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The MCDM-based Assessment of Solutions for Transition to Sustainable Industry 4.0: The Case of Serbia

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ABSTRACT

Industry 4.0 implies the transformation of organizations into digital entities. It represents a new level of industrial development that has changed demands, competition, industry structure, and sustainability awareness. The primary objective of this paper is to use Multiple-Criteria Decision Making (MCDM) to identify the principal obstacles and solutions for successfully adopting the technologies that will facilitate a transition of the Serbian industry to sustainable Industry 4.0. The barriers' significance was defined using the Preference Selection Index – PSI. The assessment of the solutions was performed by three decision-makers using the following MCDM methods: PSI, Compromise Ranking of Alternatives from Distance to Ideal Solution – CRADIS, and Integrated Simple Weighted Sum-Product Method—WISP. The results revealed that logistics, reverse logistics management, and technology integration are the most significant barriers. The significance of logistics and warehousing management lies in their role as crucial facilitators for the sustainable development of industries, ensuring efficient and responsible movement, storage, and distribution of goods. Also, the application and development of new technologies can improve efficiency and reduce the environmental impact of the Serbian industry. Based on the MCDM methods, the framework enabled the assessment of the barriers and solutions for technology adoption in light of the current business conditions in the Republic of Serbia. Managers and policymakers can easily perceive the main obstacles and optimal actions needed to fulfill the requirements of Industry 4.0 and promote sustainable operations.

Keywords: *Sustainable Industry 4.0, PSI, WISP, CRADIS, technologies*

JEL Classification: O330, D810

INTRODUCTION

The business world has changed due to the influence of digital transformation that has caused the fourth industry revolution, Industry 4.0. The world faces the challenge of growing production and consumption while natural resources become exhausted and endangered by industrial activity. Industry 4.0 positively impacts the economy, environment, and society, enabling sustainable development and occupying the attention of governments, economists, and scientists (Ghobakhloo, 2020).

Sustainability is a broad concept that involves preserving the environment, economic and social resources (Ford and Despeisse, 2016). The essence of sustainability lies in the imperative for

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present generations to meet their needs while ensuring that future generations can meet theirs. The strong point of Industry 4.0 is the application of modern information technologies, but its impact on sustainability may need to be revised. While the application of modern technologies contributes to increased productivity and pollution reduction, it also places greater pressure on natural and energy resources. The influence of Industry 4.0 on achieving sustainability has yet to be discovered, but its benefits cannot be denied.

Artificial intelligence, big data and analytics, blockchain, cloud, industrial internet of things, simulation, and additive production belong to the technology of Industry 4.0 (Bai et al., 2020; Ibarra et al., 2018). Their application could contribute to the growth of the industry competitiveness and the sustainability of the existing industrial system (Bai et al., 2020; Müller et al., 2018). Adopting proper Industry 4.0 technologies in companies is necessary and deserves attention and evaluation because it has far-reaching consequences (Bai & Sarkis, 2020). Modern technology adoption in a developing country, such as Serbia, suffers from various problems, ranging from operational to strategic level (Javaid et al., 2022). The existing issues should be resolved by applying adequate solutions.

This paper examines the possibility of applying the Multiple-Criteria Decision-Making Approach (MCDM) to define essential obstacles and solutions for transforming the Serbian industry to Industry 4.0. The Preference Selection Index – PSI method (Maniya and Bhatt, 2010) was used to define the barrier importance. The PSI, Compromise Ranking of Alternatives from Distance to Ideal Solution – CRADIS (Puška et al., 2022a), and Integrated Simple Weighted Sum-Product Method – WISP (Stanujkic et al., 2021) were used to prioritize the considered solutions pointed to reducing the identified barriers. The research question that occupied the authors' attention was twofold:

- What are the essential obstacles to introducing Industry 4.0 into the Serbian economy and how to overcome them?
- How can MCDM techniques enhance and facilitate the assessment of obstacles and solutions?

The list of the barriers and solutions is borrowed from the paper of Javaid et al. (2022). Although many authors have observed the obstacles and opportunities for introducing Industry 4.0 (for example, Nimawat & Das Gidwani, 2022; Rikalovic et al., 2021; Bajic et al., 2020), Javad et al. (2022) systematized the barriers and solutions in a comprehensive manner suitable for applying the MCDM analysis procedure and applicable to Serbian economy conditions. Three experts (in the fields of industrial management, digital transformation and sustainable development) performed the initial estimation considering the current state in Serbia. The main goal is to underscore five imperative barriers and three key solutions that would address the recognized issues and bring the Serbian industry closer to Industry 4.0. The remainder of the paper is organized as follows: Section 2 gives the theoretical background; Section 3 presents the proposed methodology; Section 4 provides the results; the conclusion contains the main findings, implications, limitations, and prepositions for future research.

