# Proposal of Industry 4.0 Maturity Model in the Energy Sector

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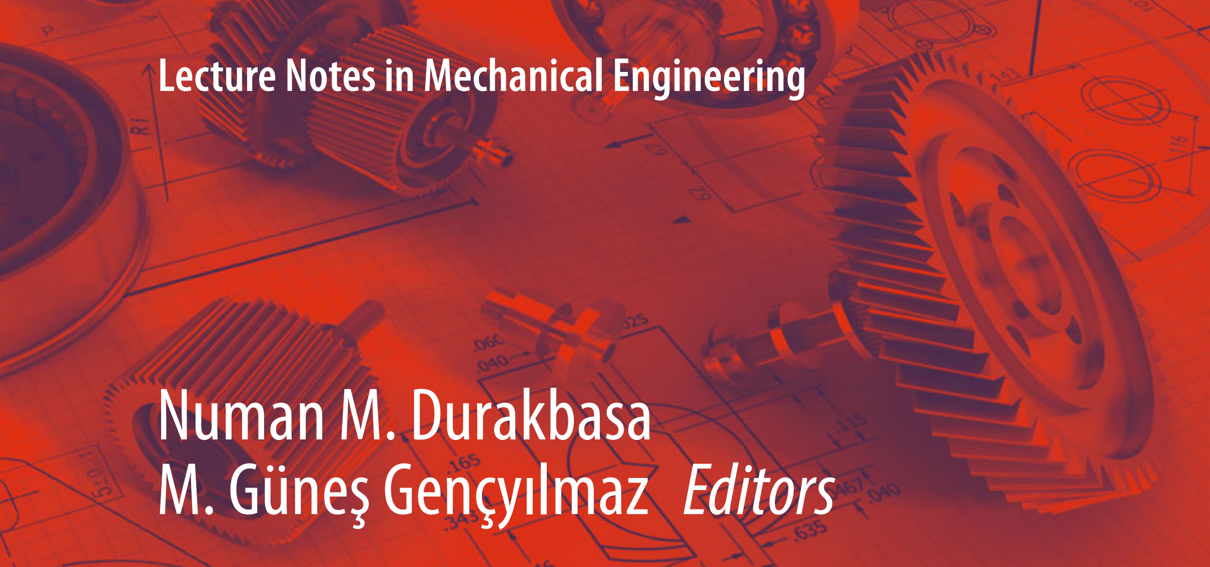
**3 authors**, including:

Emine Elif Nebati

Zehra Binnur Avunduk
Istanbul University-Cerrahpaşa



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Numan M. Durakbasa
M. Güneş Gençyılmaz *Editors*

# Industrial Engineering in the Industry 4.0 Era

Selected Papers from ISPR2023, October 5–7, 2023, Antalya

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# Industrial Engineering in the Industry 4.0 Era

## Selected Papers from ISPR2023, October 5–7, 2023, Antalya

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*Editors*
Numan M. Durakbasa
Institute of Production Engineering
and Photonic Technologies
TU Wien
Vienna, Austria

M. Güneş Gençyılmaz
Society for Production Research
Istanbul, Türkiye

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# Foreword

Dear Colleagues and Friends,

It is a great pleasure to welcome you to the "**International Symposium for Production Research - ISPR 2023**," Antalya/Turkey, from October 5 to 7, 2023, with the overall theme of "**Industrial Engineering in the Industry 4.0 Era"**. As in all previous years, we continue to cherish and benefit from our successful collaboration with Society for Production Research, Istanbul, Turkey, in the organization of this event.

The purpose of the symposium is to bring together researchers, scientists, and leading world experts at universities, companies, institutions, communities, associations, and societies in the domain of interest from around the world to share ideas, experiences, research, results, and vision on production and operations management and technology. This organization shall also provide a forum for experts and professionals to discuss the challenges, opportunities, and advanced innovation of the theme of this year's symposium.

We hope that this year's gathering in hybrid form will provide an opportunity to exchange ideas and discuss issues in person and virtually with the participants and speakers.

We wish you all a productive symposium.

