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Identification of Critical Components using ANP for Implementation of Reliability Centered Maintenance

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Abstract

Identification of critical components and their prioritization for implementation of maintenance is an important task in industry. It is also one of the essential step of reliability-centered maintenance. In this paper, an attempt made is being made to find out the key factors associated with the criticality of components. Five major criteria affecting criticality of components i.e. cost, functional dependency, complexity, maintainability, and safety impact were proposed for criticality analysis. In addition, to identify the critical components a hierarchical network is proposed based on analytic network process. The proposed methodology evaluated with a case study on CNC lathe machine. This study can provide a realistic solution to decision-making problems for maintenance planning in prioritizing the critical component for reliability-centered maintenance.

Keywords: RCM; Critical component; ANP; CNC Lathe

1. Introduction

In present scenario, the role of maintenance is changing as the manufacturing is undergoing a paradigm shift towards realizing a sustainable society. The goal of manufacturing is no longer to produce products in an efficient way, but also to provide the functions needed by society. Product lifecycle management is becoming a critical issue in order to achieve this goal. In this context, the role of maintenance is redefined as an essential means for lifecycle management. Maintenance is a long-term strategic planning, which integrates all the phases of a product lifecycle, includes and anticipates changes in social, environmental, economic trends, and require benefits from innovative technologies. Recently, Reliability-centered maintenance (RCM) is basically found to be the most efficient strategy in comparison with the existing supervision of maintenance strategies [1]. RCM is a systematic process for development and optimization of the maintenance requirements of a physical resource in its operating context. This is achieved by realizing resource's inherent reliability by logically incorporating the maintenance strategies like reactive, preventive, condition-based and proactive maintenance. RCM develops a cost-effective method to intentionally manage the maintenance procedures from a reliability point of view [2]. RCM process includes five basic stages. The first stage is the selection of system and subsystem. The second and crucial stage in RCM is the identification of critical component, which has a considerable influence on system reliability. The third stage is failure mode and effect analysis (FMEA) of critical components, which helps in preventing the critical failure causes. Then follows the optimal maintenance strategy selection (stage 4) which precedes a cost analysis in the final stage. Also, RCM provides a proper framework for management of the complexity of the maintenance issues by complementing all the traditional strategies [3]. Therefore, it would seem rather logical to have the operators focus their priorities on some critical components to avoid missing the possible opportunities for cost-effective decisions. Only then, it is possible to focus and allocate our resources effectively and

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efficiently to make our actions as useful as possible. To meet this challenge, in the essential step of RCM, it would be of great value to prioritize the equipment by finding the most critical component to apply the maintenance strategies in a more efficient manner. Most of the research in literature focuses on the identification of the critical failure modes of the components using FMECA, but a little work has been done on how to identify the critical component of the system. Birnbaum [4] was the first to measure the importance of a component in a structural manner for the coherent system, which evaluates the "criticality" of a component. Barlow [5] and Boland [6] have studied the structural importance of the components of a system. The component criticality analysis is extremely important for the system, where the failure of any critical component leads to failure of the entire system. A component is said to be critical if the failure of that component has serious consequences [7]. Carot [8] has studied the criticality analysis of each component for a non-repairable systems. Dehghanian [3] presented a methodology for critical component identification of a power distribution system using fuzzy AHP approach. Elyasi-Komari [9] presented criticality analysis for a computer network system using FMECA. Ye and Kelly [10] presented a methodology for criticality analysis to assess the failure impact of software components with respect to system safety. Silvestri [11] proposed a total risk priority index (TRPN) using analytic network process (ANP) to improve the FMECA process for manufacturing systems.

From the above literature, it is clear that the analysis for identification of critical components of a system based on the criteria related to the criticality of the system is available mainly for power distribution networks, computer network systems, and software systems so far. However, The RCM implementation is not limited to these areas only. It needs to implemented in the manufacturing sector also, as the complexity of manufacturing machines is increasing due to automation. Therefore, an attempt has been made to find out the key factors associated with criticality and identification of critical components in the manufacturing sector (for CNC lathe machine) using ANP.

2. Analytic Network Process (ANP)

The identification of critical components of a system is a multi-criteria decision-making problem since it involves various criteria and sub-criteria. The ANP was proposed by Saaty [12]. ANP used to solve the hierarchical problems, which are having inner/outer dependencies, influences between and within clusters (criteria, sub-criteria, and alternatives). In the ANP technique, three types of matrices (unweighted supermatrix, weighted supermatrix, and limit matrix) required for further analysis. Since its introduction, ANP is widely used in decision-making problems like selection of best maintenance strategy [13–16], supplier selection [17,18], Strength, Weakness, Opportunity and Threats (SWOT) analysis [19], R&D Project selection [20,21], forecasting models for financial crisis[22], evaluation of advanced technologies [23], modelling of risk-based maintenance [24] in literature. This study proposed a model by using ANP for identification of a critical component of a CNC lathe machine based on various criteria, sub-criteria and alternatives.

