

Selection of Maintenance Strategy Using Hybrid AHP-VIKOR Approach for a Smart Manufacturing Application in Industry 4.0

Rahul Chakrawarti^{1,*}, Devendra Singh Verma²

Abstract

In Industry 4.0, choosing the right maintenance strategy is important for improving machine performance, reducing downtime, and ensuring smooth operation in smart manufacturing systems. This study aims to find the most suitable maintenance strategy for a customized machine-making company by using a combination of AHP and VIKOR methods. In this study, four types of maintenance strategies are considered: breakdown maintenance, time-based maintenance, condition-based maintenance, and predictive maintenance. First, the AHP method is used to decide the importance of different factors such as cost, reliability, system availability, and efficiency. Then, the VIKOR method is used to compare these strategies and rank them based on their performance. The results show that condition-based maintenance is the best option among all the strategies, as it gives a good balance between cost, performance, and reliability. This shows that modern maintenance methods are more effective for smart manufacturing systems. This study provides a clear and simple approach that can help managers and decision-makers choose the right maintenance strategy in Industry 4.0 environments. The proposed decision-making framework can also be applied to similar manufacturing industries facing maintenance-related challenges. The findings of this study support effective resource utilization improved operational performance, and better maintenance planning for sustainable industrial operations.

Keywords: Industry 4.0, smart manufacturing, maintenance, analytic hierarchy process (AHP), VlseKriterijumska Optimizacija Kompromisno Resenje (VIKOR).

INTRODUCTION

According to reference [1], the present world is influenced by the Fourth Industrial Revolution. It includes technologies such as Big Data, Cloud Computing, Advanced Robotics, Internet of Things, and Digital Twins, which are collectively known as “Industry 4.0.” The aim is to improve production so that better quality products can be produced in less time and at lower cost. One important concept under this is “smart manufacturing,” which uses data-based methods to address these issues.

As stated in reference [2], in recent years, more focus is being given to “smart manufacturing” by researchers and industry experts. It is a system that can be adjusted in real time according to changing customer needs with the help of advanced technologies. However, these systems require regular maintenance. According to reference [3], even in advanced factories, maintenance is still an important and difficult activity, and it is not fully automated.

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In today's competitive industrial world, maintenance is very important. Machines require regular servicing to avoid downtime and loss of productivity. When machines break down, it leads to delays, loss of reputation, and financial losses. Maintenance requires proper planning, budgeting, and management. While making a plan, a suitable maintenance strategy should be selected according to the company's goals and daily operations. A good maintenance plan is useful for all types of industries. Different maintenance strategies are available, each with its own advantages and disadvantages. Machine performance depends on the maintenance method used. These methods may vary from machine to machine based on safety, cost, and satisfaction. It is also necessary to manage the factors that affect machine performance. The use of an unsuitable maintenance method increases the maintenance cost [4].

Considering the above facts, the present research work deals with the selection of a maintenance strategy for a manufacturing firm. For this purpose, multiple-criteria decision-making (MCDM), also known as MCDA, is used. It is a method in which different alternatives are compared on the basis of various criteria using scoring and weighting. It is suitable when many alternatives are available and different criteria must be considered. It also helps in balancing positive and negative aspects [5]. In this method, alternatives are compared based on different criteria to achieve the objectives. In the present study, the VIKOR method was used for the evaluation of alternatives, and AHP was used as a prioritization technique for the evaluation of criteria.

Objectives of Research

The following are the objectives of the present research work:

1. Identification of a set of evaluation criteria for evaluation;
2. Evaluation of different alternatives; and
3. Identification of optimum maintenance strategy for the firm.

LITERATURE REVIEW

The present section discusses the research contributions made by different researchers in the field of maintenance strategies and concludes with gaps in the research.

Research contributions in the Field of Maintenance Strategies

The present section is based on the contributions of different researchers in the fields of Industry 4.0, smart manufacturing, and maintenance strategy selection, as follows:

Global interest in the Fourth Industrial Revolution has been growing steadily over the last several years, as reported by reference [6]. According to reference [7], "Industry 4.0" leads to shorter production cycles, higher product quality, and enhanced organizational efficacy. The scope of Industry 4.0 is vast, including not only manufacturing but also efficiency, data management, customer relationships, and business competitiveness. Simultaneously, it is clear that Industry 4.0 has emerged as a central topic in the study of management and business economics, with several articles published on a wide range of related topics [8].