October 2023 Kurt Matyas

# Preface

This book consists of the selected papers presented at the 23th International Symposium for Production Research (ISPR2023) held from October 5 to 7, 2023, in hybrid form, face-to-face and virtual with the participants and speakers who came to Antalya, Türkiye, on the first day, and virtually in the presentation sessions on the subsequent days. This technical infrastructure of this virtual symposium was provided by the vice-rectorate for Digitalization and Infrastructure of TU Wien, and we are very grateful to Univ. Prof. Dipl. -Ing. Dr.techn. Dr.h.c.mult. Josef Eberhardsteiner, for his kind consideration and support.

This symposium was organized by Society for Production Research, İstanbul, Türkiye, and TU Wien, Austria, for the sixth year in a row.

The generic theme of "Industry 4.0" was first adopted in the symposium held in 2016 and maintained in the following six symposiums in 2017, 2018, 2019, 2020, 2021, and 2022 but each time with an updated emphasis on the relevant developments and progress on the various aspects of this theme.

Applications and developments in Industry 4.0 in recent years have revealed the fact that the human element is somehow to be involved in Industry 4.0 applications. It is now widely considered that Industry 5.0 complements the existing Industry 4.0 paradigm by having research and innovation provide the transition to a sustainable, human-centric, and resilient industry. Due to this fact, the generic theme "Toward Industry 5.0" was adopted in last year's symposium. The document titled "Industry 5.0" released by the European Commission in 2021 sped up the applications in industry and research works of academia. It was inevitable that these developments in industry would have an impact on education, especially on higher education. As a matter of fact, it was observed that the curricula of some engineering fields were changed shortly after the implementation of Industry 4.0 in industry, and the some courses were added to the curricula in a way to include the fundamentals of Industry 4.0 and 5.0. In recent years, it has been observed that some research papers on the necessity of including Industry 4.0 and 5.0 topics into the curricula of industrial engineering education have started to be published. Topics such as which new courses should be added, which courses should be removed, which programming language/s should be taught, and which software programs required for Industry 4.0 should be used in the courses leading to a new education system for industrial engineering have started to be discussed. In light of these developments, the motto of ISPR2023 has been chosen as "Industrial Engineering in Industry 4.0 Era."

Given the importance of this theme, ISPR2023 hosted numerous distinguished speakers from both the academia and the industry to hear their views on the applications of the Industry 4.0 and 5.0 on the various components of production systems and the influence of Industry 4.0 and 5.0 on industrial engineering education.

A total of over **182** participants attended this year's symposium—academics, practitioners, and scientists from **15** countries, who contributed **15** invited talks and **62** papers on the plenary, special, workshop, and ordinary sessions. The symposium program included keynote addresses (opening/closing session), breakout sessions, and workshop discussions.

This book contains **62** refereed selected papers in **18** categories shown in the contents of the book.

We would like to express our gratitude to Prof. Kurt Matyas, Honorary Chairman of the Scientific Committee of this symposium, for his leadership and generous support. Our thanks also go to Prof. Friedrich Bleicher, Head of the Institute for Production Engineering and Photonic Technologies for his interest and support for this symposium.

We would like to thank all the keynote and invited speakers whose contributions enhanced the success of the symposium. In organizing this event, our colleagues in Vienna and Istanbul contributed endless hours of hard work, energy, and wisdom to make this event a success. On the Vienna side, our sincere thanks goes to the staff of the Research Group Production Metrology and Adaptronic Systems of the Institute for Production Engineering and Photonic Technologies, in particular, Dipl. Ing. Erol Güçlü for his invaluable leadership. On the İstanbul side, we are grateful to Prof. Dr. Hatice Camgöz Akdağ from Istanbul Technical University and Asst. Prof. Dr. Zeynep Gergin from Istanbul Kultur University, for their invaluable efforts in presenting the keynote speakers and managing the first-day activities with great competence. Our special thanks goes to our research assistants, Ind. Eng. (MS) Tuğçe Apaydın and Mathematics Eng.-Ind. Eng. (MS) Aziz Kemal Konyalıoğlu at Istanbul Technical University and University of Strathclyde, Glasgow, who prepared this book with great care and Comp. Eng. Tufan Tunçbilek, Amazon Company Canada who managed the virtual sessions and, Biset Toprak, Mehmet Güdelek from Istanbul Sabahattin Zaim University, Paşa Çiçeklidağ, University of Western Australia and Muhammed Ali Erdem who spent great efforts in managing virtual rooms under the guiding of Mr. Tunçbilek. We also thank to research assistants at TU Wien, Dr. Günther Poszvek, Dr. Osman Bodur, and Dipl. Ing. Eva Walcher for their hard and dedicated works and finally to Prof. Dr. Gül E. Kremer Dean of Engineering Faculty, University of Dayton USA, Prof. Dr. Berna Dengiz, Dean of Engineering Faculty Başkent University Türkiye, Prof. Dr. Bahadır Tunaboylu, Faculty of Engineering Marmara University, Prof. Dr. Hatice Camgöz Akdağ, Faculty of Management Istanbul Technical University Türkiye, and Dr. Ömer Şahin Ganiyusufoğlu, QIAP China, for their valuable role and efforts in the organizing committee.