THEORETICAL BACKGROUND

Until now, the authors have used the MCDM approach to analyze different issues regarding Industry 4.0. The topics that gained the researcher's attention are as follows: comparing the Industry 4.0 maturity models (Elibal and Özceylan, 2022), supply chain improvement (Hsu et al., 2022), strategy prioritization (Kumar et al., 2021a; Erdogan et al., 2018), technology assessment (Javaid et al., 2022; Chang et al., 2021), cybersecurity evaluation (Torbacki, 2021), and sustainability (Eldrandaly et al., 2022).

Addressing the challenges of implementing Industry 4.0 technologies and employing MCDM techniques to facilitate informed decision-making held a significant position in previous research studies. For example, Kumar et al. (2023) applied an MCDM framework based on the Neutrosophic

Analytical Hierarchy Process (N-AHP) and the Neutrosophic Combined Compromise Solution (N-CoCoSo) to rank the performance outcomes gained by adopting Industry 4.0 enablers. The authors observed the obstacles to introducing lean-green and Industry 4.0 using Principal Component Analysis-Interpretive Structural Modeling (PCA-ISM) and Fuzzy Matriced' Impacts Croise's Multiplication Applique'e a' un Classement (MICMAC) (Gadekar et al., 2023). To identify the main barriers to adopting modern technologies, Kumar et al. (2021b) proposed the application of PCA, fuzzy AHP, and K-means clustering. Raj et al. (2020) investigated the barriers to adopting Industry 4.0 technologies in developed and developing countries using an approach based on the Grey Decision-Making Trial and Evaluation Laboratory (DEMATEL).

As mentioned earlier, this research aims to identify the major barriers and propose suitable solutions to bring the Serbian industry closer to the principles of Industry 4.0 using PSI, CRADIS, and WISP methods.

The PSI method (Maniya and Bhatt, 2010) is very convenient for application because it incorporates determining the criteria significance and final ranking of the alternatives, estimating the criteria weights based on the input data, and giving more reliable and objective results. Until now, this method was used for different purposes, such as: evaluation of the supply chain sustainability risk (Sutrisno and Kumar, 2023, 2022), optimization of the 3D scanning process (Pathak et al., 2019), evaluation of the design solutions (Wang and Zhang, 2023), and resolving manufacturing problems (Patnaik et al., 2020; Madić et al., 2017). It is believed that this method will yield satisfactory results in addressing challenges associated with the implementation of Industry 4.0 as well.

The CRADIS method (Puška et al., 2022a) is the new approach based on the TOPSIS, MARCOS, and ARAS methods. The starting idea for creating the CRADIS method was to use the good aspects of the mentioned methods to achieve a reliable, ideal solution. Despite having been proposed relatively recently, the CRADIS method was used for optimizing different business and real-world problems in various fields, such as material selection (Chakraborty et al., 2024), electric car selection (Puška et al., 2023a), agriculture (Puška et al., 2022b), economic development (Starčević et al., 2022), supplier selection (Puška et al., 2023b; Puška et al., 2022c), and distribution center location selection (Puška et al., 2023c).

The WISP method, proposed by Stanujkic et al. (2021), integrates the weighted sum and weighted product approaches. This method combines four utility measures to define the alternative that maximizes the total utility. This method was used to facilitate the decision-making process in many business areas, and some of them are: technology evaluation and selection (Rani et al., 2023; Hezam et al., 2023), logistics (Ulutaş et al., 2022a), and supplier selection (Ulutaş et al., 2022b).

METHODOLOGY

There was a necessity to establish a research plan that effectively identifies the main obstacles to the adoption of modern technologies and finding the solution to enhance the transition of the Serbian industry into Industry 4.0. This plan is illustrated in Figure 1.