3. Methodology and Case Study

The process of criticality analysis by ANP described in the following steps and the results establish its effectiveness.

3.1. Description of the CNC lathe machine

In order to examine the applicability of the proposed methodology, CNC lathe machine which is part of the manufacturing system is considered as a test system and 11 subsystems of CNC lathe machine similar to [25] are identified and shown in Table 1 by using preliminary elimination for increasing the quality of the decision.

Table 1: Alternative/components defined for test system

Alternatives / components	Name of the Alternative/component
A1	Turret
A2	Clamping Accessory
A3	Electric and Electronics system
A4	Main transmission
A5	X feed system
A6	Z feed system
A7	CNC system
A8	Hydraulic system
A9	Servo system
A10	Cooling system
A11	Spindle assembly

3.2 Determining the important criteria affecting the criticality

In this stage, a number of meetings and interviews were conducted with the maintenance engineers and managers of various manufacturing organizations to determine the criteria and sub-criteria for the selection of critical components in order to define the criticality of a component/system. Based on the feedback received from experts a total of 15 sub-criteria are determined under the below mentioned five major criteria clusters: (1) Cost (2) Functional dependencies (3) Complexity (4) Maintainability and (5) Safety impact for the proposed criticality analysis model. All the criteria, sub-criteria, and alternatives were given a specific code number which is shown in Table 2. The definitions of these major criteria from criticality point of view are described in the following subsections.

3.2.1 Cost

The consideration of economic aspects of a component is the major factor in its criticality. The total cost of a component with respect to maintenance in the manufacturing industry includes (a) maintenance cost (b) component investment cost and (c) cost of production loss. In comparison to other components, if a component has a higher maintenance cost then it needs to be assigned a higher criticality value. Maintenance cost directly affects the availability of resources of repair and complexity of the component. Cost of production also directly depends on total downtime of the system, which is controlled by the availability of resources to repair. Next, to maintenance cost, cost of production loss and component investment cost are assigned criticality values respectively.

3.2.2 Functional dependencies

According to these criteria, the functional dependence of a component in terms of process and their design is one of the main factors in finding a critical component of a system. The design of a component has its significant contribution in the system reliability indices. If a component is having the leading role in the system but if the design of the component is not reliable, then that particular component was assigned to be more critical from a design point of view.

3.2.3 Complexity

To ensure the smooth operation of a manufacturing system, the complexity of the component is of a great concern. This criterion is divided into three sub-criterion as the probability of failure, total no. of parts and their failure effect on the system. Component multiplicity will play an important role in finding out the critical component. A module, which is having a large number of parts, will have a significant contribution in the overall system reliability. In addition, at the same time, the failure frequency and their effect on the system will affect the system availability. A component with large no. of parts and high failure probability is much more critical to maintain.

3.2.4 Maintainability

The fourth criterion is maintainability. Maintainability is also having a significant role in identifying the critical component of a manufacturing system. This criterion further classified into four sub-criteria as the availability of technical specification, failure detection, total downtime and facility required to repair. The repair process of some components can sometimes take a long time resulting in large downtimes of the system. In some cases, specific failures are difficult to detect because of less availability of technical specification. In such cases, when a failure occurs, the time to repair will considerably increase and will be difficult to maintain the entire system up to the desired level of functioning. Hence, the component having the large downtime assigned to be more critical.

