Selection of Maintenance Strategy using Hybrid AHP-VIKOR Approach for Industry 4.0 Applications

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Abstract
The present study centers on the selection of a maintenance approach for a smart manufacturing system in a manufacturing company, utilizing hybrid multi-criteria decision-making techniques. These options underwent assessment employing a hybrid AHP-VIKOR model. The findings of the study reveal that condition-based maintenance emerged as the most favorable alternative.

Keywords: Industry 4.0, smart manufacturing, maintenance, Analytic Hierarchy Process (AHP), Vlse Kriterijumska Optimizacija Kompromisno Resenje(VIKOR).

1 Introduction

In recent years, academics and manufacturing specialists have reportedly been focusing on the concept of "smart manufacturing," as stated by reference [1,2]. To adapt in real time to fluctuating customer needs, "smart manufacturing" defines a collaborative production infrastructure that is enabled by technological advancements. One of the problems it has is that it requires constant upkeep. Reference [3] state that even in the most advanced factories, maintenance is still an essential but challenging activity that has not been totally automated.

Every kind of industrial establishment may benefit greatly from a well-developed maintenance plan. The benefits and downsides of each approach to maintenance are different. The effectiveness of a machine is directly related to the maintenance methods used on it. Industrial machinery need regular servicing to prevent costly downtime and lost productivity. Machine to machine, maintenance strategies might differ due to competing priorities including security, cost, and user happiness. Machine performance factors should be identified and managed. The maintenance cost might rise if an unsuitable technique is used [4].

Considering all the above mentioned facts, present research work is devoted to selection of a maintenance strategy for a manufacturing firm. For the purpose of evaluation of alternative *multiple-criteria decision making* approaches are being adopted.. While dealing with MCDM, alternatives are compared on the basis of different criteria, which ultimately characterize the goal [5]. In present research work, the use of VIKOR has been proposed for evaluation of alternatives. For the purpose of evaluation of criteria, a prioritization technique, Analytical Hierarchy Process (AHP) is used.

1.1 Objectives of Research

Following are the objectives of present research work:

(a) Identification of set of evaluation criteria for the purpose of evaluation;
(b) Evaluation of different alternatives; and
(c) Identification of optimum maintenance strategy for the firm.

2. Literature Review

Following are the details of research contributions along with the gaps of research.

2.1 Research contributions in the field of Maintenance Strategies

The present section is based on the contribution of different researchers in the field of industry 4.0, smart manufacturing and maintenance strategy selection, presented as follows:

In recent times, there has been a burgeoning global fascination with the Fourth Industrial Revolution, as detailed in citation [6]. Nevertheless, a dearth of comprehensive reviews exists in the current literature concerning the contemporary status of this transformative phase in industrial development [7, 8].

According to reference [9], the concept of "smart manufacturing" was first developed in the United States and has since spread throughout the world. Smart manufacturing, as described by reference [10], dates back to the second part of the twentieth century. From basic digitalization to computer integrated manufacturing with the support of the Internet of Things and other technologies, the notion of smart manufacturing has come a long way in the previous three decades. According to reference [11], IoT is a manufacturing technology that increases efficiency and quality. With the use of IoT, a smart factory may be built out of 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 larger sense, "smart manufacturing" might 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 by reference [12], concentrated on the many technologies already in use in the industrial sector. New studies in this field, however, go far further by covering such topics as strategy, design, production, human resources, and more. Through the use of tools like simulation and big data, smart manufacturing is able to carry out duties like global monitoring and performance optimisation. 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 by reference [13].

Using cost, safety, value added services, and equipment and technology as factors, reference [4] explore the issue of choosing the best maintenance plan. Reference [14] study work seeks to identify the most effective approaches of 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 between preventative, condition-based, corrective, and opportunistic maintenance for a given plant, with the former focusing on the occurrence, severity, and detectability of maintenance problems.

2.2 Gaps in the Research

During the review of literature, it was found that very few research papers were focused on the selection of maintenance of strategies based on multi criteria decision making approaches.

3 Solution Methodology

Present section is devoted to the solution techniques used to solve the research problem:

3.1 Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) is one of the popular techniques used for suggesting the complex decisions. During the process, based on pairwise comparison principle, a goal gets converted into different criteria and alternatives get tested on them. [16].

3.1.1 General Procedure of AHP

The initial stage of the analytic hierarchy process involves structuring the problem into a hierarchical model. During this phase, individuals analyze different facets of the problem, progressing from broad to specific levels, and subsequently represent it in the multilayered format mandated by the AHP methodology, as shown by Figure 1.