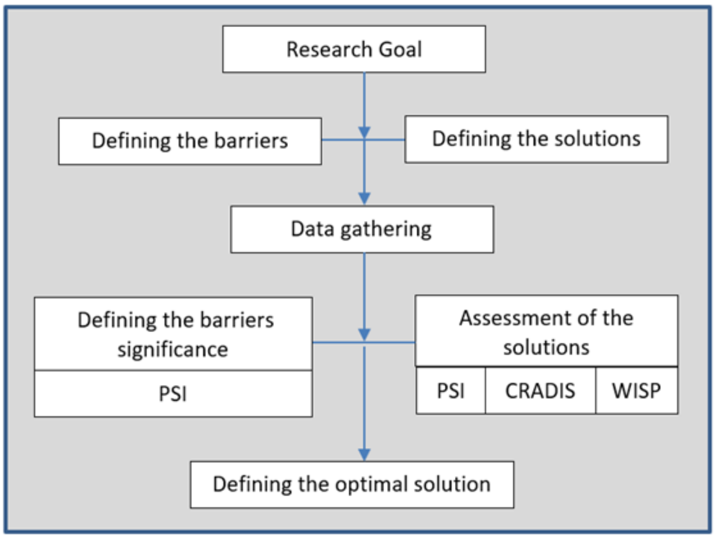

Figure 1. Research plan

Source: Authors' research

As it can be seen from Figure 1 the research plan consists of the following steps. First, we had to define the obstacles and solutions, which we did based on the research conducted by Javaid et al. (2022). Second, the questionnaire was used to provide an initial assessment of potential solutions for perceived obstacles. It was distributed to three decision-makers well-versed in the Serbian economy, and their responses served as the foundational data for the subsequent procedure. Third, the PSI method (Maniya and Bhatt, 2010) was applied to define the significance of the considered barriers, while the combination of the PSI, CRADIS (Puška et al., 2022), and WISP (Stanujkic et al., 2021) methods were used for the assessment of the possible solution. Ultimately, the optimal solution suitable for application in the current conditions was determined using the domination method. The explanation of the computational procedure for the employed MCDM methods is presented in the following subsections.

The PSI Method

Maniya and Bhatt (2010) proposed the PSI method, which represents an objective approach to evaluating and comparing the alternatives. The PSI method takes into account all the criteria involved in the evaluation process, allowing for more informative and reliable decision-making. Moreover, the PSI method incorporates defining the weights of the criteria and estimating the alternatives, making it easy to apply even for decision-makers unfamiliar with MCDM methods.

The computational procedure of the PSI method involves the presented series of steps.

Step 1. Selection of the criteria and alternatives that will be submitted under evaluation.

Step 2. The alternatives evaluation and construction of the initial decision matrix *D*:

$$D = \left[x_{ij}\right]_{nxm}, \quad (1)$$

where x_{ij} represents ratings of the alternative *i* regarding the criterion *j*, *n* is the number of alternatives, and *m* is the number of criteria.

Step 3. The normalized decision matrix construction, which elements are calculated as follows:

$$r_{ij} = \frac{x_{ij}}{x_{ij}} \text{ for maximization criteria,} \quad (2)$$

$r_{ij} = \frac{x_{ij}}{x_{ij}}$ for minimization criteria. (3)

Step 4. The preference variation value calculation concerning each criterion as follows:

$$\chi_j = \sum_{i=1}^{m} \left(r_{ij} - \bar{r}_j\right)^2, \quad (4)$$

where $\bar{r}_j$ is the mean value of normalized ratings of criterion *j*, and it is defined as follows:

$$\bar{r}_j = \frac{1}{m} \sum_{i=1}^{m} r_{ij}. \quad (5)$$

Step 5. Deviation in the preference variation value calculation as follows:

$$\Omega_j = 1 - X_j. \quad (6)$$

Step 6. Determination of the criteria weights in the following way:

$$w_j = \frac{\Omega}{\sum_{i=1}^{n} \Omega_j}. \quad (7)$$

Step 7. Computation of the preference selection index of alternatives as follows:

$$S_i = \sum_{j=1}^{n} r_{ij} w_j. \quad (8)$$

The ranking is performed based on the preference selection index values of the alternatives, where the best option is the alternative with the highest value.

The CRADIS Method

The CRADIS method is designated as a new approach rather than a method because it represents a sublimation of the good features of the TOPSIS, MARCOS, and ARAS methods (Puška et al., 2022a). The main idea is finding the optimal solution closest to the ideal point. The following steps could illustrate the computational procedure of this method.

Steps 1 and 2. The CRADIS method also requires the decision matrix *D* creation with *n* alternatives and *m* criteria and its normalization.

Step 3. The weighted decision matrix is defined in the following way:

$$v_{ij} = r_{ij} \cdot w_j, \quad (9)$$

where v_{ij} represents the weighted normalized performance rating of the alternative *i* in relation to the criterion *j*.