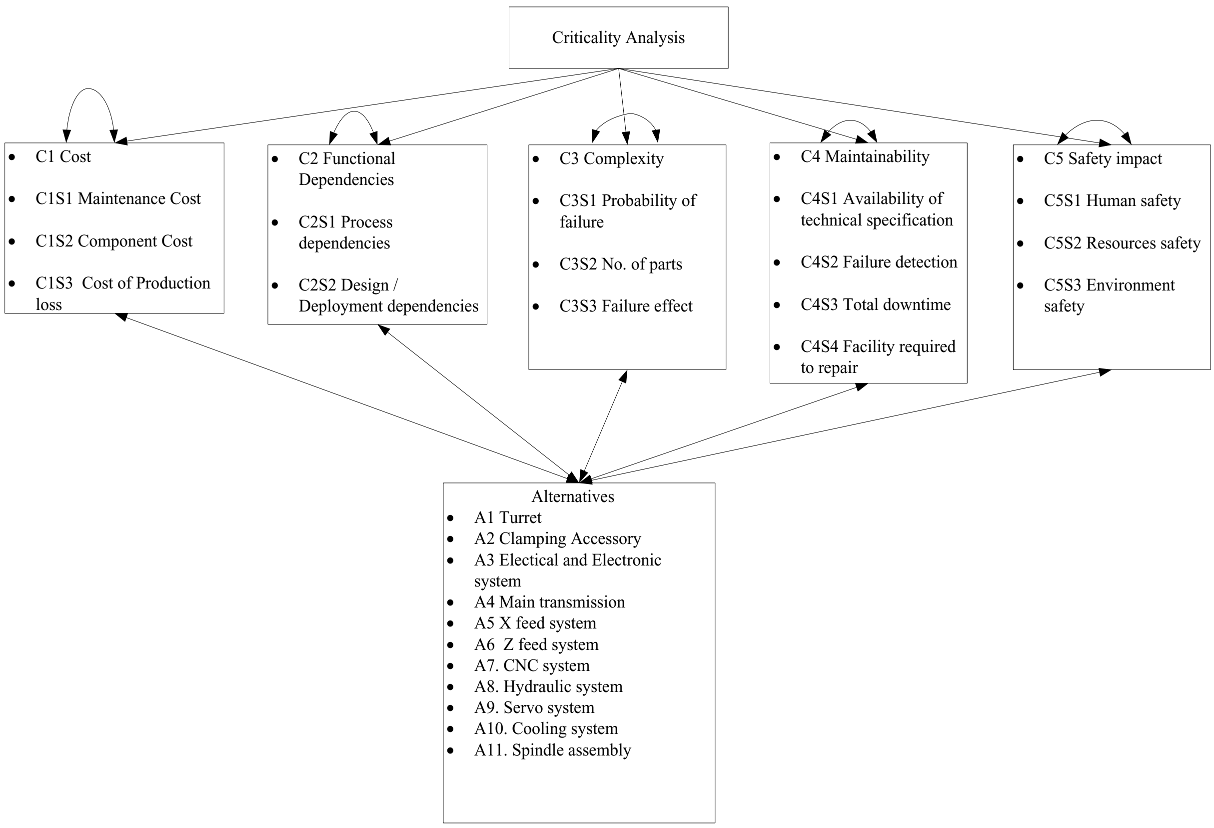

Fig. 1. The decision-making network for identifying critical component

3.2.5 Safety impact

While identifying the critical component of any system, safety impact is of great concern. This criterion is classified into three sub-criteria, human safety, resources safety, and environment safety. In case of a manufacturing system, human and resource safety have significant roles while environment safety also needs to be considered because of cooling systems. The increasing requirements of maintenance in the unproductive use phase of the product lifecycle of manufacturing systems produce a significant impact on the environment as the defective parts; used oils, grease and cleaning agents are discarding into the environment. If any accidents happen during any process, it will directly affect the human beings. Hence, the safety factor considered, while performing the criticality analysis of any system.

Table 2: Criteria and sub-criteria defined to prioritize the components

No.	Major Criteria	Sub Criteria
C1	Cost	• C1S1 Maintenance Cost • C1S2 Component cost • C1S3 Cost of production loss
C2	Functional dependencies	• C2S1 Process dependency • C2S2 Design dependency
C3	Complexity	• C3S1 Probability of failure • C3S2 Total no. of parts • C3S3 Failure effect
C4	Maintainability	• C4S1 Availability of technical specification • C4S2 Failure detection • C4S3 Total downtime • C4S4 Facility required to repair
C5	Safety Impact	• C5S1 Human safety • C5S2 Resources safety • C5S3 Environment safety

3.3. Designing the network of decision

In this step, the interactions between and within clusters and their elements are determined based on interdependencies among each other. To determine the interdependencies, an input-output analysis was made. To do this, Interviews with the same experts were conducted. Based on the input-output analysis, the proposed criticality analysis network model is shown in Fig. 1.

3.4 Determining the unweighted, weighted supermatrix

In this stage, considering the input-output analysis and decision network, a questionnaire was designed to derive pairwise comparison judgments. The comparison or unweighted matrix among the elements was integrated after the responses in questionnaire. In the last part of the questionnaires, some questions asked to find out the impact of the clusters on each other. The matrix is composed of several sub-matrices in which each column of each block is a vector indicating the impact of the elements of the left side corresponding cluster on the elements at the top of the unweighted supermatrix. To have a stochastic supermatrix, clusters should be compared with each other. The resulting priorities of the clusters used to weight the corresponding blocks. This led to the final comparison matrices to achieve the ratio scale vectors. The results of obtained final comparison matrices and the ratio scale vectors shown in Table 3. After that, the final weighted supermatrix was determined by multiplication of Table 3 elements of their corresponding block in the unweighted supermatrix.

