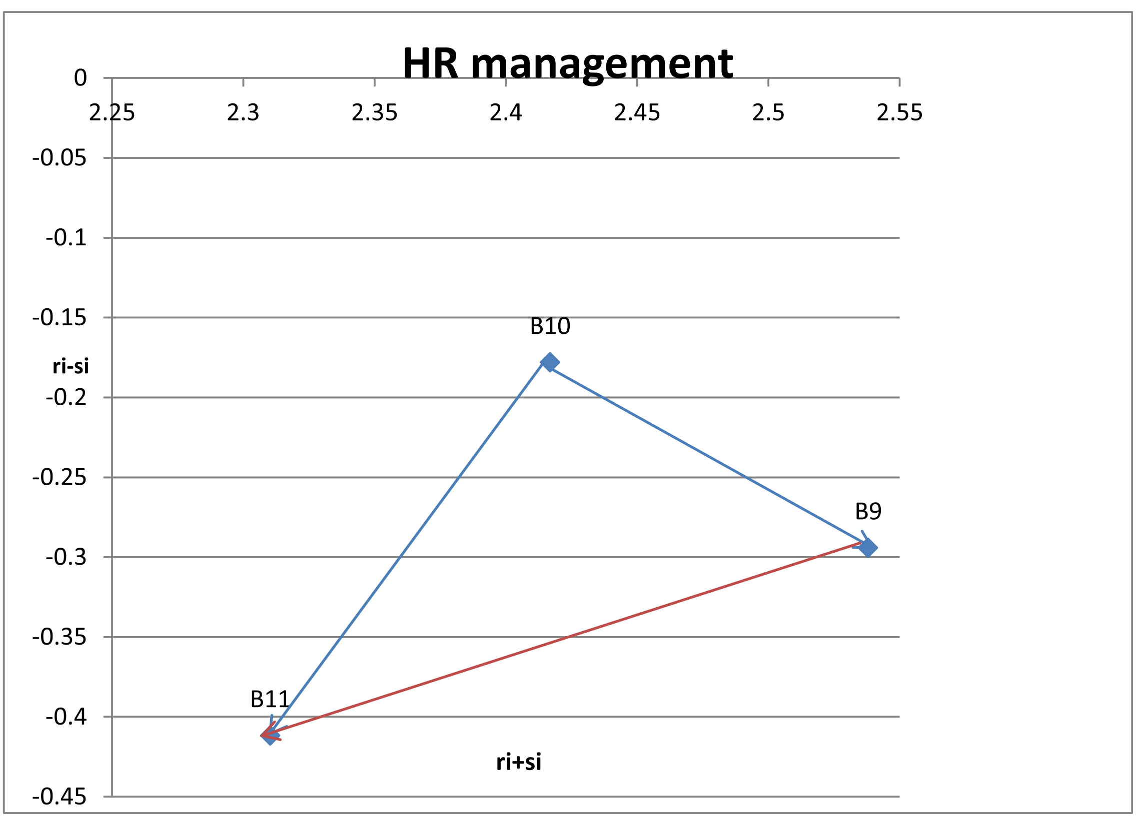

Fig. 10. Causal diagram with degree of central role and degree of relation of HR management aspect's barriers.

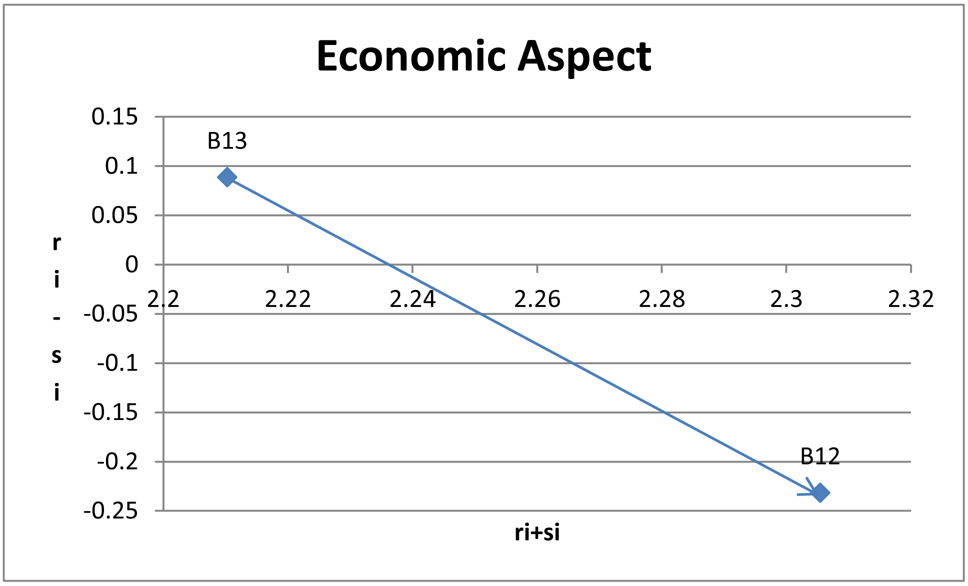

Fig. 11. Causal diagram with degree of central role and degree of relation of Economic Aspect's barriers.