Step 4. Definition of the ideal t_i and anti-ideal t_{ai} solution is done using Eqs. (10) and (11):

$$t_i = max v_{ij}, \quad (10)$$

$$t_{ai} = min v_{ij}. \quad (11)$$

Step 5. Calculation of the deviations from ideal and anti-ideal solutions is performed in the following manner:

$$d^{+} = t_i - v_{ij}, \tag{12}$$

$$d^{-} = v_{ij} - t_{ai}. \tag{13}$$

Step 6. Computation of the deviation levels of the separate alternatives from ideal and anti-ideal solutions is done in the following way:

$$s_i^{+} = \sum_{j=1}^{n} d^{+}, \tag{14}$$

$$s_i^{-} = \sum_{j=1}^{n} d^{-}. \tag{15}$$

Step 7. The utility function relative to the deviation from the optimal ones should be computed for each alternative in the following way:

$$K_i^{+} = \frac{s_0^{+}}{s_i^{+}}, \tag{16}$$

$$K_i^{-} = \frac{s_i^{-}}{s_0^{-}}, \tag{17}$$

where s_0^{+} denotes the optimal alternative that is the least distant from the ideal solution, while s_0^{-} is the optimal alternative that is the most distant from the anti-ideal solution.

Step 8. The final ranking order of the alternatives determination by using the Eq.:

$$Q_i = \frac{K_i^{+} + K_i^{-}}{2}, \tag{18}$$

where the alternative with the highest Q_{i} represents the optimal choice.

The WISP Mthod

The WISP method, introduced by Stanujkic et al. (2021), incorporates four relationships between maximization and minimization criteria to define the final utility of a considered alternative. The computation procedure of the WISP method involves the following steps.

Step 1. As in the case with the PSI and CRADIS, the creation of decision matrix D is also required.

Step 2. Formation of a normalized decision matrix in the following way:

$$r_{ij} = \frac{x_{ij}}{\max_i x_{ij}}, \tag{19}$$

where r_{ij} is a dimensionless number representing a normalized rating of alternative i regarding the criterion j.

Step 3. Calculation of the values of four utility measures in the following way:

$$u_i^{wsd} = \sum_{j\in\Omega_{max}} r_{ij}w_j - \sum_{j\in\Omega_{min}} r_{ij}w_j, \tag{20}$$

$$u_i^{wpd} = \prod_{j\Omega_{max}} r_{ij}w_j - \prod_{j\in\Omega_{min}} r_{ij}w_j, \tag{21}$$

$$u_i^{wsr} = \frac{\sum_{j\in\Omega_{max}} r_{ij}w_j}{\sum_{j\in\Omega_{min}} r_{ij}w_j}, \tag{22}$$

$$u_i^{wpr} = \frac{\prod_{j\in\Omega_{max}} r_{ij}w_j}{\prod_{j\in\Omega_{min}} r_{ij}w_j}, \tag{23}$$

where: u_i^{wsd} and u_i^{wpd} are differences between the weighted sum and weighted product of normalized ratings of alternative *i*, respectively. Analogous to the previous one, u_i^{wsr} and u_i^{wpr} are ratios between the weighted sum and weighted product of normalized ratings of alternative *i*, respectively.

Step 4. Recalculation of the values of four utility measures as follows:

$$\bar{u}_i^{wsd} = \frac{1+u_i^{wsd}}{(1+u_{max_i}^{wsd})}, \tag{24}$$

$$\bar{u}_i^{wpd} = \frac{1+u_i^{wpd}}{(1+u_{max_i}^{wpd})}, \tag{25}$$

$$\bar{u}_i^{wsr} = \frac{1+u_i^{wsr}}{\left(1+u_{max_i}^{wsr}\right)}, \text{ and} \tag{26}$$

$$\bar{u}_i^{wpr} = \frac{1+u_i^{wpr}}{\left(1+u_{max_i}^{wpr}\right)}, \tag{27}$$

where: $\bar{u}_i^{wsd}$, $\bar{u}_i^{wpd}$ $\bar{u}_i^{wsr}$ and $\bar{u}_i^{wpr}$ denotes recalculated values of u_i^{sd}, u_i^{pd}, u_i^{sr} and u_i^{pr}.