According to reference [9], the concept of "smart manufacturing" was first developed in the United States and has since spread worldwide. Smart manufacturing, as described in reference [10], dates back to the second part of the twentieth century. According to reference [11], the IoT is a manufacturing technology that increases efficiency and quality. With the use of IoT, a smart factory can be built using sensors, actuators, and other components. One of the primary goals of manufacturing process management is the minimization of industrial waste and the enhancement of goods. In a broader sense, "smart manufacturing" can be defined as the use of interconnected, networked, and data-rich equipment to carry out predetermined, repetitive activities.

Initial studies on smart manufacturing, as reported in [12], concentrated on the many technologies already in use in the industrial sector. However, new studies in this field go further by covering topics such as strategy, design, production, and human resources. Through the use of tools such as simulations and big data, smart manufacturing can perform tasks such as global monitoring and performance optimization. Management and other production factors, including efficiency, quality, delivery, and flexibility based on current technology, are key to achieving sustainable development in smart manufacturing, as stated in reference [13].

Using cost, safety, value-added services, and equipment and technology as factors, reference [4] explored the issue of choosing the best maintenance plan. Reference [14] study work seeks to identify the most effective approaches to servicing vital centrifugal pumps in an oil refinery. They claim that the model can factor in the maintenance strategy for each potential failure mode of the pump. References [15] and [14] both investigate how to choose among preventative, condition-based, corrective, and opportunistic maintenance for a given plant, with the former focusing on the occurrence, severity, and detectability of maintenance problems.

Gaps in the Research

Most studies focused on the selection of maintenance strategies. In addition, there is little research on the use of combined MCDM techniques in decision-making problems.

SOLUTION METHODOLOGY

The Analytic Hierarchy Process (AHP) was developed by Saaty in the 1970s. It is a method used to solve difficult decision-making problems in a simple and systematic manner. It is based on mathematics and human thinking. AHP does not provide a direct decision but helps select the best option. It is useful for clearly understanding the problem, dividing it into parts, and comparing different alternatives. Therefore, it is used in government, business, industry, healthcare, and education [16].

In AHP, the problem is arranged in the form of a hierarchy. The main objective is at the top, criteria and sub-criteria are in the middle, and alternatives are at the bottom. A hierarchy means arranging things at different levels, where lower elements are connected to higher ones. Each element is called a node, and their relationship is called parent and child (Figure 1). After preparing the hierarchy, priorities are decided by considering the opinions of people and performing simple calculations. This helps select the most suitable option among the available alternatives [17].

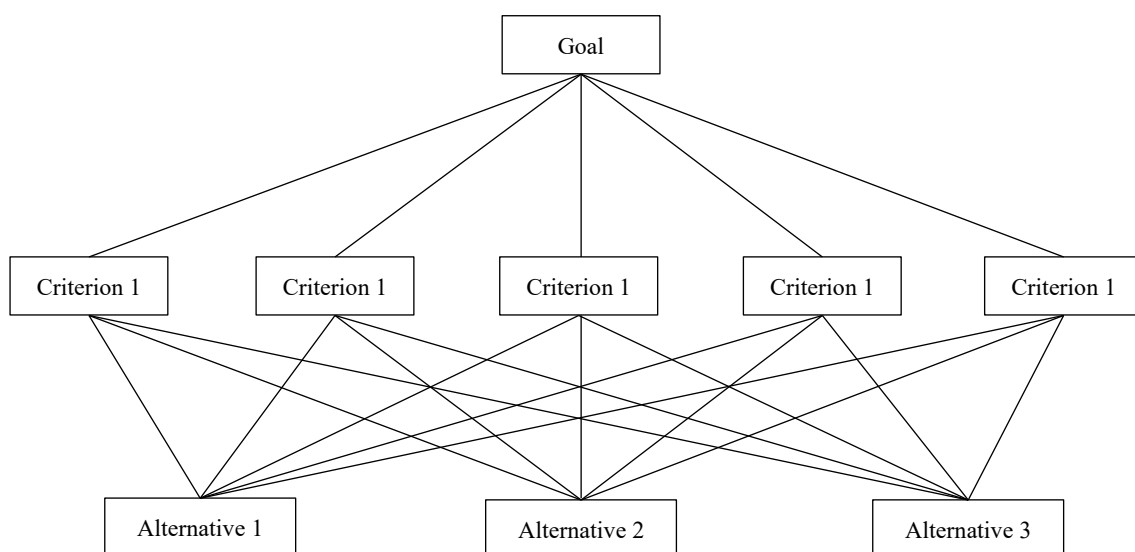


Figure 1. General AHP hierarchy structure [17].