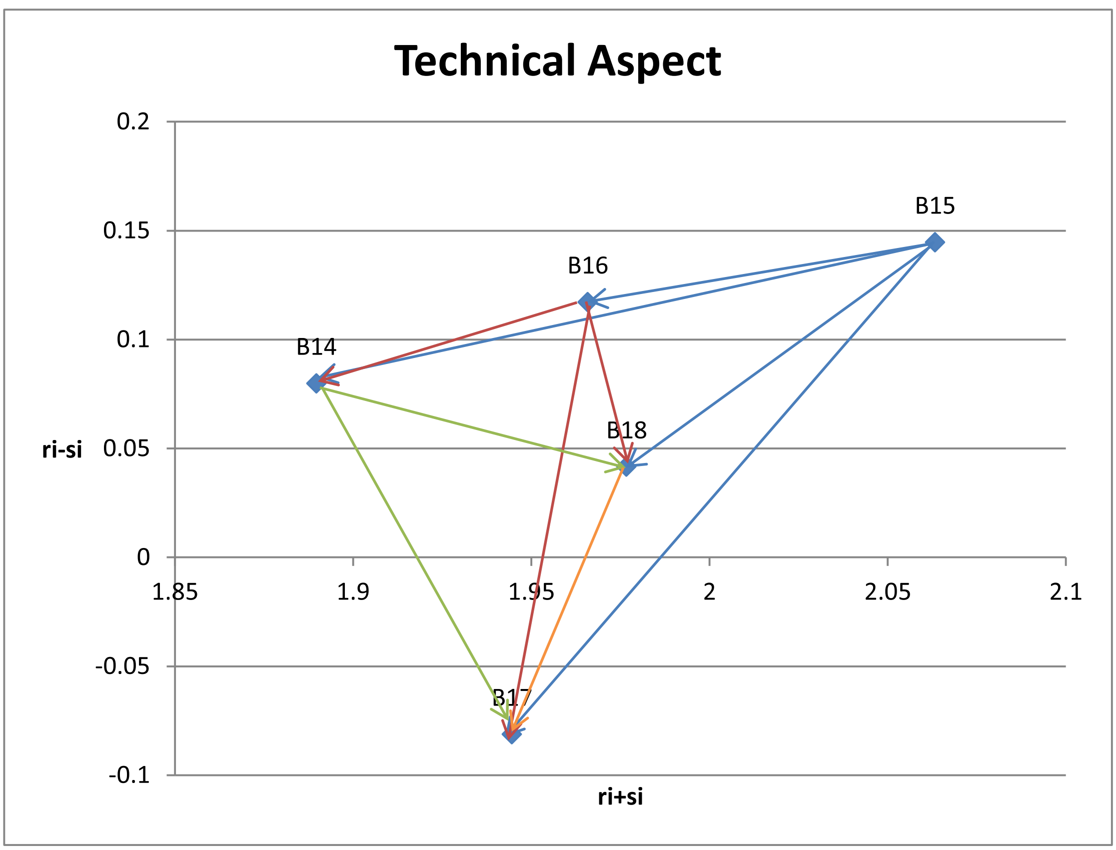

Fig. 12. Causal diagram with degree of central role and degree of relation of Technical Aspect's barriers.

only the B9 (Lack of skilled employees). B1 (Leadership) has a special bidirectional relationship with all the HR category barriers, B9 (Lack of skilled employees), B10 (Resistance to change by employees), and B11 (Training and implementation team); they influence each other. This fact makes sense; leadership will likely determine not to implement Industry 4.0 if they lack skilled employees capable of utilizing Industry 4.0 key technologies. Further, employees might resist any technological change because it will destroy current working routines and it is a real barrier to plan training and to formulate implementation teams for Industry 4.0 technologies. Leadership's decisions influence the three HR barriers (B9, B10, and B11). Beatriz et al. (2018) say that leadership strongly affects the application of emerging trends in manufacturing companies.