Step 5. Definition of the overall utility u_i of each alternative in the following manner:

$$u_i = \frac{1}{4}(\bar{u}_i^{wsd} + \bar{u}_i^{wpd} + \bar{u}_i^{wsr} + \bar{u}_i^{wpr}), \tag{28}$$

where the higher u_i represents a better ranking position of the particular alternative.

RESULTS

Fourteen solutions were evaluated against the twenty-two barriers proposed by Javaid et al. (2022). The barriers are categorized into three groups: technological, managerial, and social. The list of the proposed solutions is presented in Table 1, and the possible barriers are given in Table 2.

Table 1. The list of solutions

Abbreviation	Solution
SO_1	Optimization of the production rate
SO_2	Training aimed at capacity building
SO_3	Adequate protocol development
SO_4	The raw materials availability
SO_5	Modern and supporting technologies management
SO_6	Improved logistics and warehousing management
SO_7	Getting quality market data and support analysis
SO_8	Updated policy and practical implementation
SO_9	The required amount of data
SO_{10}	Imports of advanced and supporting technologies are not restricted

Abbreviation	**Solution**
SO_{11}	Coordinate the environmental laws with new needs
SO_{12}	Industries have the freedom to select desired technology
SO_{13}	Adequate maintenance and handling of new technologies
SO_{14}	Supportive research, development, and commercialization environment

Source: Javaid et al. (2022)

Table 2 illustrates the anticipated barriers.

Table 2. The list of barriers

	Abbreviation	**Barrier**
Technological barriers	T_1	The high initial cost of technology
	T_2	High level of technological complexity
	T_3	Lack of simulation and software support
	T_4	Maintenance of technological support, including IT
	T_5	Integration of technologies
	T_6	Availability of raw material
	T_7	Communication technology
	T_8	Systems not tested to handle emergencies or disruption
Management barriers	M_1	Spare parts, logistics, and reverse logistics management
	M_2	Poor forecasting and prediction for decision-making
	M_3	Change management
	M_4	Policy, regulation, and legal issues
	M_5	Appropriate support infrastructure
	M_6	Skilled workforce
	M_7	Training and capacity building
	M_8	Industry-academia interaction
Social barriers	S_1	Fear of unemployment/Job reduction
	S_2	Import restrictions and government policy
	S_3	Requirements for environmental clearances
	S_4	Ethical and privacy issues
	S_5	Lack of awareness of new technological developments
	S_6	Security concerns

Source: Javaid et al. (2022)

Three experts from different research fields familiar with the state of the Serbian economy were asked to fill out a questionnaire that will provide the data necessary for further analysis. They had to evaluate the solutions regarding the given barriers using ratings from 1 (the worst rating) to 5 (the best rating). The geometric mean was applied to obtain the overall input data. Table 3 represents the initial decision matrix.

