Product-Service Systems across Life Cycle

Bayesian Networks-based association rules and knowledge reuse in maintenance decision-making of Industrial Product-service Systems

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Abstract

Equipment manufacturing firms nowadays increasingly provide Industrial Product-Service Systems (IPS^2) to improve productivity and service capacity, particularly in the current age of big data. Vast amounts of data are collected using database management systems from areas of product design, manufacturing, marketing, fault detection and maintenance service of IPS^2. An urgent challenge in context of IPS^2 is how to form reusable knowledge taking advantage of these data records for the sake of guiding subsequent maintenance decision-making. To handle this issue, data mining technology has been used in knowledge acquisition from different databases. However, it needs further investigation how to represent and reuse knowledge mining from these databases in IPS^2 in relation to maintenance decision-making. Given this observation, this study first presents association rules in the form of Bayesian Networks that are mined from different databases of IPS^2 and can be used to represent knowledge acquired. It then establishes a knowledge reuse framework based on Bayesian inference, which is used to support related decision-making in maintenance operations. Lastly, the proposed methodology is applied to a real-world case in an agricultural equipment manufacturing enterprise. The experimental results using real-time data sets illustrate the effectiveness of the proposed methodology in handling maintenance decision-making associated with related fault phenomena.

1. Introduction

Association rules of events/nodes can be regarded as probability rules due to their co-occurrence [1]. Equipment manufacturing firms usually use association rules, which are mined from databases from areas of product design, manufacturing, fault detection and maintenance service of IPS^2 with data mining technology, to seek the relation between the fault phenomenon and the fault treatment. Such relation is useful to support related decision-making in maintenance operations. However, it's difficult and expensive to generate knowledge from document resources [2]. Since that, many researches focus on applying data mining technology to assist equipment operation and maintenance.

Data mining is known to be an excellent tool which helps the decision makers to discover the hidden knowledge and patterns when dealing with a large amount of data [3]. During the last decades, different methods of data mining technology have been used in various industries to find the tacit knowledge. According to the mode of the extracted knowledge, data mining tasks can be subdivided into: classification, clustering, association rules, prediction, and sequence mining, etc [4-6]. Association rules mining is part of the data mining methods. And up to now, there have been several tools of association rules mining, such as SPMF and WEKA, which use the algorithms such as Apriori and Fp-growth to find and generate association rules from database. Maintenance is known as a field where a great mass of data is daily collected [7]. So in the field of operation and maintenance, people applied this technology to discover the relation between the variation of the parameter and the different faults [8]. Paula Potes Ruiz and Bernaerd Kausu Foguem established a framework to manage and generate the knowledge mined from the maintenance data, by using association rules mining, to support the decision-making [9]. Baohui Jia find out different kinds of influence between different fault phenomena by using the association rules mining [10].

Bayesian network was defined explicitly by Pearl in 1988, and nowadays is one of the most effective theoretical models in the field of representing uncertain knowledge and reasoning [11]. It's widely utilized in industry, such as fault diagnosis, fault prediction, military decision-making, information fusion, data mining based on probabilistic causal relationship, etc[12]. The application of Bayesian network in the field of fault diagnosis can be seen as a kind of diagnosis decision inference model, and it can be used in three aspects: fault classification, decision-making and fault prediction.

From these studies we can know that there are two question for the applications of the association rules, which are:

(i) It's difficult to use the discrete rules. Several studies show how to generate association rules or knowledge of maintenance from the database and store in database, but the representing of these rules is discrete and can't express the relationship between rules. And it's challenging to use the association rules properly when the number of association rules increases greatly. Moreover, how to maintain and reuse the discrete rules database is also a problem.

(ii) It's complex to construct the Bayesian network based on the dataset. This method needs to traverse the entire dataset many times and its' search space is large. The flexibility is poor and it can't adapt to the dynamic data well.

In that context, this paper combines association rules with Bayesian network technology, and suggests a usual approach for generating the association rules mining with the tool SPMF, by storing association rules in the form of Bayesian Networks, and establishing a knowledge-reusing framework based on the Bayesian inference. In this way, the relationship of association rules can be expressed well by a Bayesian network. Moreover, it's more convenient to utilize the association rules.

The rest of the article is organized as follows: In section 2, we describe the problem. Section 3 introduces the presentation method of association rules with the Bayesian network and suggests a reuse framework of association rules. Section 4 presents an illustrative example based on actual data dealing with the maintenance of agricultural machinery.

2. Problem statement

In this paper, we consider a real-world situation where the manager takes decisions for the maintenance service of IPS^2 by utilizing maintenance experience to improve the service capacity and efficiency. It is founded in China's agriculture equipment manufacturing where decision-making of maintenance service is serious and urgent to be dealt with.

Agricultural equipment manufacturing enterprises provide parts and maintenance service to customers. In consideration of the influence of maintenance service, usually the manager will try to improve the evaluation from his clients. To enhance maintenance service capacity and efficiency, the staff in maintenance service center should try to provide the consumers or the maintenance engineer with maintenance suggestions quickly to solve the fault when they receive a maintenance task. However, only the experts have the skill response quickly for the fault treatment. And it's impractical

to employ various experts in the maintenance service centers. In such situation, it's urgent to add the function for decision-making in the service system.

In fact, agricultural equipment manufacturing enterprises have accumulated a large amount of maintenance data, which contains so much hidden knowledge about the maintenance service. And we want to generate knowledge from the maintenance data to assist the decision-making in maintenance service. Because the number of maintenance data is large. Moreover, it contains the closed relationships between data, for example: fault phenomenon → fault solution. These relationships are so helpful for the decision-making. Therefore we advocated a model of using knowledge to assist the decision-making of maintenance service.

We study the model consisting of three parts: knowledge acquisition from maintenance experience, knowledge representing and knowledge application in maintenance service. Considering the features of maintenance data, we choose the association rule mining technology of data mining technology to acquire the rules, we then represent the association rule with the Bayesian network, and finally we utilize the rule network to assist the decision-making.

3. Methodology

3.1 Generation of association rule

3.1.1 Definition of an association rule

Association rule is one of the results of data mining, which can describe the relationship among things. It has two attributes: support and confidence. Assuming that x and y is two item sets, and $X \cap Y = \varnothing$, so we can call $X \rightarrow Y$ association rules. The rule is established on the condition that it meets the requirement of support and confidence, which are determined by the user. The support of the association rule is the proportion of transactions in the database that contains both X and Y, and the frequency of the occurrence of the rule is as follows (Eq.(1)).

$$support = \frac{number\ of\ transactions\ containing\ both\ X\ and\ Y}{total\ number\ of\ transactions} \quad (1)$$

The confidence of the association rule is determined by the percentage of transactions in the database containing X that also contains Y (Eq.(2)).

$$confidence = \frac{number\ of\ transactions\ containing\ both\ X\ and\ Y}{number\ of\ transactions\ containing\ X} \quad (2)$$

3.1.2 Mining of the association rule

Mining of association rule mainly contains two tasks: the one is to find the frequent item sets which meet the support in data source; and the other one is to generate association rule between item sets according to the confidence. Obviously the core of the mining process is to find the frequent item sets. So the difference of several algorithms mainly focuses on the optimizing of finding the frequent item sets.