Vlsekriterijumska Optimizacija I Kompromisno Resenje (VIKOR)

Vlsekriterijumska Optimizacija I Kompromisno Resenje, which translates to "multi-criteria optimization and compromise solution" in Serbian, is the acronym for VIKOR. Opricovic created it in 1998. The focus of this strategy is on evaluating and choosing the best option out of many that have competing criteria. In addition, it facilitates the final choice by helping decision-makers locate the optimal compromise [18].

VIKOR method is based on L_p -metric used in compromise programming. This metric is used to find a solution that is nearest to the ideal solution. Its mathematical form is given in reference [19]. VIKOR is a multi-criteria decision-making (MCDM) method based on the outranking principle. It is used to find a compromise ranking list, best compromise solution, and weight stability intervals.

$$L_{p,j} = \left\{ \sum_{i=1}^n \left[\frac{w_i(f_i^* - f_{ij})}{(f_i^* - f_i^-)} \right]^p \right\}^{1/p} \quad (1)$$

$$1 \leq p \leq \infty, j = 1, 2, 3, \dots, J \quad (2)$$

General Procedure of VIKOR

The following steps are involved in the VIKOR method:

Step 1: Representation of normalized decision matrix

The normalized decision matrix can be expressed as

$$F = [f_{ij}]_{m \times n} \quad (3)$$

Here,

$$f_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^m x_{ij}^2}}, i = 1, 2, \dots, m; \quad (4)$$

and, x_{ij} is the performance of alternative A_i concerning the j^{th} criterion.

Step 2: Obtain the maximum criterion function f_j^* and the minimum criterion function f_j^- , where $j = 1, \dots, m$.

Maximum criterion functions

$$f_j^* = \max_i \max[(f_{ij}) \setminus i=1, 2, 3, \dots, n] \quad (5)$$

Minimum criteria functions

$$f_j^- = \min_i \min[(f_{ij}) \setminus i=1, 2, 3, \dots, n] \quad (6)$$

Step 3: Calculation of utility measure and regret measure

The utility measure and the regret measure for each alternative are given as

Utility measure

$$S_i = \sum_{j=1}^n w_j \frac{(f_j^* - f_{ij})}{(f_j^* - f_j^-)} \quad (7)$$

Regret measure

$$R_i = \max_j [w_j] \frac{(f_j^* - f_{ij})}{(f_j^* - f_j^-)} \quad (8)$$

Step 4: Computation of VIKOR Index

The VIKOR index can be expressed as follows:

$$Q_i = v \left[\frac{S_i - S^*}{S^- - S^*} \right] + (1 - v) \left[\frac{R_i - R^*}{R^- - R^*} \right] \quad (9)$$

Q_i represents the VIKOR index value of i^{th} alternative. $i=1,2,\dots,n$.

$$S^* = \min_i S_i = \min \left[\frac{(S_i)}{i=1,2,3,\dots,n} \right] \quad (10)$$

$$S^- = \max_i S_i = \max \left[\frac{S_i}{i=1,2,3,\dots,n} \right] \quad (11)$$

$$R^* = \min_i R_i = \min \left[\frac{R_i}{i=1,2,3,\dots,n} \right] \quad (12)$$

$$R^- = \max_i R_i = \max \left[\frac{R_i}{i=1,2,3,\dots,n} \right] \quad (13)$$

where v is the weight for the maximum value of group utility and $1-v$ is the weight of individual regret. v is generally set to 0.5.

CASE STUDY

In this study, the selection of appropriate maintenance strategies for firms dealing with smart manufacturing practices was targeted using multi-criteria decision-making techniques. For this purpose, an MCDM model formulation was first created, and then its solution was derived, the details of which are presented in the following sections.

