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# Machine and Equipment Classification as a Foundation for Maintenance Methods: A Qualitative Approach*

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## Abstract

Maintenance teams ensure reliable machinery operation to maintain productivity and quality, while growing data availability supports analysis and informed decision-making, aided by machinery classification. The aim of this article is to define a classification of criteria based on the source of data, enabling the determination of the value of each criterion used in the analysis, and to propose a method for calculating a value representing the criticality of an object. Criticality analysis identifies key system components and prioritizes maintenance activities. A review of the literature reveals various classifications used to distinguish criteria applied in criticality analysis. However, there is a noticeable lack of categorization of these criteria based on the source of the data. To address this gap, a qualitative research method was used, allowing for an in-depth understanding of the analyzed phenomenon through a literature review and participant observation. On this basis, a new criteria classification was defined which takes data sources into account, providing a foundation for conducting a two-dimensional analysis and enabling a more comprehensive assessment of criticality.

**Keywords**: maintenance, MCDA, FMEA, asset management, BPM

## Introduction

Modern maintenance methods have their roots in the Lean Management approach, which focuses on eliminating waste and maximising the efficiency of production processes. Machine classification in modern maintenance management is typically based on multi-criteria analysis, which allows equipment to be assessed not only through a single factor but across a set of interrelated parameters. This approach enables more accurate decision-making regarding operation, maintenance, and investment, as it simultaneously considers technical, organisational, and economic aspects. One of the most commonly used approaches in multi-criteria analysis involves methods focusing on machine and equipment failures, particularly those based on FMEA (Failure Modes, Effects and Analysis). This method enables the identification of potential failure modes, the determination of their causes, and the assessment of their effects on system operation. In practice, FMEA is often extended to include additional criteria, such as repair costs, downtime, or the difficulty of performing maintenance activities. Fattah et al. (2020) incorporate the severity of each failure mode into this model instead of using the Risk Priority Number (RPN). In addition to the three standard risk factors - probability of occurrence (O), severity (S), and detectability (D), three additional criteria are introduced. Furthermore, the proposed model accounts for both the weights of these criteria and the priority weights of decision-makers, calculated using modified methods described in the study. Similarly, Liou et al. (2024) propose an FMEA-based method integrated with an economic risk factor. Extending FMEA methods with additional parameters enables a more comprehensive analysis and better reflects actual operating conditions within an enterprise, thereby supporting the prioritisation of maintenance activities and the optimisation of resources. Another important aspect of multi-criteria analysis is the classification of machines according to their critical importance to

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organisational operations. In this context, equipment is evaluated in terms of its impact on production continuity and the potential consequences of failure. This type of analysis typically considers the machine's technical condition, risk of damage, occupational safety aspects, as well as economic consequences resulting from downtime or replacement requirements. Rodkumnerd et al. (2026) propose a weighted multi-criteria analysis of assets to support maintenance prioritisation. Each asset is evaluated across two dimensions, technical condition and operational impact, based on indicators derived from the literature and expert judgement. Jamshidi et al. developed a three-stage approach to criticality analysis. The first stage is based on a fuzzy FMEA incorporating multiple risk factors. In the second stage, seven dimensions are considered, including usage-related hazards, age, and utilisation, to comprehensively assess risks in the prioritisation of medical devices. Finally, the third stage introduces a simple method for selecting the most appropriate maintenance strategy for each device, based on the results obtained in the earlier stages. Such classifications are particularly useful in maintenance planning, as they help identify which machines require the most urgent attention and where financial and technical resources should be allocated. As a result, organisations can manage risk more effectively, minimise losses, and enhance the reliability of the entire production system.

## Methodology

A qualitative research approach was applied, enabling an in-depth understanding of the phenomenon under analysis and capturing its context and underlying conditions. This approach allows not only for the identification of key relationships but also for the interpretation of processes occurring within the organisation or community under study. The first stage of the research involved an analysis of the available literature on the subject. Based on this review, criteria used in criticality analyses were identified. Particular attention was paid to identifying the research gap. The second stage of the research was based on direct observation, which is one of the key techniques of qualitative research (Mroczko, 2014). This method involves the researcher engaging in the life of the community under study and functioning as a participant for a specified period. It enables the observation of phenomena "from the inside", that is, from the perspective of the individuals who constitute the group. Such an approach allows for the capture of natural behaviors, relationships, and mechanisms that often remain unobservable when external methods are applied. In the conducted study, the researcher was a member of the observed group and thus acted as a participant-observer. The use of this method provided access to contextual information, informal practices, and actual decision-making processes. At the same time, it required maintaining an appropriate level of self-reflection and awareness of the researcher's own influence on the studied environment in order to minimise potential bias. The combination of literature review and direct observation provided a complementary perspective on the phenomenon under study, linking theoretical insights with practical understanding of the functioning of the analysed community.

