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Industrial maintenance decision-making: A systematic literature review

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A R T I C L E   I N F O

A B S T R A C T

The increasing competition among industries has leveraged the emergence of various tools and methods for maintenance decision-making support. This paper identifies in literature the application areas of industrial maintenance decision-making, the relationships between these areas and the ways in which authors integrate tools and methods. This information makes it possible to identify trends and deficiencies in this context, helping to centralize the efforts required for future work. This work follows a series of structured steps for a systematic literature review of papers related to the main topic available in online databases. The selected papers are subject to a content assessment and grouped according to the application areas. The direct comparison between these areas and the construction of a relational matrix provide a quantitative interpretation of the results and well-structured information. Additionally, this paper proposes a framework based on information from the literature, which summarizes the origin and flow of information used in the development of models, showing the relationship among application areas of decision making. The research undertaken identifies trends focused on joint production systems optimization and increasing the deployment of methods for autonomous equipment predictions.

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1. Introduction

The competitiveness of organizations requires good maintenance planning. Appropriate management provides greater reliability and uptime for equipment, considerably reducing losses in production processes. Bardey [1] states that the effectiveness of maintenance is directly linked to good planning of the intervention intervals and often the managers make decisions with inadequate criteria. Cavalcante and Almeida [2] state that a multitude of models for decision-making provides conflicting and poor results, which suggests the need for further exploring the concepts in this universe.

To clarify these concepts and provide better understanding of decision-making in industrial maintenance, understanding the elements involved in this process is necessary. To this end, one of the fundamentals is the *Decision Theory* of Almeida and Bohoris [3], which consists in eight basic elements: *Conditions and basic laws* that govern a particular problem and are in reference to its natural state over which the decision maker has no control; *Set of possible actions* among which decision makers can select a course of action; *The consequence*, called the result according to the decision-making process in question; *Function of loss and utility*, quantifies losses or gains for each result; *Multi-attribute utility theory* (MAUT), related to multi-criteria decision-making, allows quantification and aggregation of multiple objectives, even when comprised of conflicting attributes; *Elicitation and consistency check* involves the understanding and modeling of the decision maker's preferred structure based on the consequences; *Optimization*, a key objective in the decision-making attempt to obtain the best solution for any given problem; *Sensitivity analysis*, aims to investigate and verify the robustness of the solution.

In this context, the present paper investigates in literature the application areas of industrial maintenance decision-making, the proposed models and the application of methods and tools. The establishment of groups applying a relational matrix enables evaluating the main objectives and improvements proposed by the respective authors and the way they establish the inter-relations among application areas integrating different optimization and decision-making models. This analysis aims to provide broader insight and knowledge of the perceived trends and existing difficulties, assisting in the centralization of efforts necessary for future work development. As an additional support for this analysis, the Framework proposed in this work assists in the perception of the origin of data that feed the models and information flow. In addition, it highlights the integration and relationship among application areas of decision-making in industrial maintenance.

The paper is organized as follows: the research methodology is briefed in Section 2; the results of the systematic literature review
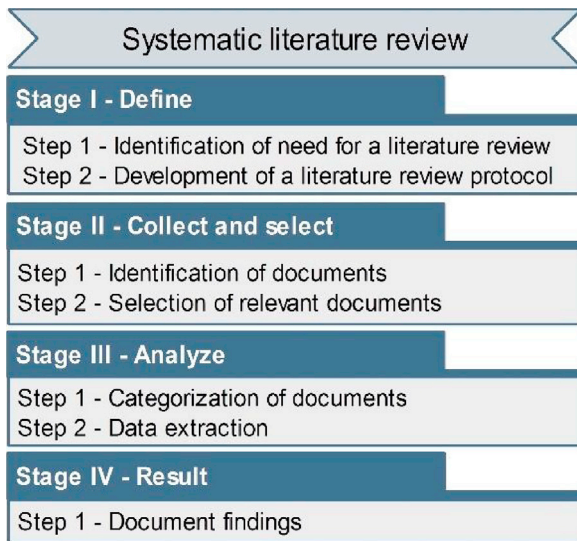
Fig. 1. Systematic literature review phases.
Source: adapted from Tranfield et al. [4].

Table 1
Review protocol.