Problem Formulation

The research was accomplished in a customized machine manufacturing firm. The firm produces customized machines and lab equipment of prime quality. Owing to the versatile nature of the items produced via smart manufacturing practices, the management of the firm wanted to choose a successful maintenance strategy, which is the focus of this study.

The first step in the implementation of research tools to the case problem was problem formulation, for which the help of industry personnel as well as academicians was taken. A list of criteria was obtained, the details of which are as follows (Table 1).

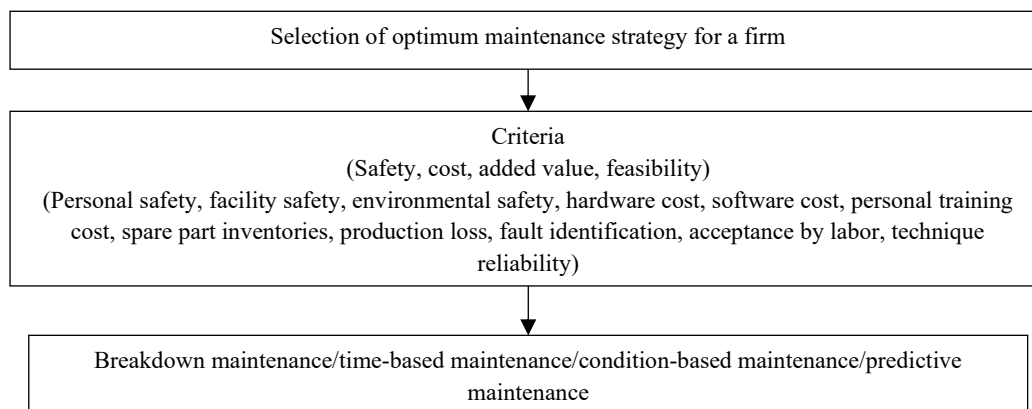
Regarding alternatives, with the help of industry personnel and academicians, maintenance types, breakdown maintenance, time-based maintenance, condition-based maintenance, and predictive maintenance were chosen as alternatives. Based on the available criteria and alternatives, an MCDM model was developed, the details of which are presented below (Figure 2).

Solution of the Model

To solve the model, two well-known multi-criteria decision-making techniques *Analytical Hierarchy Process (AHP)* and *Vlsekriterijumska Optimizacija I Kompromisno Resenje (VIKOR)* were used. The details of the procedure adopted for solving the model are as follows:

First, the weights of the criteria were identified using the AHP. For this purpose, A systematically designed questionnaire for the identification of weights of criteria was circulated among the industry personnel. The scale used in the questionnaire was a pairwise comparison scale. The responses were then fed to the AHP-CGI software available at <http://www.isc.senshu-u.ac.jp/~thc0456/EAHP/AHPweb.html>. Following are the details of responses as well as weights of criteria as well as sub-criteria (Tables 2–11).

In the next step, the scores of the different alternatives were investigated using the VIKOR process. The following are the details of the results obtained during the VIKOR calculations (Tables 12–15).

**Figure 2.** Model formulation for research problems.**Table 1.** List of criteria for model formulation.

S.N.	Criteria	Sub criteria
1.	Safety	Personal safety
2.		Facility safety
3.		Environmental safety
4.	Cost	Hardware cost
5.		Software cost
6.		Personal training cost
7.	Added value	Spare part inventories
8.		Production loss
9.		Fault identification
10.	Feasibility	Acceptance by labor
11.		Technique reliability

Table 2. Pairwise comparison matrix for criteria.

From/to	Safety	Cost	Added value	Feasibility
Safety	1	5	6	7
Cost	1/5	1	4	4
Added value	1/6	1/4	1	1
Feasibility	1/7	1/4	1	1

Table 3. Weights of criteria.

S.N.	Criteria	Weights
1.	Safety	0.638
2.	Cost	0.2917
3.	Added value	0.07282
4.	Feasibility	0.0691
	CR = CI/RI = 0.06	

Table 4. Pairwise comparison matrix for sub-criteria under criteria 'Safety'.

From/to	Personal safety	Facility safety	Environmental safety
Personal safety	1	7	3
Facility safety	1/7	1	1/4
Environmental safety	1/3	4	1

Table 5. Weights of sub-criteria under criteria ‘Safety’.