We would like to express our gratitude to the board members of the Society for Production Research in Istanbul, Türkiye, and in other countries for their strong support and involvement in the successful organization of the symposium, Prof. Serpil Erol, Prof. Dr. Semra Birgün, Prof. Dr. Selim Zaim, Prof. Dr. Kemal Güven Gülen, Prof. Dr. Alptekin Erkollar (Austria), Prof. Dr. Dursun Delen (USA), and Assis. Prof. Dr. Nükhet Tunçbilek (Canada).

Our very special thanks goes to our colleagues and the participants of this symposium. Undoubtedly, they were the core component of this organization.

We would like to recognize and thank our dear colleagues who graciously accepted to join the honorary and scientific committees or who served as peers in this event.

Finally, no such event is possible without the generous support of patrons and sponsors. In this regard, we would like to thank Dr. Michael Ludwig, the Mayor of Vienna, for his continued generous support of this symposium series and to all the corporations and individuals who provided invaluable financial and intellectual contributions.

M. Güneş Gençyılmaz
Numan M. Durakbasa

# Industrial Engineering in the Industry 4.0 Era

In the era of Industry 4.0, industrial engineering assumes a pivotal role as an essential discipline with a comprehensive impact. It harnesses the power of advanced technologies, data analytics, and automation to orchestrate a symphony of operational excellence. Predictive maintenance systems are meticulously constructed to minimize downtime, supply chains are optimized through data-driven insights, and product quality is elevated through automated quality control processes. Smart factory layouts and efficient workforce management strategies are integral components, ensuring the continuous flow of information. Furthermore, there is a heightened focus on energy efficiency and cyber-security, protecting both the environment and data. Industrial engineering promotes human-machine collaboration, creating work environments where automation and human expertise harmonize effectively. Cost optimization, regulatory compliance, and the capacity for mass customization all fall within its purview. Additionally, the evaluation of the environmental impact of processes leads industries toward sustainability.

The advent of Industry 4.0 signifies a seismic change in the domain of industrial engineering. Industrial systems that promise to be more efficient, agile, and intelligent are on the horizon. In the field of industrial engineering within the context of Industry 4.0, we observe a profound shift characterized by intelligent automation driven by decentralized control mechanisms and smart connectivity solutions. This transformative era brings about a landscape marked by high-value products and services, with elevated standards of flexibility, quality, and efficiency across manufacturing, logistics, and production systems. In response to this wave of change, businesses are diligently embracing digitalization strategies, harnessing the power of extensive machine-to-machine communication (M2M), and Internet of things (IoT) implementations. Automation, communication, and self-monitoring within industrial processes are intended to be reinforced, signifying a critical juncture in the global industrial landscape. This profound modification, especially within manufacturing, is believed to have the potential to redefine the very structure and dynamics of industrial systems, guiding an era defined by unified technological integration and heightened operational efficiency.