Table 3. Initial decision-matrix

	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	M_1	M_2	M_3	M_4	M_5	M_6	M_7	M_8	S_1	S_2	S_3	S_4	S_5	S_6
SO_1	3.9	3.7	3.9	1.8	4.3	4.6	1.6	2.6	3.6	2.6	2.6	1.8	2.9	1.8	2.5	1.8	2.9	3.0	3.3	1.8	2.7	2.3
SO_2	3.4	3.6	2.9	3.0	3.3	2.3	2.5	3.1	3.6	2.7	3.3	2.3	3.6	4.3	4.6	2.7	3.9	3.6	3.9	3.1	3.1	4.3
SO_3	2.9	3.1	2.6	2.3	3.0	3.6	3.1	2.9	3.0	3.9	2.9	3.9	3.6	4.0	4.0	2.0	3.6	3.6	3.6	2.6	2.5	4.3
SO_4	2.9	2.6	3.3	2.6	3.0	4.6	2.3	2.9	4.0	2.3	3.1	2.7	3.1	3.1	2.9	2.7	2.6	4.6	3.3	3.6	3.1	2.6
SO_5	4.2	3.3	2.6	4.3	3.6	3.9	3.1	2.5	2.9	4.6	4.2	3.6	2.9	3.6	3.0	3.3	2.9	4.0	4.6	3.6	4.0	4.0
SO_6	5.0	4.3	3.9	3.6	3.1	5.0	2.6	3.9	4.3	4.6	4.2	4.3	3.0	2.6	4.3	2.3	2.9	4.6	3.6	3.6	3.0	4.6
SO_7	4.0	4.0	1.8	3.6	3.6	3.9	2.5	3.3	3.3	4.3	4.3	3.6	3.9	3.0	3.6	3.3	4.6	2.6	3.3	3.0	2.9	3.6
SO_8	3.1	3.9	2.3	2.9	3.3	3.3	3.6	3.0	2.6	3.6	3.7	3.3	4.0	3.6	4.3	3.0	3.6	2.6	3.9	2.7	3.3	3.6
SO_9	3.3	2.9	2.5	3.0	2.9	3.3	2.9	3.6	3.6	3.1	2.7	2.9	3.0	3.6	3.3	3.1	2.6	3.3	3.3	2.6	3.6	3.6
SO_{10}	4.2	3.6	3.3	3.6	3.9	2.9	1.8	2.9	3.6	4.3	4.3	3.6	3.9	4.0	3.2	3.3	2.9	4.6	4.2	2.9	2.6	4.0
SO_{11}	3.9	3.6	2.3	2.3	3.3	3.2	2.1	3.3	3.4	2.5	3.3	3.3	3.0	3.0	2.9	2.6	3.6	4.6	4.6	3.6	3.3	2.9
SO_{12}	4.2	4.2	4.3	4.3	3.6	3.3	3.1	3.6	3.4	3.4	3.2	3.3	4.0	3.0	4.3	3.3	3.9	4.0	4.3	3.3	4.6	3.6
SO_{13}	4.6	5.0	3.2	4.6	4.3	3.3	3.3	4.3	3.6	4.0	4.2	4.3	3.6	3.3	4.3	2.9	4.3	3.9	4.6	3.6	4.3	3.6
SO_{14}	3.7	3.9	3.0	3.3	3.2	2.9	2.6	4.0	3.2	3.4	2.7	4.0	4.0	2.6	4.0	3.3	3.4	4.0	5.0	3.6	3.6	4.3

Source: Authors' research

Based on the data from Table 3, the PSI method is applied to define the barriers' significance (Table 4).

Table 4. The significance of the barriers

	Abbreviation	**Significance**
Technological barriers	T_1	0.0493
	T_2	0.0503
	T_3	0.0405
	T_4	0.0362
	T_5	0.0532
	T_6	0.0435
	T_7	0.0417
	T_8	0.0496
Management barriers	M_1	0.0540
	M_2	0.0384
	M_3	0.0436
	M_4	0.0392
	M_5	0.0516
	M_6	0.0433
	M_7	0.0446
	M_8	0.0436
Social barriers	S_1	0.0470
	S_2	0.0430
	S_3	0.0508
	S_4	0.0440
	S_5	0.0474
	S_6	0.0450

Source: Authors' research

The obtained results in Table 4 revealed that the most prominent is the barrier from the management group M_1 – Spare parts, logistics, and reverse logistics management. The absence of readily available spare parts or the challenges associated with their timely procurement can disrupt the operational continuity of these technologies, potentially leading to downtime and decreased productivity. In a rapidly evolving Industry 4.0 landscape, where precision and efficiency are paramount, any hindrance to the seamless functioning of technology can have far-reaching implications.

This barrier is followed by the technological barrier T5 – Integration of technologies. This barrier holds significant importance in the context of a sustainable transition to Industry 4.0, as it directly influences the ability of organizations to effectively harness the potential of advanced technologies. In a digitalized and interconnected industrial landscape, the effective coordination and interaction of various technologies are imperative. When integration is compromised, it can lead to disjointed and inefficient processes, rendering the potential benefits of Industry 4.0 elusive.

According to the revealed significance, the management barrier M5 – Appropriate support infrastructure is in the third place. The essence of barrier M5 lies in the essential role that adequate support infrastructure plays in the successful adoption and integration of new technology within an organization. As industries evolve toward Industry 4.0, the reliance on advanced technologies and digital systems becomes increasingly pronounced. To effectively harness the potential of these technologies, companies must have the necessary infrastructure in place to support their implementation and operation. Inadequate support infrastructure can lead to system failures, security vulnerabilities, and operational inefficiencies, ultimately undermining the intended benefits of technological advancement.

When considering social barriers in the context of the Industry 4.0 transition, one of the most influential impediments is the barrier S3 – Requirements for environmental clearances. It revolves around the complexities associated with obtaining the necessary environmental clearances for implementing Industry 4.0 technologies. Environmental clearances are typically required to ensure that the introduction and operation of new technologies do not harm the environment or violate regulatory standards. However, the intricate and time-consuming nature of these clearance procedures can become a bottleneck, slowing down the process of integrating innovative technologies into a company's operations and deployment of technologies that could enhance efficiency, reduce waste, and improve sustainability.

