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An expert knowledge-based dynamic maintenance task assignment model using discrete stress–strength interference theory

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ABSTRACT

Expert knowledge has become an important factor in optimization decision-making for complex equipment maintenance. Motivated by the challenges of quantifying expert knowledge as a decision basis, we presented an expert knowledge-based dynamic maintenance task assignment model by using discrete stress–strength interference (DSSI) theory. We constructed the task assignment framework consisting of three parts: building expert database, selecting experts for tasks, and implementing the tasks, in which selecting experts for tasks based on expert knowledge is the key part of the model. To quantify tacit knowledge (experience) in optimization decision for expert recommendation, experience was defined as a probability, which is relevant to two random variables: quantity of task successfully implemented (strength) and quantity of task failed (stress), and experience is defined as the probability that the former (strength) is larger than the latter (stress). Further, universal generating function (UGF) method was used to calculate the experience, and decision rule was designed for the dynamic maintenance task assignment. The model can help collaborative maintenance platform periodically review experts' performances and assign the corresponding task to the most suitable expert at different periods. A case study shows that the proposed model helps not only to achieve rational allocation of expert resources, but to promote positive competition among experts.

1. Introduction

Nowadays, manufacturing enterprises are confronted by challenges arising from continuous innovations, global collaborations, and complex risk management. To continuously improve production efficiency and meanwhile reduce production costs, these enterprises strive for more efficient management methods and technological innovation [1–3]. For manufacturing enterprises, one of the main expenditure items is maintenance cost which reaches 15–70% of production costs [4]. However, as the result of improper maintenance activities, one third of the total maintenance costs is wasted [5]. To achieve operational competitive advantages and world-class competitiveness, the role of maintenance has changed from a "necessary evil" to a "profit contributor", and to a"partner" of enterprises [6]. Along with the development of advanced technologies of information and communication, the maintenance system also has undergone considerable change, from the autonomic system to the integrated system [7]. Besides, Bekkaoui et al. [8] pointed out that the end of the 20th century is a century of the information society, and today, the early 21st century is a century of the knowledge society. In the knowledge society, knowledge is an important resource of product manufacture and maintenance, as well as an essential factor of individual [9].

According to the AFNOR (2001) standard [10], maintenance includes all administrative, technical, or managerial activities that are intended to restore or maintain the equipment in a dependable state or data condition to perform a required function. In the context of industrial operation, industrial maintenance or industrial logistic support, and intelligence collaboration promotes the development of the new generation of maintenance system [11, 12]. In this kind of collaborative maintenance system, the significant role of human factor is indisputable, since decision-making for complex equipment maintenance requires knowledge — intellectual and intangible resources [13]. According to Alidaee et al. [29], task assignment model refers to establishing correspondences between the set of tasks and the set of experts. In this kind of model, each expert has the corresponding capabilities (skills), and each task requires a specific capability (skill) that is possessed by at least one of the experts. This implies that different experts have different capabilities (skills) on the corresponding task, and the optimal task assignment is to select the most suitable expert

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for the corresponding task. On the other hand, Bekkaoui et al. [8] pointed out that knowledge (experience and skill) is one of the most important capabilities for equipment maintenance. For example, the task of fault diagnosis /location requires the relevant experts to identify the fault reason and location by experience, and to repair the fault by skill. In this sense, the consideration of expert knowledge in maintenance task assignment problem is essential to enhance not only the efficiency and reliability of maintenance, but also the utilization of the limited expert resources. Given the importance of knowledge, more and more studies take into account knowledge in the optimization model of maintenance task assignment [14].

To facilitate the cooperation and integration of maintenance process, Liu et al. [15] proposed an agent-based system framework, where various intelligent agents worked together to implement maintenance tasks in a collaborative way. Based on the system operating condition, Li and Ni [16] introduced a short-term decision support system for the optimization of maintenance task assignment. On the background of petroleum industry, Aissani et al. [17] presented a dynamic maintenance task scheduling model based on a multi-agent approach. Sheikhalishahi [18] estimated production and maintenance functions by using historical data, and presented an integrated simulation-data envelopment analysis approach for maintenance activities planning.

Different from the literature mentioned above, Bouzidi-Hassini et al. [19] and Wang and Liu [20] both considered human resource as an essential factor in the optimization model. The former discussed a new approach to optimize the scheduling of maintenance tasks, explicitly taking into account human resources — skills and availability. The latter investigated maintenance task assignment problem with multiple dependent resources, and proposed a multi-objective integrated optimization method to solve this problem. Further, Ruiz et al. [14] integrated multi-expert knowledge in industrial maintenance management to support collaborative decision making. Similarly, Kamsu-Foguem and Noyes [11] formalized the expert knowledge to provide support tools to accomplish the tasks in collaborative frameworks. To improve the decision-making related to the maintenance activity, Ruiz et al. [21] proposed a framework allowing to manage knowledge from the information on past experience, and suggested an original experience feedback process for maintenance.