Adapting to these industrial advancements necessitates a thorough approach, encompassing not only the technical aspects but also elements such as organizational behaviors and culture. Collaborative efforts from organizations, government bodies, and academic institutions are vital to foster the competencies required to navigate the sociotechnical changes introduced by Industry 4.0. Higher education institutions find themselves at the center of this transformation, requiring a realignment of their curricula with the vision of Industry 4.0. Giving priority to the integration of Industry 4.0 concepts into engineering education, this compels undergraduate students to acquire a fresh set of skills and competencies. These include adaptability, effective communication, advanced analytics, and proficiency in digital security. This shift in education is essential to prepare the next generation of engineers for the challenges and opportunities presented by the

Industry 4.0 era, ensuring they are well-equipped to drive innovation and excellence in the ever-evolving field of industrial engineering.

In the context of Industry 4.0, it is worth noting the growing direction toward Industry 5.0. This next stage of industrial evolution is expected to further blur the lines between technology and human-centric operations. Industry 5.0 emphasizes the symbiotic relationship between humans and machines, focusing on collaborative decision-making. Preparing for Industry 5.0 will require a continued commitment to enhancing both technical competencies and the adaptability of individuals and organizations to fully embrace this new wave of innovation in the field of industrial engineering.

M. Güneş Gençyılmaz
Numan M. Durakbasa

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ISPR2023 was organized by TU Wien, Austria, and the Society for Production Research, Türkiye. The symposium took place in Antalya, Türkiye.

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# Proposal of Industry 4.0 Maturity Model in the Energy Sector

Emine Elif Nebati[1](✉), Zehra Binnur Avunduk[2], and Abdullah Fatih Akcan[3]

[1] Department of Industrial Engineering, İstanbul Sabahattin Zaim University, 34303 İstanbul, Turkey
emine.nebati@izu.edu.tr

[2] Vocational School of Social Sciences, İstanbul University-Cerrahpaşa, 34303 İstanbul, Turkey
zehrabinnur.avunduk@iuc.edu.tr

[3] School of Applied Sciences, Nişantaşı University, 34398 İstanbul, Turkey
fatih.akcan@nisantasi.edu.tr

**Abstract.** With the widespread use of the Internet, traditional methods that have been going on for a long time have begun to change. A new transformation has been entered with digital technologies. This transformation has brought about changes and developments in various sectors. The Industry 4.0 revolution has also provided the opportunity for significant transformations in the energy sector. In this study, research has been conducted on the changes digital transformation has created in the energy sector, how it affects the industry, and how it contributes. Within the scope of this research, a digital roadmap was created for a leading company in Türkiye's energy sector, which tends to digitalize and focuses on development and innovation. Thus, a tool will be designed for the self-evaluation of institutions in the energy sector. In the model proposed within the scope of the study, a total of 25 criteria, including five main and twenty sub-criteria, were determined. It is aimed to measure the level of digital maturity for a company selected as an alternative with the determined criteria. In the study, the DEMATEL method was preferred in determining the criteria priorities in the first step of the application. The company's digital maturity score was calculated in the second step and the results were shared. It is anticipated that the study will contribute to both the literature and the energy sector since the subject of digital transformation has been attracting attention and demand recently, and the methodology applied in this area is limited.

**Keywords:** Digital Maturity Model · Industry 4.0 · Technology · DEMATEL · Energy Industry

## 1 Introduction

With the widespread use of the Internet, traditional methods have begun to change, and a new transformation has been entered into by leaving the place of conventional methods in the digital environment. Digitization presents any information in a form not tied to a physical location. In addition, the transfer of digital technologies to daily life is called digitalization.Ensuring that companies' activities are sustainable in electronic environments


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such as computers and mobile phones; Digital transformation, which increases employees' productivity and the sophistication of work, is now indispensable for companies. For organizations, digitalization is a new and mature concept. Therefore, it introduced the "digital maturity" concept to improve measurement and compare it with competitors. The digital maturity model is a guide used to describe and measure the current state of an organization and compare it with the desired maturity level. It helps organizations decide when and how to act during their transition to digital transformation [1]. Organizations implementing this approach rapidly increase their production capacity and improve their ability to produce added value [2].