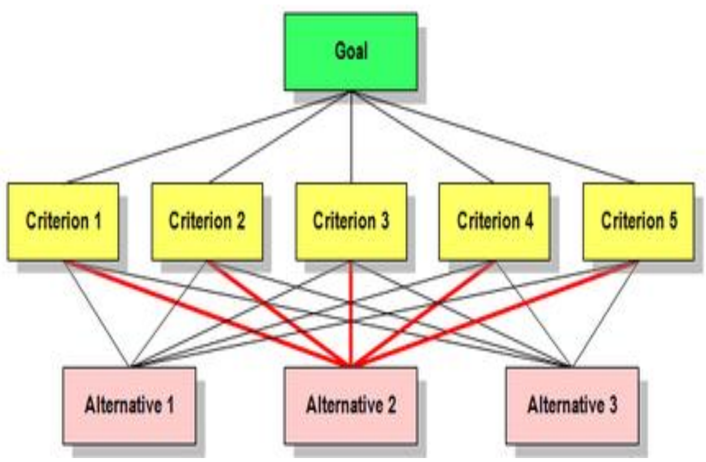

Fig. 1. General AHP Hierarchy Structure [17].

After constructing the hierarchy, AHP enables the determination of priorities for all its components. This involves gathering input from participants and applying mathematical processing to the information.

3.2 VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR)

VIKOR translates to "multi-criteria optimisation and compromise solution" in Serbian, is the acronym for VIKOR. Opricovic created it back in 1998. The focus of this strategy is on evaluating and choosing the best option out of many that have competing criteria [18]. These indices are based on a specific assessment of how near a solution is to the ideal. VIKOR uses Lp-matric which is calculated as follows[19].

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

$$1 \le p \le \infty, \qquad j = 1, 2, 3, \ldots\ldots\ldots\ldots J \quad (2)$$

4 Case Study

The current research focuses on exploring the selection of the most suitable maintenance strategy for a company involved in smart manufacturing. Multi-criteria decision-making techniques are employed for this investigation. Initially, a model for multi-criteria decision-making was formulated, followed by the derivation of its solution, which will be elaborated on in the subsequent sections.

4.1 Problem Formulation

The research was accomplished in a customized machine manufacturing firm. The firm produces customized machines and lab equipment of prime quality. Due to versatile nature of items it produces via smart manufacturing practices, the management of the firm wanted to choose a successful maintenance strategy, due to which present research work came into picture. The initial stage in integrating research tools into the case problem involved formulating the problem. Assistance was sought from industry personnel and academics to compile a list of criteria, which are outlined below.

Table 1. List of Criteria for Model Formulation

S.No	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

Regarding alternatives, again with the help of industry personnel and academicians was taken and maintenance types, *breakdown maintenance, time based maintenance, condition based maintenance, and predictive maintenance* were chosen as alternatives. Based on available criteria and alternatives, a MCDM model was developed, the details of which are as presented as follows.

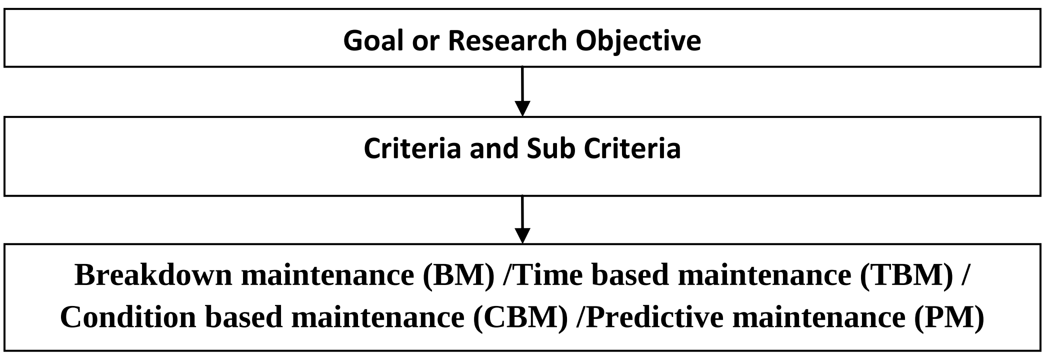

Fig. 2. Model Formulation for Research Problem

4.2 Solution of the Model

Details of procedure adopted for solution of the model are as follows:

a) First of all, weights of criteria were identified with the help of 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 pair wise comparison scale. The responses were, then, fed to AHP-CGI software. Following are the details of responses as well as weights of criteria as well as sub-criteria.