Table 3: The weight of blocks of decision network in decision making for criticality analysis

	Goal	C1	C2	C3	C4	C5
Goal	0	0	0	0	0	0
C1	0.1747	0.0001	0	0	0	0
C2	0.2912	0	0.0909	0	0	0
C3	0.1941	0	0	0.0909	0	0
C4	0.2427	0	0	0	0.0909	0
C5	0.0970	0	0	0	0	0.0001
Alternatives	0	0.9999	0.9090	0.9090	0.9090	0.9999

3.5 Calculating the final weights of the alternatives and the criteria

In this step, the powers of weighted supermatrix were calculated to help in obtaining the limit supermatrix. After 15th iteration (15th power), the limit supermatrix is obtained. Each column of the limit supermatrix determines the final ratio scale priority or weight of elements in the network. Table 4 presents the final weight / ratio scale priority of each element and cluster. In this table, the cluster's ratio scale priority was calculated as equal to the sum of its elements' ratio scale priority. The ratio scale priorities of the elements within their clusters were calculated by normalizing their ratio scale priority in the related cluster. The comparison of the final weights of all alternatives is shown graphically also in Fig. 2. The unweighted, weighted and limit super matrix are available at [26].

Table 4: The relative importance of clusters and elements

Clusters	Elements	Ratio scale priority in the network (1)	Ration scale priority of clusters (2)	Ratio scale priority of elements in their cluster (3)= (1)/(2)
Cost	C1S1	0.030824	0.083248	0.370267
	C1S2	0.016874		0.202696
	C1S3	0.03555		0.427037
Functional dependencies	C2S1	0.071276	0.152607	0.467056
	C2S2	0.081331		0.532944
Complexity	C3S1	0.018106	0.103772	0.174479
	C3S2	0.044634		0.430116
	C3S3	0.041032		0.395405
Maintainability	C4S1	0.007664	0.122085	0.062776
	C4S2	0.036067		0.295425
	C4S3	0.062524		0.512135
	C4S4	0.01583		0.129664
Safety Impact	C5S1	0.015035	0.055498	0.270911
	C5S2	0.031458		0.566831
	C5S3	0.009005		0.162258
Alternatives	A1	0.088643	0.482787	0.183607
	A2	0.056359		0.116737
	A3	0.030017		0.062174
	A4	0.035369		0.07326
	A5	0.033667		0.069735
	A6	0.038063		0.07884
	A7	0.032003		0.066288
	A8	0.027365		0.056681
	A9	0.045023		0.093256
	A10	0.05943		0.123098
	A11	0.036848		0.076324

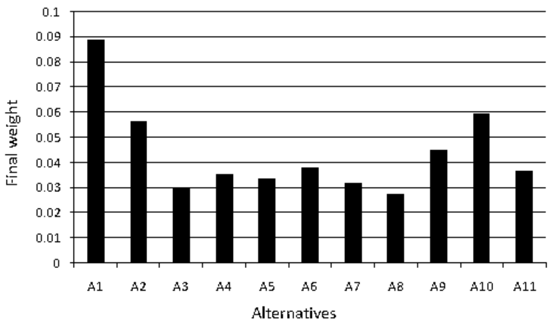

Fig. 2. Comparison of final weights of alternatives

4. Results

This study indicates that the functional dependencies cluster has the most precedence among all criteria clusters in decision-making and within this cluster; the design dependency of each alternative has the most precedence in decision-making. The maintainability of each alternative has the second most precedence in decision-making within which the total downtime of each alternative has the most precedence in decision-making. The limit supermatrix shows that turret is the most critical and hydraulic system is the least critical component of a CNC lathe machine. However, these results were validated based on the method used and interdependency of selected criteria only. There may be a possibility of variation in results if the criteria and their interdependency will changes.

5. Summary and conclusion

Identification of critical components and their prioritization of maintenance activities is the essential step for the implementation of RCM. RCM provides a proper framework for management of the complexity of the maintenance issues by complementing all the traditional strategies[3]. In this paper, identification of critical components considered as a multi-criteria decision problem and a hierarchical network was developed by using Analytic Network Process (ANP). The evaluation criteria and sub-criteria proposed based on component- type criticality and importance of decision making for maintenance. The proposed network was tested using a case study on a CNC lathe machine. This study removes the ambiguity and uncertainty of pair-wise comparisons in Analytic Hierarchy Process (AHP). This will provide a realistic solution to decision-making problems for maintenance planning in prioritizing the critical component for RCM procedure. It can be concluded that the "turret" is the most critical and the "hydraulic system" is the least critical component of a CNC lathe machine. In addition, the functional dependencies are the most precedence among all criteria in decision-making and within this cluster, the design dependency of each alternative has the most precedence in decision-making. The maintainability of each alternative has the second most precedence in decision-making within which the total downtime of each alternative has the most precedence in decision-making.

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