Furthermore, B1 (Leadership) and B6 (Cooperation) influence the economic aspect's barriers. There are bidirectional relationships among B1 (Leadership), B12 (High Investment/Cost) and B13 (Unclear

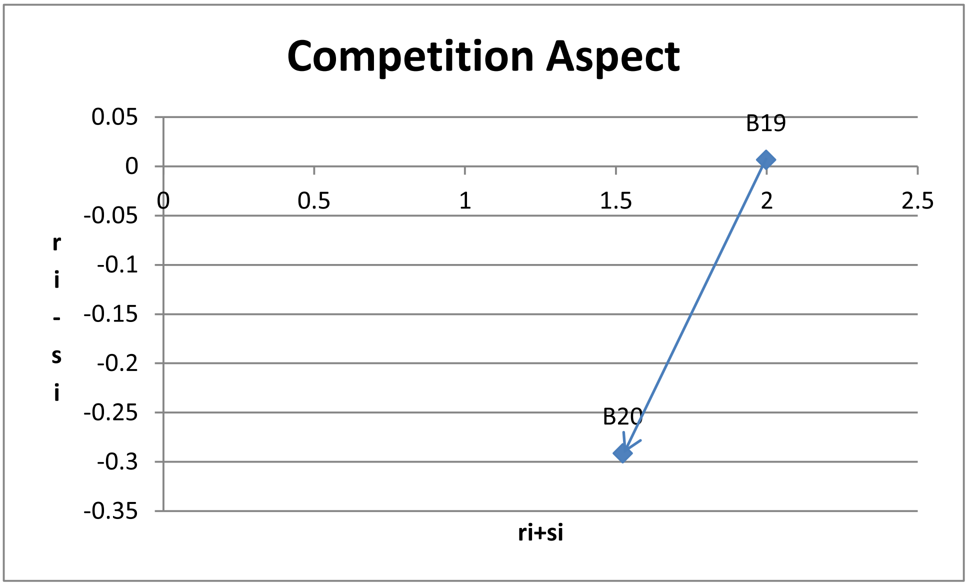

Fig. 13. Causal diagram with degree of central role and degree of relation of competition aspect barriers.

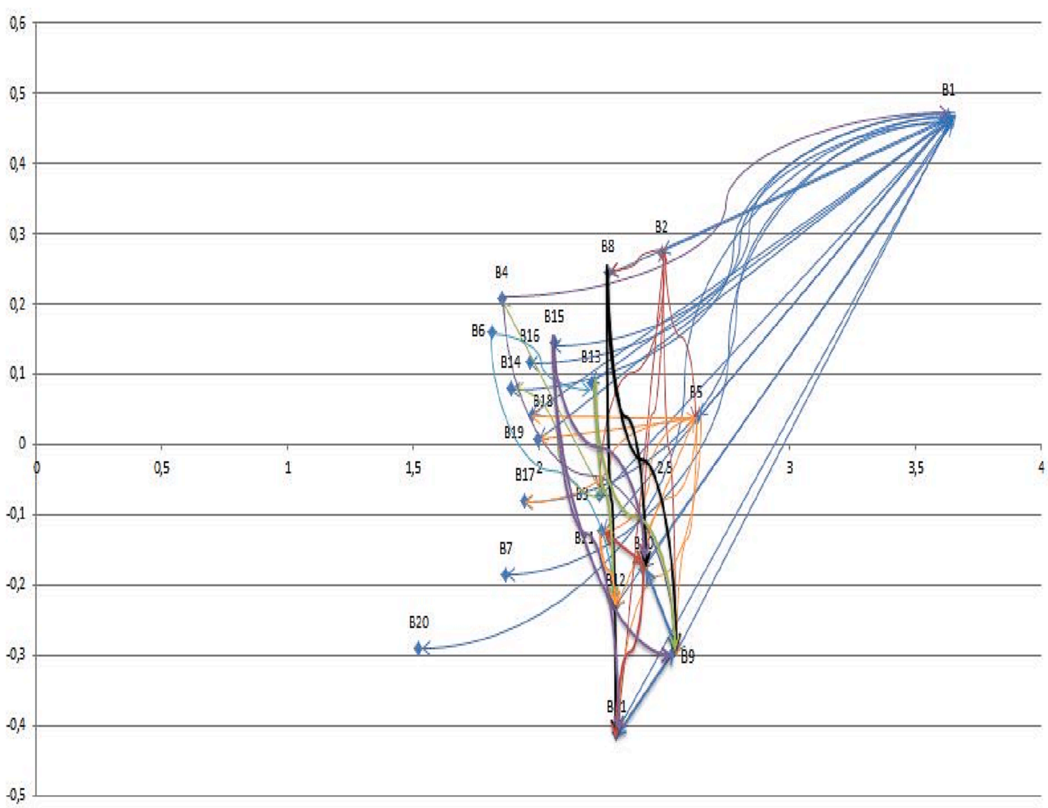

Fig. 14. The prominence-causal DEMATEL graph.