S.N.	Criteria	Weights	
		<i>Local Priorities</i>	<i>Global Priorities</i>
1.	Personal safety	0.658	0.419804
2.	Facility safety	0.0786	0.050147
3.	Environmental safety	0.2627	0.167603
	CR = CI/RI = 0.027		

Table 6. Pairwise comparison matrix for sub-criteria under Criteria ‘Cost’.

From/to	Hardware cost	Software cost	Personal training cost
Hardware cost	1	1/4	1/5
Software cost	4	1	1/3
Personal training cost	5	3	1

Table 7. Weights of sub-criteria under criteria ‘Cost’.

S.N.	Criteria	Weights	
		<i>Local Priorities</i>	<i>Local Priorities</i>
1.	Hardware cost	0.0936	0.027303
2.	Software cost	0.279	0.081384
3.	Personal training cost	0.626	0.182604
	CR = CI/RI = 0.0724		

Table 8. Pairwise comparison matrix for sub-criteria under criteria ‘Added Value’.

From/to	Spare part inventories	Production loss	Fault identification
Spare part inventories	1	1	1/2
Production loss	1	1	1
Fault identification	2	1	1

Table 9. Weights of sub criteria under criteria ‘Added Value’.

S.N.	Criteria	Weights	
		<i>Local priorities</i>	<i>Local priorities</i>
1.	Spare part inventories	0.2599	0.018926
2.	Production loss	0.327	0.023812
3.	Fault identification	0.4125	0.030038
	CR = CI/RI = 0.044		

Table 10. Pairwise comparison matrix for sub-criteria under criteria ‘Feasibility’.

From/to	Acceptance by labor	Technique reliability
Acceptance by labor	1	1
Technique reliability	1	1

Table 11. Weights of sub-criteria under criteria ‘Feasibility’.

S.N.	Criteria	Weights	
		<i>Local Priorities</i>	<i>Local Priorities</i>
1.	Acceptance by labor	0.5	0.03455
2.	Technique reliability	0.5	0.03455
	CR = CI/RI = 0		

Table 12. Values of X_{ij} .

S.N.	Alternative	Personal safety	Facilities safety	Environmental safety	Hardware cost	Software cost	Personnel training cost	Spare part inventories	Production loss	Fault identification	Acceptance by labor	Technique reliability
1.	Breakdown maintenance	5	5	1	1	1	1	2	5	5	5	2
2.	Time-based maintenance	2	1	1	1	1	1	1	1	1	1	4
3.	Condition-based maintenance	3	2	2	5	5	2	1	1	2	3	5
4.	Predictive maintenance	1	1	2	1	5	2	2	1	1	1	3

Table 13. Values of f_{it} .

S.N.	Alternative	Personal safety	Facilities safety	Environmental safety	Hardware cost	Software cost	Personnel training cost	Spare part inventories	Production loss	Fault identification	Acceptance by labor	Technique reliability
1.	Breakdown maintenance	0.801	0.898	0.316	0.189	0.139	0.316	0.632	0.945	0.898	0.833	0.272
2.	Time-based maintenance	0.320	0.180	0.316	0.189	0.139	0.316	0.316	0.189	0.180	0.167	0.544
3.	Condition-based maintenance	0.480	0.359	0.632	0.945	0.693	0.632	0.316	0.189	0.359	0.500	0.680
4.	Predictive maintenance	0.160	0.180	0.632	0.189	0.693	0.632	0.632	0.189	0.180	0.167	0.408

Table 14. Values of f_{max} , f_{min} and $f_{max}-f_{min}$.

S.N.	Criteria											
	Parameter	Personal safety	Facilities safety	Environmental safety	Hardware cost	Software cost	Personnel training cost	Spare part inventories	Production loss	Fault identification	Acceptance by labor	Technique reliability
1.	f_{max}	0.801	0.898	0.632	0.189	0.139	0.316	0.316	0.189	0.898	0.833	0.680
2.	f_{min}	0.160	0.180	0.316	0.945	0.693	0.632	0.632	0.945	0.180	0.167	0.272
3.	$f_{max}-f_{min}$	0.641	0.718	0.316	0.756	0.555	0.316	0.316	0.756	0.718	0.667	0.408

Table 15. Values of S_i , R_i , and Q_i .