Digital transformation can be applied in various sectors, and the energy sector is one of these areas. In today's global market, where competition and uncertainty are high, it is inevitable for companies that want to maintain their existence in the long term with sufficient performance to adapt to the fourth phase of industrialization to remain competitive [3]. In this context, businesses need to decide on the future action plan for the adaptation process to Industry 4.0 and evaluate their current situation along with their own goals [4]. The main purpose of this study is to measure and prioritize digital transformation components in the intelligent age. The evaluation presents a roadmap that can be used in digital transformation for a business operating in the energy sector.

In the study, digital maturity model criteria were determined in the first step of the application. In the proposed model, five main criteria and 20 sub-criteria as strategy, management and organization, technology, operation, people, and R&D culture, were determined, and criterion importance weights were obtained for an institution operating in the energy sector in Istanbul. DEMATEL method was preferred in determining the importance of weights. In the second step, the digital maturity score of the company was calculated and the results were shared. The study continues as follows, the second part includes the literature review, the third part deals with the digital maturity model proposed for the energy sector, and the conclusions and recommendations are presented in the last part.

## 2 Literature Review

There are various studies on digital transformation in the literature. [5] developed a maturity model to evaluate the Industry 4.0 maturity of manufacturing enterprises. [6] conducted a study to guide manufacturing companies towards digitalization. [7] deals with the prioritization of industry 4.0 maturity parameters in the defence industry with the hesitant fuzzy AHP method. [8] examined the Industry 4.0 maturity levels of enterprises in the logistics sector. [9] developed a more differentiated classification scheme to assess a firm's digital maturity. [10] compared the Industry 4.0 maturity of a company in the defence sector with 12 organizations in its supply network. [11] studied the digital maturity model in the production sector in 2018. [12] prioritized digital transformation components, and a maturity measurement model was proposed to contribute to industries, especially IT and production. [13] the most important criteria for the digital maturity model of companies were determined. [14] developed a model that production enterprises can use when determining their digital maturity level. [15] aimed to create an industry 4.0 maturity model for supply chain management. [16] A literature review was conducted on the systematic model dimensions of Industry 4.0 preparation models. [17] proposed a digital transformation capability maturity model, which enables the evaluation of industrial manufacturers. [18] aimed to examine the adaptation level of a large-scale auto parts manufacturing enterprise to Industry 4.0. [19] aimed to evaluate the digital maturity levels of all enterprises and manufacturing enterprises in central and eastern European countries. [20] proposed a model to evaluate the digital maturity of small and medium-sized enterprises. [21] aimed to assess the industry 4.0 maturity levels of companies in the manufacturing sector.

The importance of the concept of digital transformation has been increasing in recent years. In this process, it is inevitable that the studies in the field will spread to all sectors. As a result of the research, as far as we know, no study has been found in the energy sector. In this context, it is hoped that this study will make a great contribution to the literature and the industry in digital transformation research in the energy sector.

## 3 Digital Maturity Model in Energy Sector

In this section of the study, a new model proposal has been presented in order to determine the digital maturity levels of a firm in the energy sector in the adaptation stages to Industry 4.0. The created model aims to measure the digital maturity levels of enterprises operating in the energy sector in the transition to Industry 4.0. Based on results, 5 main criteria and 20 sub-criteria were determined as strategy, management-organization, technology, operations, employee and R&D culture. After determining the order of importance of the criteria determined with DEMATEL method, the company's digital maturity score was calculated.

### 3.1 Suggested Criteria for the Digital Maturity Model

In Fig. 1, the proposed model is given.