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	¼	1	1
Feasibility	1/7	1/4	1	1

Table 3. Weights of Criteria

S.No	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	/3	4	1

Table 5. Weights of Sub Criteria under Criteria 'Safety'

S.No	Criteria	Weights	
		Local Priorities	Global Priorities
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.No	Criteria	Weights	
		Local Priorities	Local Priorities
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.No	Criteria	Weights	
		Local Priorities	Local Priorities
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.No	Criteria	Weights	
		Local Priorities	Local Priorities
1.	Acceptance by labor	0.5	0.03455
2.	Technique reliability	0.5	0.03455
	CR = CI/RI = 0		

b) In next step scores of different alternatives were investigated with the help of VIKOR process. Following are the details of results obtained during VIKOR calculations.

Table 12. Values of X_{ij}

S.No	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.	BM	5	5	1	1	1	1	2	5	5	5	2
2.	TBM	2	1	1	1	1	1	1	1	1	1	4
3.	CBM	3	2	2	5	5	2	1	1	2	3	5
4.	PM	1	1	2	1	5	2	2	1	1	1	3

Table 13. Values of f_{ij}

S.No	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.	BM	0.801	0.898	0.316	0.189	0.139	0.316	0.632	0.945	0.898	0.833	0.272
2.	TBM	0.320	0.180	0.316	0.189	0.139	0.316	0.316	0.189	0.180	0.167	0.544
3.	CBM	0.480	0.359	0.632	0.945	0.693	0.632	0.316	0.189	0.359	0.500	0.680

4.	PM	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 fmax, fmin and fmax-fmin

S.No	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.	**fmax**	0.801	0.898	0.632	0.189	0.139	0.316	0.316	0.189	0.898	0.833	0.680
2.	**fmin**	0.160	0.180	0.316	0.945	0.693	0.632	0.632	0.945	0.180	0.167	0.272
3.	**fmax-fmin**	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 Si, Ri and Qi

S.No	**Alternative**	**Si**	**Ri**	**Qi**
1.	BM	4.535412	2.752339	0.528186
2.	TBM	1.898814	0.786083	0.5
3.	CBM	4.69292	1.441501	0.166667
4.	PM	2.912935	0.972285	0.365874

5 Results and Discussion

Following are the details of obtained and their discussion.

5.1 Results

Table 5.1 shows the details of rankings obtained by different maintenance alternatives.

Table 16. Rankings of Alternatives

S.No	Alternative	Qi	Ranking
1.	BM	0.528186	4
2.	TBM	0.5	3
3.	CBM	0.166667	1
4.	PM	0.365874	2

5.2 Discussion

Results of the research work show the suitability of CBM for the firm, as it earns the rank 1. For rank 2, alternative PM seems to be appropriate. In the similar manner, alternatives TBM and BM earn ranks 3 and 4, respectively.

CBM needs in depth analysis of the tools and equipment and repair activities as fault is investigated. For this purpose, a regular watch on the tools and equipment is needed. These activities need additional monitoring devices as well as skilled man power, which gets added in the total cost of resources. On investigating the reasons behind suitability of condition based maintenance for the firm, following points came into picture.

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

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

For rank 2, alternative PM appears. While dealing with this approach, prediction regarding the condition of machine which needs maintenance is used as a basis of maintaining the system. Considering this types of maintenance, following in-capabilities in the system were observed.

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

For rank 3, alternative TBM appeared. While dealing with time based maintenance, periodic checks of machines are needed. After discussions, with the employees of the firm, following points, regarding 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 BM appears which is undesired by responses due to following reasons.

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

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

6.1 Conclusion of the Research Work

Present research work is devoted to the maintenance strategy for a customized machine making firm. In the research work, there are *four* maintenance strategies which are evaluated on the basis of *eleven* criteria obtained through survey of literature and expert opinion. For the purpose of evaluation hybrid AHP-VIKOR approach is being used. Following are conclusions of the research work.

Table 17. Conclusion of the Research Work

S.No	Maintenance type	Ranking
1.	BM	4
2.	TBM	3
3.	CBM	1
4.	PM	2

On the basis of Table 17, one can find that *CBM* can be treated as *best maintenance strategy* for the firm, and alternative *BM* may be considered as the most undesired maintenance strategy for the firm. Based on the above results, following conclusions may be drawn:

1. Best maintenance strategy for the firm: CBM;
2. Second best maintenance strategy for the firm: PM; and
3. Most undesirable maintenance strategy for the firm: BM.

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