S.N.	Alternative	S_i	R_i	Q_i
1.	Breakdown maintenance	4.535412	2.752339	0.528186
2.	Time-based maintenance	1.898814	0.786083	0.5
3.	Condition-based maintenance	4.69292	1.441501	0.166667
4.	Predictive maintenance	2.912935	0.972285	0.365874

RESULTS AND DISCUSSION

This section discusses the results obtained and the discussions made about the research work, the details of which are presented in the upcoming sections.

Results

Table 16 shows the details of the rankings obtained for the different maintenance alternatives.

Table 16. Rankings of alternatives.

S.N.	Alternative	Qi	Ranking
1	Breakdown maintenance	0.528186	4
2	Time-based maintenance	0.5	3
3	Condition-based maintenance	0.166667	1
4	Predictive maintenance	0.365874	2

Discussion

Results of the research work show the suitability of condition-based maintenance for the firm, as it earns the rank 1. For rank 2, alternative predictive maintenance seems to be appropriate. Similarly, alternative time-based maintenance and breakdown maintenance were ranked 3 and 4, respectively.

Condition maintenance needs an in-depth analysis of the tools and equipment and repair activities as the fault is investigated. For this purpose, regular monitoring of tools and equipment is required. These activities need additional monitoring devices as well as skilled manpower, which gets added to the total cost of resources. On investigating the reasons behind the suitability of condition-based maintenance for the firm, the following points came into the picture.

- Type of machinery;
- High cost of machinery;
- Complexity of mechanisms used in machinery;
- High number of fragile parts in machinery;
- The high worth of orders; and
- Closer delivery dates.

Considering the above-mentioned facts, a condition-based maintenance strategy seems to be appropriate for the targeted firm.

For rank 2, alternative predictive maintenance appears. While dealing with this approach, predictions regarding the condition of the machine that requires maintenance are used as a basis for maintaining the system. Considering this type of maintenance, the following system limitations were observed.

- Semi-skilled or unskilled workers;
- Less efficient monitoring sensors;
- Lack of awareness of predictive; and
- High cost of predicting maintenance equipment as compared to condition-based maintenance equipment.

For rank 3, alternative time-based maintenance appeared. Periodic checks of machines are required when dealing with time-based maintenance. After discussions, with the employees of the firm, the following points, regarding the unsuitability of time-based maintenance, were recognized.

- Complexity of designs of machines;
- Uneven failure of tools and equipment due to uneven job designs; and
- Different demands for different types of products.

For rank 4, alternative breakdown maintenance appears, which is undesirable for the following reasons:

- Huge disturbances in delivery timings;
- Uneven nature of maintenance timings;
- Increase in in-process inventories; and
- Inappropriate quality products.

Considering the above discussion, one can analyze the reasons behind the selection of condition-based maintenance by the firm's personnel.

CONCLUSION, LIMITATIONS, AND FUTURE SCOPE OF THE RESEARCH

The present section is devoted to the conclusion of the research work, its limitations, and future scope, the details of which are presented in the upcoming sections.

Conclusion

The present study was conducted to select a maintenance strategy for a customized machine-making firm. In this study, four maintenance strategies are compared on the basis of eleven criteria taken from literature and expert opinion. The AHP-VIKOR method was used for the analysis. The results show that condition-based maintenance is ranked first, predictive maintenance second, time-based maintenance third, and breakdown maintenance fourth.

Based on these results, condition-based maintenance is the best option for the firm. The second option is predictive maintenance. Time-based maintenance is less suitable for this purpose. Breakdown maintenance is the least suitable for the firm.

Limitations and Future Scope of Research

The present study was limited to a selected set of criteria. Because of this, all factors are not covered. The study is also limited to a few approaches used to solve problems. Other methods are not considered, which may affect the results. Therefore, the study remains limited to the selected criteria and approaches only.

The future scope of the research is wide. More studies can be conducted by including more criteria to obtain better results. Different methods can also be used to solve the problem. Further work in this area can provide a better understanding and improved results in the future.