The review of the relevant literature revealed that nowadays expert knowledge has been gradually considered as a significant resource of performance improvement of collaborative maintenance task, and on the other hand, expert knowledge is closely related to experience. According to Kebede [22], in general, knowledge can be divided into two categories: explicit and tacit knowledge. The former can be articulated in a tangible way (such as certificate), and the latter is contextual and highly personal (such as experience). As a result, it is difficult to quantify tacit knowledge (experience) in optimization decision for collaborative maintenance task assignment. This is one of the reasons why most of the literature on knowledge-based collaborative maintenance management focuses on qualitative research of experience, not quantitative research of experience. Besides, although the above cited literature provides useful approaches for maintenance task assignment based on knowledge, the majority of them neglect the dynamic characteristic of knowledge. The fact is that it is difficult for the relevant experts to maintain the same knowledge (experience) conditions during all periods since they experience a wide fluctuation of capability conditions (such as time, environment, and equipment status). Therefore, in maintenance task assignment model, periodically reviewing experts' knowledge (experience) is both necessary and significant to achieve the most effective and reliable maintenance.

Making explicit the tacit knowledge (experience) is the objective of Knowledge Engineering [23, 24]. In the domain of maintenance, some systematic approaches have been suggested to formalize experience in an explicit way. Case-Based Reasoning (CBR) [2, 14, 30] and Conceptual Graphs (CGs) [31, 21] are the most commonly approaches to address the problem. These approaches provide useful tools for allowing the extraction and formalization of experience, and for improving the maintenance of the production process, but the use of them usually requires a high level of expertise. For example, knowledge representation is a necessary means when applying CGs, and the representation formalisms include Frames based systems, Semantic Networks, Description Logics, etc., where pre-processing, data mining and post-processing are generally covered [21]. In addition, the formalized experience based on the above approaches is static and deterministic, which may not be the case in practice. According to Foguem et al. [32], an experience can be defined using different information slots, e.g. context (in which the event occurred), analysis and solution. It implies that experience has uncertainty and fluctuation, which is influenced by many factors. Therefore, there is a space for the development of new approaches for the formalization or quantification of experience, emphasizing the dynamic characteristic and to some extent simplifying the formalization process.

Stress–strength interference (SSI) model that used to deal with fuzzy and uncertain factors have been widely applied in reliability engineering. Although continuous stress–strength interference (CSSI) model is the most commonly used form of SSI model, it cannot be directly applied to the quantification of expert experience. In CSSI model, the random variables of stress and strength are continuous. However, the random variables related to expert experience in this paper are discrete. Given this, discrete stress–strength interference (DSSI) theory is more applicable for our model. Based on DSSI theory, on the one hand, expert experience can be quantified as an objective probability value, and due to the characteristic of DSSI model no pre-processing or post-processing is involved during the quantification. On the other hand, the value of experience can be updated with the updated observations, which makes the decision dynamic.

The present study is motivated by the challenges of presenting an expert knowledge-based dynamic maintenance task assignment model, quantifying expert experience as a basis for decision making. Given the above analysis, we would like to use DSSI model to address uncertainties in the problem under consideration, and to our knowledge, it is the first time that DSSI model is applied to collaborative maintenance management. In this paper, we first design an expert knowledge-based task assignment framework consisting of three parts: building expert database, selecting experts for tasks, and implementing the tasks, in which selecting experts for tasks based on expert knowledge is the key part of the model. Then, according to DSSI theory, expert experience is relevant to two random variables, which are quantity of task successfully implemented (strength) and quantity of task failed (stress), and experience is defined as the probability that the former (strength) is larger than the latter (stress). Further, universal generating function (UGF) method is used to calculate the value of experience according to the observation parameters of above-mentioned two random variables. Based on the quantified experience, the proposed model can help collaborative maintenance platform periodically review experts' performances and assign the corresponding task to the most suitable expert at different periods, to maximize the efficiency and reliability of maintenance.

The rest of this paper is structured as follows. Section 2 describes the theoretical background of the proposed model. Model formulation is presented in Section 3. In Section 4, a case study is presented to illustrate the feasibility and efficiency of the proposed

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