## Criteria Characteristics

In the relevant literature, criteria for assessing facilities are most often categorised according to their origin, such as risk and safety, reliability, or impact on production. This categorisation helps to structure the analysis and focus on key aspects of a facility's operation. At the same time, an important yet often overlooked element is the source of data used to determine the values of individual criteria. There is a gap in the available literature, as it does not explicitly emphasise the need to consider this aspect, nor does it propose a classification of criteria based on data source. However, the origin of the data has a direct impact on the objectivity of the assessment of the facility under analysis. Data based on subjective judgement may vary depending on the expert's experience and perspective, whereas system-generated data is characterised by greater repeatability and measurability. Consequently, it is reasonable to propose an alternative classification of criteria into expert and independent criteria. Expert criteria are those whose values are determined based on the knowledge and experience of specialists in a given field. For example, safety experts define the values of criteria related to accident risks and hazards, while controlling specialists assess financial aspects. Such criteria allow for the inclusion of factors that are difficult to measure unambiguously but remain significant from the perspective of organisational operations. Independent criteria, on the other hand, are based on data obtained directly from IT systems, such as MES, ERP, or CMMS. Their values are derived from actual operational records, which increases their objectivity and reliability. In this case, appropriate scaling of source data can also be applied to ensure comparability and enable their use in multi-criteria analyses. The proposed classification complements existing approaches and allows for a more informed and transparent use of data in the assessment process, combining both expert judgement and objective system data.

Based on the available literature and observations, the following criteria used in criticality analyses have been identified:

**Criteria related to user and environmental safety** (Liou et al., 2024; Akogwu et al., 2024):

- Severity of consequences,
- Environmental impact,
- Risk to users.

**Criteria related to reliability** (Rodkumnerd et al., 2026; Jamshidi et al., 2015):

- Probability of failure,
- Reliability index,
- Failure duration,
- Failure frequency.

**Criteria related to economic aspects** (Lo et al., 2021; Das et al., 2021):

- Cost of downtime due to failure,
- Maintenance costs,
- Losses resulting from failure.

**Criteria related to the impact on production** (Das et al., 2021; Jasiulewicz-Kaczmarek et al., 2021):

- Production load,
- Planned production time.

**Criteria related to maintenance** (Chakhrit et al., 2024; Das et al., 2021):

- Mean time repair,
- Machine complexity,
- Required tools,
- Maintenance authorisation.

Based on the data origin, the criteria can be divided as follows:

**Table 1: Classification of criteria by data origin**

| Expert criteria | Non-dependent criteria |
| --- | --- |
| • Machine complexity level<br>• Required tools<br>• Severity of consequences<br>• Environmental impact<br>• Risk to users<br>• Probability of failure | • Mean repair time<br>• Authorization to perform maintenance<br>• Downtime cost due to failure<br>• Maintenance cost<br>• Losses resulting from failure<br>• Production load<br>• Scheduled production time<br>• Reliability indicator<br>• Failure duration |

| | |
|---|---|
| | • Failure frequency |

*Source: Authors' own elaboration*

## Discussion and Conclusions

A key advantage of the proposed approach to machine classification is the ability to clearly distinguish between criteria over which the team has direct influence and those beyond its control. This distinction enhances the usefulness of the analysis from a management and decision-making perspective. Furthermore, the proposed concept does not require the assignment of weights to individual criteria, which simplifies the analytical process and reduces the subjectivity of the results. Criticality analysis should be treated as a cyclical process, conducted at regular intervals, allowing for the continuous adaptation of activities to changing operational conditions. Its results provide a basis for determining the scope and priorities of activities carried out by maintenance teams, thereby supporting effective resource and risk management. At the same time, subsequent iterations of the analysis should take into account the status of tasks defined in earlier stages, enabling the assessment of the effectiveness of implemented actions and ensuring continuous process improvement. Research in this area is ongoing. The approach presented is preliminary in nature and serves as a foundation for further investigation. In the next stage, it is planned to develop a two-dimensional multi-criteria analysis based on real-world data, which will enable the evaluation of the practical usefulness of the proposed classification and its applicability under real operating conditions. The article also provides a basis for conducting a comprehensive analysis of business processes. In this context, it is worth undertaking a detailed evaluation not only of the criteria themselves but also of the grouping of criteria assigned to individual classes, as well as the approach adopted for monitoring the progress of specific tasks. Such a broader perspective enables a more comprehensive understanding of organisational functioning and facilitates the identification of areas requiring optimisation.

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