REFERENCES

1. Reddy, S. Srinivasa, T. Akhila, K. Siva Ganesh, S. Vamsi Krishna, M. Pavan Kali, and K. Sasidhar. "Maintenance Enhancement of Smart Manufacturing Units in Industry 4.0." In 2023 International Conference on Inventive Computation Technologies (ICICT), 1488-1492, IEEE, 2023.
2. Zenisek, Jan, Norbert Wild, and Josef Wolfartsberger. "Investigating the potential of smart manufacturing technologies." *Procedia computer science* 180, 507-516, (2021).
3. Runji, Joel Murithi, Yun-Ju Lee, and Chih-Hsing Chu. "Systematic literature review on augmented reality-based maintenance applications in manufacturing centered on operator needs." *International Journal of Precision Engineering and Manufacturing-Green Technology* 10, no. 2 567-585, (2023).
4. Chandrahas, Santosh Kumar Mishra, and Deepak Mahapatra. "Maintenance strategy and decision making-AHP method." *Int. J. Adv. Engg. Res. Studies/IV/II/Jan.-March* 256-258, (2015).
5. Linkov, I., Wenning, R. J., & Kiker, G. A. *Managing critical infrastructure risks*. Springer Science & Business Media, 445-469, Springer (2007).
6. Liao, Yongxin, Fernando Deschamps, Eduardo de Freitas Rocha Loures, and Luiz Felipe Pierin Ramos. "Past, present and future of Industry 4.0-a systematic literature review and research agenda proposal." *International Journal of Production Research* 55, no. 12, 3609-3629, (2017).
7. Kamble, Sachin S., Angappa Gunasekaran, and Shradha A. Gawankar. "Sustainable Industry 4.0 Framework A Systematic Literature review identifying the current trends and future perspectives." *Process safety and environmental protection*, 117, 408-425, (2018).
8. Piccarozzi, Michela, Barbara Aquilani, and Corrado Gatti. "Industry 4.0 in management studies A systematic literature review." *Sustainability* 10, no. 10, 3821(2018).
9. Mittal, Sameer, Muztoba Ahmad Khan, David Romero, and Thorsten Wuest. "Smart manufacturing Characteristics, technologies, and enabling factors." *Proceedings of the Institution of Mechanical Engineers, Part B Journal of Engineering Manufacture* 233, no. 5, 1342-1361(2019).
10. Kusiak, A. Smart manufacturing. *International Journal of Production Research*, 56(1-2),508-517, (2017).

11. Khan, Ibrahim Haleem, and Mohd Javaid. "Role of Internet of Things (IoT) in the adoption of Industry 4.0." *Journal of Industrial Integration and Management* 7, no. 04, 515-533(2022).
12. Shao, Xue-Feng, Wei Liu, Yi Li, Hassan Rauf Chaudhry, and Xiao-Guang Yue. "Multistage implementation framework for smart supply chain management under industry 4.0." *Technological Forecasting and Social Change* 162, 120-354(2021).
13. Kang, Hyoung Seok, Ju Yeon Lee, SangSu Choi, Hyun Kim, Jun Hee Park, Ji Yeon Son, Bo Hyun Kim, and Sang Do Noh. "Smart manufacturing Past research, present findings, and future directions." *International journal of precision engineering and manufacturing-green technology* 3, 111-128(2016).
14. Bertolini, Massimo, and Maurizio Bevilacqua. "A combined goal programming—AHP approach to maintenance selection problem." *Reliability Engineering & System Safety* 91, no. 7, 839-848(2006).
15. Bevilacqua, Maurizio, and Marcello Braglia. "The analytic hierarchy process applied to maintenance strategy selection." *Reliability Engineering & System Safety* 70, no. 1 71-83(2000).
16. Saaty, Thomas L. "Highlights and critical points in the theory and application of the analytic hierarchy process." *European Journal of Operational Research* 74, no. 3, 426-447(1994).
17. Saaty, T.L. *The Analytic Hierarchy Process*. McGraw Hill, New York, 1980.
18. Opricovic, Serafim. "Multicriteria optimization of civil engineering systems." *Faculty of Civil Engineering, Belgrade* 2, no. 1 5-21(1998).
19. Opricovic, Serafim, and Gwo-Hshiung Tzeng. "Compromise solution by MCDM methods A comparative analysis of VIKOR and TOPSIS." *European Journal of Operational Research* 156, no. 2 445-455(2004).