The technological barrier T2 – High level of technological complexity occupies a notable fifth position in the hierarchy of barriers. This placement underscores the critical role that skilled and trained employees play in the successful implementation and application of modern technologies within the context of Industry 4.0. The technologies associated with Industry 4.0 are often intricate and sophisticated. To effectively harness their capabilities, organizations must rely on a workforce equipped with the requisite knowledge and expertise. In essence, the barrier highlights the imperative need for a workforce that possesses the necessary skills to navigate, operate, and troubleshoot these advanced systems. Skilled employees not only facilitate the seamless integration of technology but also contribute to innovation and efficiency gains. Their proficiency in handling complex technology ensures that organizations can maximize the benefits of Industry 4.0, ranging from improved productivity to data-driven decision-making and enhanced competitiveness.

To provide a point of comparison, in the research by Javad et al. (2022) in India, upon which this study is based, the tremendous significance among the technological barriers is the barrier T1 – High initial cost of technology, while in Serbia, the primary obstacle is T5 – Integration of technologies. However, in both countries, in the second place regarding the technological aspects is the barrier T2 – High level of technological complexity. The main impediment to introducing modern technologies in India regarding the management barriers is M3 – Change management, unlike Serbia, where it is M1 – Spare parts, logistics, and reverse logistics management. Again, within this group, the second most influential barrier is the same in both countries, and it is M5 – Appropriate support infrastructure. Moreover, finally, the social barrier that has the most significant importance in India is S1 – Fear of unemployment/job reduction, while it is revealed that in Serbia, the leading social barrier is S3 – Requirements for environmental clearances.

The conditions in a particular country submitted under analysis cause variations regarding the considered barriers and suitable solutions. For example, the main obstacles to implementing Industry 4.0 into the Morrocan environment are high implementation costs, unclear ROI definition, and restricted corporate structure and culture (Gallab et al., 2021). A research study by Yüksel (2020), who investigated the main challenges of introducing Industry 4.0 in Turkey, discovered that the main problems are the lack of technical expertise and scarce financial resources followed by insufficient information. In the case of Romania, the main issues are connected to insufficient knowledge about Industry 4.0, absence of standards, and lack of human resources (Türkeș et al., 2019). Although the obstacles set vary in the observed research studies, they have matching points. As presented studies highlight, the identified differences result from different levels of sustainable development in the analyzed economies.

The final ranking order of the alternative solutions obtained using the PSI, CRADIS, and WISP methods is presented in Table 5.

Table 5. Ranking order of the solutions

	PSI		CRADIS		WISP	
	S_i	**Rank**	Q_i	**Rank**	u_i	**Rank**
SO_1	0.6451	14	0.9093	14	0.9325	14
SO_2	0.7609	9	1.1055	9	0.9629	9
SO_3	0.7324	11	1.0495	11	0.9554	11
SO_4	0.7067	13	0.9901	13	0.9486	13
SO_5	0.8093	4	1.2093	4	0.9756	4
SO_6	0.8540	2	1.3242	2	0.9874	2
SO_7	0.7883	7	1.1747	7	0.9701	7
SO_8	0.7613	8	1.1076	8	0.9630	8
SO_9	0.7134	12	1.0080	12	0.9504	12
SO_{10}	0.8034	6	1.1955	6	0.9741	6
SO_{11}	0.7359	10	1.0622	10	0.9563	10
SO_{12}	0.8525	3	1.3225	3	0.9870	3
SO_{13}	0.9021	1	1.4639	1	1.0000	1
SO_{14}	0.8075	5	1.2053	5	0.9751	5

Source: Authors´research

The solution SO_{13} – Adequate maintenance and handling of new technologies emerges as an optimal choice for implementation within the context of Serbia's transition to Industry 4.0. This solution underscores the significance of not just acquiring cutting-edge technologies but also ensuring their efficient and effective utilization. Namely, its essence lies in the idea that merely introducing new technologies is insufficient. They must be maintained and operated correctly to realize their full potential and deliver optimal business outcomes. It's important to recognize that the adoption of advanced technologies often involves a learning curve for employees. They need time to become proficient in using these technologies to their advantage. The successful Industry 4.0 implementation hinges on the seamless integration of technology into existing processes. Inadequate maintenance or improper handling can result in operational disruptions, reduced efficiency, and unrealized benefits. Moreover, investing in training and skill development for employees is vital to ensure they can harness the technology's capabilities effectively.