Item	Description
Keywords	maintenance; decision-making
Boolean Operators	AND between keywords; OR between Database search fields
Search fields	Title; Abstract; Keywords
Exclusion criteria	Papers that use maintenance and decision-making terms out of industrial context; Papers that use maintenance term but do not address the main topic
Language	English
Publication type	Article
Time window	January 2006 to December 2015

Table 2
Modification of the search string by database.

Database	Search string
Web of Science	Title: ("maintenance" AND "decision" AND "making") Refined by: Language: (ENGLISH) AND Research Area: (ENGINEERING) AND Document Type: (ARTICLE)
Emerald Insight	Content Item Title ("maintenance" AND "decision" AND "making") OR Abstract ("maintenance" AND "decision" AND "making") OR Keywords ("maintenance" AND "decision" AND "making")
Science Direct	TITLE ("maintenance" AND "decision" AND "making") OR ABSTRACT ("maintenance" AND "decision" AND "making") OR KEYWORDS ("maintenance" AND "decision" AND "making") AND LIMIT-TO (topics, "maintenance, decision")
Scopus	TITLE ("maintenance" AND "decision" AND "making") OR ABS ("maintenance" AND "decision" AND "making") OR KEY ("maintenance" AND "decision" AND "making") AND (LIMIT-TO (LANGUAGE, "English")) AND (LIMIT-TO (SUBJAREA, "ENGI")) AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (SRCTYPE, "j")) AND (LIMIT-TO (EXACTKEYWORD, "Decision making") OR LIMIT-TO (EXACTKEYWORD, "Maintenance"))

are presented and detailed in Section 3; a discussion of the findings is carried out in Section 4; and Section 5 concludes with the inferences on the research undertaken.

2. Research methodology

The research methodology was based on the steps proposed by Tranfield et al. [4], as shown in Fig. 1. The first stage is called *Define* and contains *Identification of need for a literature review* and *Development of a literature review protocol* as steps. The second stage, *Collect and select*, has two steps, called *Identification of documents* and *Selection of relevant documents*. The third stage is called *Analyze* and has *Categorization of documents* and *Data extraction* as steps. The last stage, *Result*, has the *Document findings* step in which it is possible to review all the documentation collected extracting knowledge from information.

The need for a systematic literature review in the *Maintenance decision-making* topic is grounded in the potential support that this research will bring to future work in the area, enabling better targeting by verifying trends and the evolution of the tools used in solving the problems being addressed.

A systematic search begins with the identification of keywords and search terms; which are built from the scoping study; the literature and discussions within the review team [4]. It is an iterative process that requires protocol refinement for approval; as shown in Fig. 2.

Using the main keywords (*maintenance*, and *decision-making*), the "*AND*" and "*OR*" Boolean operators between keywords and search fields, the following search string was defined: Title: ("maintenance" AND "decision" AND "making") OR Abstract: ("maintenance" AND "decision" AND "making") OR Keywords: ("maintenance" AND "decision" AND "making"). However, this search string did not guarantee returning only papers focused on the research topic, forcing the creation of exclusion criteria, excluding any work that did not address the issue of maintenance decision-making within the industrial context.

The English language was chosen, since it has the largest number of publications and hence more likely to offer relevant papers. The time window set for the research was ten years (January 2006 to December 2015).

The definition of the time window is directly linked to the pretensions of the research work that involves it. For the case of this

paper, one of the main objectives is to identify trends for models and methods of decision making in industrial maintenance. Therefore, a sampling that covers the last decade of research performed becomes sufficient for the identification of such trends. Additionally, we can use the evidence that papers in the current literature use previous works (past decades) as support in the development of new methodologies [5–7].

The review protocol is shown in Table 1, where criteria and requirements have been defined to return results on the subject under study.

Four online databases were used to canvas for published articles: Web of Science; Emerald Insight; Science Direct and Scopus. Although there is a striking similarity between the search engines of the databases used, subtle differences made it necessary to change the search string to adapt it to each of the mechanisms. Table 2 shows the final search string used in each of the databases.

3. Categorization of documents

After submitting the search string in the database, it was obtained 864 papers. The titles and abstracts reading provided a selection and subsequent disposal of papers that met the exclusion criteria defined in the research protocol. A total of 154 articles were selected.

In the analysis phase, the selected papers were grouped into categories, according to the publications (Table 3 and Fig. 3) and organized by year of publication (Fig. 4). This form of grouping helps in extracting important information regarding the research trends in the study area.

A complete reading of the papers allowed the identification of certain industrial maintenance areas related to decision-making