Benefits/Profitability (ROI)). This fact is justifiable since leadership resolution towards the Industry 4.0 era goes through the volume of the necessary investment and the size of the future profitability the investment may bring. The opposite approach also holds. Moreover, B1 (Leadership) influences all the technical aspect barriers: B14 (Security/Privacy), B15 (High complexity), B17 (Reluctance to change current technology/legacy equipment). B1 is mutually influenced with B18 (Regulatory and quality constraints) by having bidirectional relationships. Additionally, the B3 (Legal issues) influences the B14 (Security/Privacy) since the security and privacy of the business-critical data is a legal issue against the cyber threats. B1 (Leadership) also influences the competition aspect's barriers, one-way influence with B19 (Lack of leading companies in Industry 4.0) because if the firm's leadership refuses to adopt Industry 4.0 technologies, then the lack of leading companies in Industry 4.0 will be preserved. However, there are bidirectional relationships between B1 (Leadership) and B20 (Low application rates of Industry 4.0) since the low rates may obscure the leadership to implement Industry 4.0 technologies. On the other hand, the denial from leadership for Industry 4.0 adoption will preserve the low application rates of Industry 4.0. What is more, bidirectional relationships exist between the B1 (Leadership) and the social aspect's barrier B21 (Loss of many jobs) meaning that they influence each other mutually. Leadership decisions to apply Industry 4.0 key technologies may result in the loss of many job positions, especially for low qualification blue collar workers. Obviously, the graph illustrates that the greatest influencer barrier of all is the B1 (Leadership) since it has bidirectional relationships with 12 of the remaining barriers and a one direction influence on 6 barriers.

The HR management aspect's barrier B10 (resistance to change by employees) influences mutually the barrier of social aspect B21 (Loss of many jobs). This interrelationship is very reasonable since employees, under fear of losing their jobs, resist the changes that Industry 4.0 application could bring. On the other hand, resistance to change by some employees will lead them to unemployment. Also, the economic aspect's barrier B13 (Unclear Benefits/Profitability (ROI)) influences the HR managements aspect's barrier B9 (Lack of skilled employees).

From Fig. 14, we can also see that technical aspect barrier B15 (High Complexity) influences the three barriers of the HR management: B9 (Lack of skilled employees), B10 (Resistance to change by employees), and B11 (Training and implementation team). The explanation on those interrelations is that the high complexity of Industry 4.0 key technologies influences the lack of skilled employees since a skilled workforce is needed to master technological complexity. In addition, high technological complexity can drive changes in working conditions and routines, a fact undesirable for some employees. The need to be comfortable with high complexity requires a robust implementation team and intensive training of the workers. The social barrier B21 (Loss of many jobs) influences the economic barrier B12 (High investment/cost).

6. Conclusion

The advent of Industry 4.0 concepts brings several benefits for those who will embrace it. Regardless of their size, many firms strive to adopt the core technologies of Industry 4.0 and to reap their benefits. Despite the opportunities evident in Industry 4.0, industries do face several challenges in its implementation. Hence, to assist the companies to motivate and promote the effective implementation of Industry 4.0, this study proposes a research framework with two research phases. In the first phase, the readiness of the case industry towards the transformation and implementation of Industry 4.0 were assessed. In the second phase of research, the barriers exist within the case industry in the implementation of Industry 4.0 were identified and analyzed. Both the phases are processed in the same Danish case context with the combined assistance of literature review and experts' opinion. Phase I used only interviews to identify the readiness of the firm, and Phase II used both interviews and the MCDM tool, DEMATEL, to analyze the response data. Phase I results have been indicated that the case industry is not a beginner regarding Industry 4.0 since it has completed several steps towards embracing digitization by having the highest average score in the "Business Models & Products" category. That means that they have accomplished a high grade of horizontal integration and mass-customization according to individual customer's product requirements. This reveals the case industry is roughly halfway towards achieving Industry 4.0 (referred to in this study as Industry 3.5). Further, the next phase II sought to address the barriers that are the main cause of being positioned at Industry 3.5 level. Clearly revealed is that "Leadership" (**B1**) emerged as the greatest influencer of all. This is logical since leadership is the factor which decides the policy of a firm towards Industry 4.0 implementation or not.