The second place occupies the solution SO_6 – Improved logistics and warehousing management, which can be viewed as an imperative element in ensuring a sustainable transition to Industry 4.0. As industries evolve to embrace digitalization and automation, the efficiency and optimization of logistics and warehousing become paramount. Streamlined logistics and efficient warehousing operations are essential for maintaining a smooth supply chain, reducing lead times, minimizing costs, and meeting the increasingly demanding requirements of modern manufacturing and distribution. This is particularly pertinent in the context of Industry 4.0, where real-time data, automation, and interconnected systems necessitate an agile and responsive logistics network. It not only emphasizes the importance of technological investments in this area but also the need for robust management practices, workforce training, and process optimization.

The SO_6 solution is followed by the solution SO_{12} – Industries have the freedom to select desired technology. It underscores the importance of allowing organizations the flexibility to choose the technology that best aligns with their specific needs and objectives. This approach recognizes that a one-size-fits-all approach to technology adoption may not be suitable for all industries or contexts. Instead, by affording industries the freedom to select technologies that suit their unique requirements, they can optimize their production processes and overall business performance. Furthermore, this freedom to choose technology plays a crucial role in the efficient utilization of available resources, including human capital, financial investments, and natural resources. It allows industries to make strategic decisions that maximize resource utilization, minimize waste, and enhance sustainability.

On the other hand, Javad et al. (2022) emphasized the solution SO_{14} – Supportive research, development, and commercialization environment as the most appropriate for application in India to achieve the goals of Industry 4.0, which is followed by SO_8 – Updated policy and practical implementation and SO_2 – Training aimed at capacity building.

CONCLUSION

Utilizing the proposed approach, which is grounded in the PSI, CRADIS, and WISP methods, we have identified the primary barriers and appropriate solutions for transitioning the Serbian industry to a sustainable Industry 4.0. The MCDM approach presented here integrates various methods that achieve optimal results in distinct ways. More precisely, the PSI method represents the method that involves determining the criteria weight and the final ranking of the alternatives. The CRADIS method chooses the closest solution to the ideal one, while the WISP method selects the solution that provides the most significant utility.

We emphasized five main barriers that characterize the current economic environment in Serbia and three essential solutions for their overcoming. The need for spare parts, logistics, and reverse logistics management stood out as the most severe barrier to implementing Industry 4.0 in the Serbian economy. This obstacle is followed by the problem of technology integrations, which slow down the process of Serbian industry transformation. Serbia needs adequate support infrastructure and environmental clearances. Finally, among the most influential obstacles is a high level of technological complexity, which could hinder the transformation of Serbian industry to Industry 4.0. Adequate maintenance and handling of new technologies, improving logistics and warehousing management, and finally, giving the industry freedom to select the desired technology will speed up the transformation process of the Serbian industry to Industry 4.0, and they represent the priority solutions.

The presented framework is concise, easy to apply, and reliable and could be very helpful and valuable for researchers and managers. From an academic perspective, this research presents a new combination of methods that could be used for determining the optimal solutions in the research regarding Industry 4.0 and other purposes. The mentioned approach enables managers and policymakers to perceive the barriers hindering industry transformation and development. Additionally, they could define the actions and measures that must be applied to achieve desired goals.

Although the proposed framework has mentioned benefits, it also has some shortcomings. For example, the research is based on crisp numbers that could not represent the hesitation and vagueness of decision-makers. Introducing fuzzy, grey, or neutrosophic numbers would better express the ambiguity of the decision environment. Besides, although it is stated that the PSI method belongs to the objective type of methods, the qualitative type of data certainly biases the results to some extent. This subjectivization of the results could be reduced by involving more decision-makers.

Furthermore, this research is based on the barriers and solutions recognized by authors from India. Even though they were convenient for application in this research, defining the set of obstacles and solutions fully connected to the state in Serbia is highly recommended. In that way, the obtained results will be more relevant.

Finally, regardless of the mentioned flaws, the proposed framework showed its usefulness and applicability. The results are justified and in line with the current situation in Serbian industry. Overcoming recognized barriers and acknowledging the proposed optimal solution will contribute to the Serbian industry getting closer to the desired sustainable Industry 4.0. Additionally, the suggested MCDM framework could find application in planning and formulating policies for various business fields. The rationale behind these recommendations lies in the fact that decisions informed by analysis and mathematical methods tend to be more authoritative and robust.

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