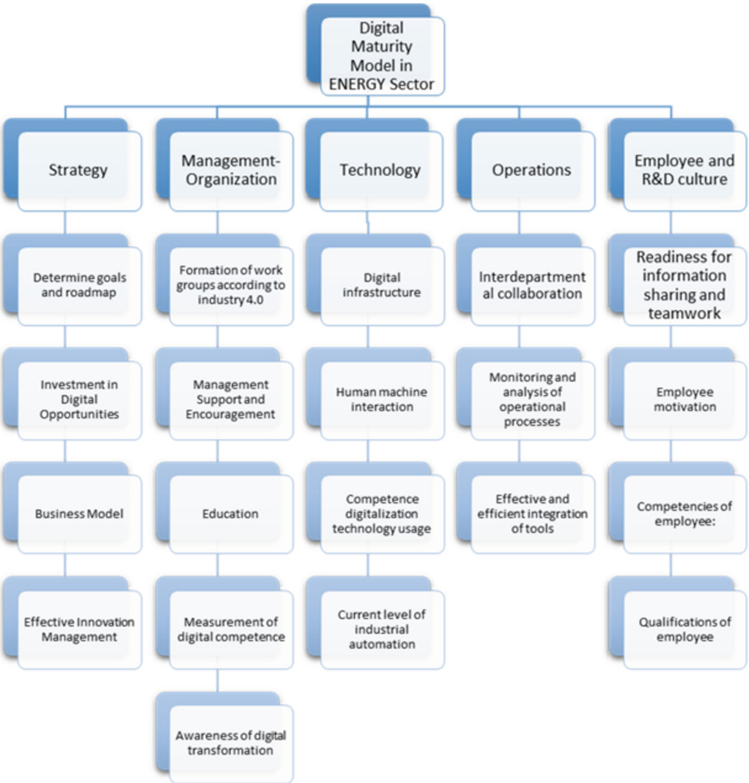


**Fig. 1.** Recommended model diagram

## 3.2 DEMATEL Method Application

The DEMATEL method was first employed in a study conducted at The Battelle Memorial Institute between 1972 and 1976. DEMATEL is a technique that assists in analyzing cause-and-effect relationships among factors in complex problems [22] DEMATEL is a graph-based method [23]. It enables a better understanding of causal relationships and the determination of criteria weights [24]. In determining the importance weights of the criteria, the following DEMATEL method steps were applied [24]. Firstly, the steps were applied for main criteria (Table 1). Then the same steps were applied in the sub-criteria.

**Table 1.** Main Criteria

| S | Strategy |
|---|---|
| M | Management-Organization |
| T | Technology |
| O | Operations |
| E-R&D | Employee and R&D culture |

**Step 1:** Create the direct relationship matrix The direct relationship matrix for determining the digital maturity level is given in Table 2.

**Table 2.** The direct relationship matrix of the main factors.

| | S | M | T | O | E-R&D | Sum |
|---|---|---|---|---|---|---|
| S | 0.000 | 2.600 | 2.800 | 2.400 | 2.400 | 10.200 |
| M | 2.600 | 0.000 | 2.000 | 3.000 | 2.800 | 10.400 |
| T | 2.400 | 1.600 | 0.000 | 2.200 | 2.600 | 8.800 |
| O | 1.600 | 1.900 | 1.300 | 0.000 | 1.900 | 6.700 |
| E-R&D | 1.600 | 1.700 | 1.800 | 1.600 | 0.000 | 6.700 |
| Sum | 8.200 | 7.800 | 7.900 | 9.200 | 9.700 | |

**Step 2:** Determine of the normalized direct-relation matrix. The normalized direct relationship matrix for the main criteria affecting digital maturity level is given in Table 3.

**Table 3.** Normalized Direct Relationship Matrix of Main Criteria

| | S | Y | T | O | I |
|---|---|---|---|---|---|
| S | 0.000 | 0.250 | 0.269 | 0.231 | 0.231 |
| Y | 0.250 | 0.000 | 0.192 | 0.288 | 0.269 |
| T | 0.231 | 0.154 | 0.000 | 0.212 | 0.250 |
| O | 0.154 | 0.183 | 0.125 | 0.000 | 0.183 |
| I | 0.154 | 0.163 | 0.173 | 0.154 | 0.000 |

**Step 3:** Obtain the total relationship matrix T. The unit matrix related to the main criteria is given in Table 4.

**Table 4.** Unit Matrix of Main Criteria

| | S | Y | T | O | E-R&D |
|---|---|---|---|---|---|
| S | 0.840 | 1.010 | 1.028 | 1.112 | 1.157 |
| M | 1.038 | 0.813 | 0.976 | 1.151 | 1.182 |
| T | 0.918 | 0.843 | 0.712 | 0.979 | 1.046 |
| O | 0.720 | 0.722 | 0.682 | 0.647 | 0.833 |
| E-R&D | 0.722 | 0.708 | 0.719 | 0.782 | 0.680 |