This study helps industrial managers to understand their priorities on the implementation of Industry 4.0. In addition, with the understanding on the readiness level, the managers can also eliminate the barriers that hinder the firm's transformation towards better readiness for Industry 4.0 implementation. However, this study clearly highlights leadership as the key for achieving industry 4.0, and it urges industrial managers to employ institutional policies with the support of the stakeholders to implement Industry 4.0 effectively.

While this study provides some serious contributions from academic and practitioner perspectives, it is not free from certain limitations. Only one case industry has been considered as evidence from a whole Danish or a general industrial context in this study. Whereas it does serve admirably as a pilot study, a practitioner level implementation may need more validated models of study. Hence, this study can be extended with statistical approaches as a consortium to improve the reliability of the obtained results. Additionally, future research could define more precisely the barriers of Industry 4.0 non-implementation and identify additional barriers suggested by business experts. Future research can proceed with larger samples to deal with barriers, and a promising future endeavor could be the detection or invention of respective practices to tackle embedded barriers effectively and to more quickly advance the implementation of Industry 4.0 standards and practices. In terms of methodological aspects the future research can address the uncertainties involved in data collection could be represented in a fuzzy (Xu et al., 2023; Zarbakhshnia et al., 2023) or grey (Govindan et al., 2021; Govindan, 2023) approach.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data is included in the paper

Appendix

The basic steps of DEMATEL are presented below (Kannan et al., 2022; Govindan, 2022):

STEP 1: Direct-relationship (Average) matrix

The respondents need to evaluate the pairwise comparison of the factors by estimating the influence of one factor to another. The score could vary from 0 to 4 as follows:

0 = no influence.
1 = low influence.
2 = medium influence.
3 = high influence.
4 = very high influence.

The score is notated as x_{ij} meaning the influence the factor i exerts to the factor j. For each respondents, an nXn matrix is constructed as $x^k = [x_{ij}^k]$, where n is the number of the factors and × the number of respondents. After collecting the direct-relation from all the experts, we build the direct-relation (average) matrix by using the averages of the scores from all the experts. The direct-relation matrix is based on Eq. (1):

$$A = [aij] = 1/H\sum_{k=1}^{H} xkij \tag{1}$$

STEP 2: Normalization – Normalized direct-relation matrix "S"

In the second step, the initial direct-relation matrix is normalized through Eqs. (2) & (3):

$$S = m \times A, \tag{2}$$

Where

$$m = \min\left[\frac{1}{maxi\sum_{j=1}^{n} aij}, \frac{1}{\max j\sum_{j=1}^{n} aij}\right], i,j \in \{1,2,\ldots,n\} \tag{3}$$

Every value of the matrix D should be between 0 and 1.

STEP 3: Calculation of total relation matrix "M"

The total relation matrix "M" is computed with the assistance of Eq. (4):

$$M = S(I-S)^{-1} \tag{4}$$

STEP 4: Calculation of sum of rows and columns of Matrix M.

The sum for every row will be calculated through equation below:

$$r_i = \left[\sum_{j=1}^{n} aij\right]_{nX1} \tag{5}$$

It expresses the sum of direct and indirect effect a factor i exerts to the other factors.

The sum for every column will be calculated by the equation below:

$$S_i = \left[\sum_{j=1}^{n} aij\right]_{1Xn} \tag{6}$$

It expresses the sum of direct and indirect effect a factor j receives from the other factors. When the i = j, then the total of $r_i + s_i$ represents the sum of influences given and received by factor i and also shows the degree of importance of the factor i in the entire system. On the other hand, the difference $r_i - s_i$ represents the net influence the factor i contributes to the system. If that difference is positive then factor i is a net cause, if it's negative then it's an effect (Kaushik & Somvir, 2015).

STEP 5: Calculation of threshold value (θ).

The goal is to eliminate some minor effect elements in matrix M. The computation returns the mean of the value of the elements in matrix M. The equation is illustrated below:

$$m = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}[aij]}{N} \tag{7}$$

N is the total number of elements in the matrix "M".

We also need the standard deviation. The threshold value (θ) is computed if we add the mean with the standard deviation.

STEP 6: Creating the impact-relation map.

In the last step, the impact-relation map is created by depicting the dataset containing the values of $((r_i + s_i),(r_i - s_i))$.

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