**Step 4:** Identify influencing and affected criteria groups. The row and column totals of the total relationship matrix of main factors are provided in Table 5.
**Step 5:** Determine the threshold value and create the effect-oriented graph diagram. The threshold value for operational criteria is calculated as 0. 881.Values above the

**Table 5.** The row and column sums of the total relationship matrix for main factors

| | Di | Ri | Di + Ri | Di-Ri | |
|---|---|---|---|---|---|
| S | 5.147 | 4.238 | 9.385 | 0.909 | Influencing |
| M | 5.160 | 4.096 | 9.256 | 1.064 | Influencing |
| T | 4.498 | 4.117 | 8.615 | 0.381 | Influencing |
| O | 3.604 | 4.671 | 8.275 | −1.067 | Affected |
| E-R&D | 3.611 | 4.898 | 8.509 | −1.287 | Affected |

threshold are referred to as influencing, while values below are referred to as affected. The direction of impact is from influencer to the affected. The graph shows in Fig. 2. It has been observed that strategy influences management-organization and technology. Management and organization influence strategy. Technology influences strategy and management-organization. Operations influence strategy, management-organization, and technology. People and R&D Culture impact strategy, management-organization, and technology.

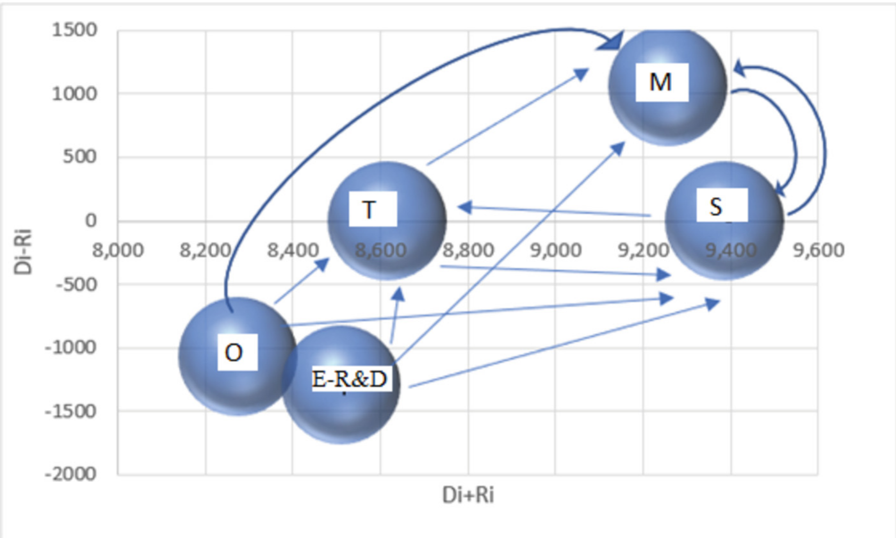


**Fig. 2.** Directional Impact Graph Diagram of Main Criteria

**Step 6:** Determine criteria weights and priorities in Tables 6 and 7.

**Table 6.** Weights of criteria

| Main Criteria | Strategy | Management, Organızatıon | Technology | Operation | Employee and R&D Culture |
|---|---|---|---|---|---|
| | 0,213 | 0,210 | 0,195 | 0,188 | 0,194 |

**Table 7.** Local and global weights of criteria

| Main Criteria | Sub-Criteria | Local Weights | Global Weights |
|---|---|---|---|
| Strategy | Determine goals and roadmap | 0,267 | 0,056871 |
| | Investment in Digital Opportunities | 0,257 | 0,054741 |
| | Business Model | 0,216 | 0,046008 |
| | Effective Innovation Management | 0,259 | 0,055167 |
| Management, Organızatıon | Formation of work groups according to industry 4.0 | 0,355 | 0,07455 |
| | Management Support and Encouragement | 0,094 | 0,01974 |
| | Education | 0,098 | 0,02058 |
| | Measurement of digital competence | 0,091 | 0,01911 |
| | Awareness of digital transformation | 0,362 | 0,07602 |
| Technology | Digital infrastructure | 0,362 | 0,07059 |
| | Human machine interaction | 0,129 | 0,025155 |
| | Competence digitalization technology usage | 0,125 | 0,024375 |
| | Current level of industrial automation | 0,385 | 0,075075 |
| Operation | Interdepartmental collaboration | 0,333 | 0,062604 |
| | Monitoring and analysis of operational processes | 0,333 | 0,062604 |
| | Effective and efficient integration of tools | 0,333 | 0,062604 |
| Employee and R&D Culture | Readiness for information sharing and teamwork | 0,312 | 0,060528 |
| | Employee motivation | 0,209 | 0,040546 |
| | Competencies of employee | 0,257 | 0,049858 |
| | Qualifications of employee | 0,222 | 0,043068 |

### 3.3 Measurıng of Digital Maturity Level

In this section, digital maturity performance score is calculated. The company aiming to achieve Industry 4.0 adaptation has evaluated its own situations for each criterion by scoring on a 1–5 Likert scale. After scoring, the average of scores obtained from experts is calculated for each criterion, and then multiplied by the respective criterion's global weight. The sum of the obtained values indicates the maturity level of the company's Industry 4.0 adaptation. The company's score has been calculated as 3.9. The company's status for main and sub-criteria is illustrated in radar analyses in Fig. 3 and Fig. 4.


**Fig. 3.** Radar Analysis of Main Criteria

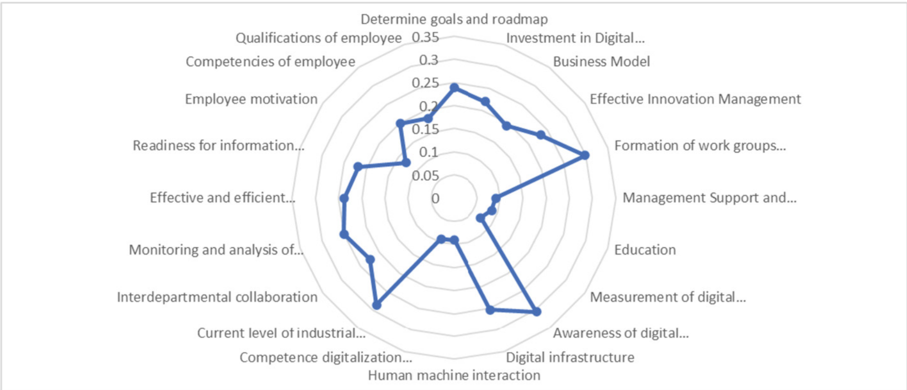


**Fig. 4.** Radar Analysis of Sub-Criteria

## 4 Conclusions

With the development of technology day by day, the concept of Industry 4.0 has emerged. Industry 4.0 is the creation of smart systems by integrating technology into sectors and life. Industry 4.0, which aims at digitalization in almost all areas, including production, consists of big data and data analytics that help in the decision-making phase, the Internet of Things that facilitate communication and tracking by combining products with the Internet, and cloud computing that facilitates the storage and access of data. In addition, cyber security, which protects companies from attacks on network systems, consists of components such as augmented reality and virtual reality used to create virtual environments. Existing and emerging technologies enable companies to use new methods and therefore stand out in their sectors by offering different products and services. It is inevitable for businesses that aim to stay in the industry and be successful, to enter digital transformation.

According to the findings, the most important criterion is strategy, while the least important criterion seems to be operation. In the sub-criteria, digital transformation awareness was the most important criterion, while target and roadmap determination, current industrial automation level, knowledge sharing, and teamwork predisposition came to the fore. According to the results obtained, it is seen that this company, which is determined to be at the experienced level, has made serious progress in digital transformation, but still, some of the criteria are at a very low level compared to the general.

As a result of the company evaluation, some of the lowest ranking criteria are continuous measurement of digital competence, training, and digitalization technologies usage competence. Therefore, the quality and number of in-house training should be increased. Thus, it will be possible for personnel to use digitalization technologies more competently. For future studies, the reliability of the study can be increased by performing sensitivity analyses with different multi-criteria decision-making methods at the stage of determining the weights of the criteria. It is recommended to expand the scope of research with different company opinions in various sectors.

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