Advanced Engineering Informatics 38 (2018) 441–457

Contents lists available at ScienceDirect

Advanced Engineering Informatics

journal homepage: www.elsevier.com/locate/aei

Full length article

Knowledge-driven intelligent quality problem-solving system in the automotive industry

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ARTICLE INFO

Keywords:
Quality management
Intelligent quality problem-solving
Knowledge management
Automotive industry
Digital fishbone diagram
Ontology

ABSTRACT

In the current automotive industry, quality management, especially quality problem-solving (QPS), plays an important role in fulfilling the expectations of demanding customers who seek high-quality products at low-cost. During the problem-solving process, various real-time and historical quality data are often not fully used, yet these data are of high value. This paper provides a comprehensive quality data mining process and method, as well as an intelligent quality problem-solving system (IQPSS). First, based on original quality problem data, an ontology library is constructed using the ontology generating module (OGM). Second, based on the generated ontology and the textual data of the original quality problem, this study builds a quality problem-solving knowledge base (QPSKB) by employing relevant algorithms in the knowledge transformation module (KTM). The component and fault relational matrix mining (CFRMM) algorithm is designed to extract the relationship matrix between the components and faults. The semi-supervised classification algorithm based on the K-nearest neighbor algorithm (KNN) is used to classify the immediate measures, causes and long-term measures into the corresponding ontology and express the ontology as their knowledge. Furthermore, the binary tree-based support vector machine (SVM) approach is applied to classify the cause texts into the factors of Man, Machine, Material, Method, and Environment (4M1E), which are the five factors in a fishbone diagram. In particular, the digital fishbone diagram is a brand-new type of fishbone diagram that subverts the traditional method of fishbone diagram analysis through brainstorming. A pilot run of the IQPSS has been undertaken in an automotive manufacturing company to demonstrate how quality management employees obtain this knowledge by searching in the IQPSS. The results show that the IQPSS contributes appreciably to the quality problem-solving in the manufacturing industry.

1. Introduction

Given the growing maturity and competition in the automotive market, the automobile industry has developed into one of the most important manufacturing industries. As living standards continuously improve, consumer demands for high-quality automotive products are also increasing. In addition to increased competitiveness about product performance, price, and brand, quality is a critical factor. Various studies show that product quality is related to brand image and brand trust [1].

Quality management in automotive companies involves the entire process of design, procurement, manufacturing, and post-sales service. In automobile manufacturing quality management, quality problem-solving (QPS) is an important aspect. QPS refers to the processes of problem definition, problem analysis, cause identification, generation and selection of measures, and testing and evaluation of measures [2]. These corrective actions are important facets of continuous quality improvement.

With the continuous advancement of information technology, intelligent quality management (IQM) has gradually become a trend in quality management. The IQM process focuses on applying data mining techniques to extract knowledge by identifying previously unknown cause-effect relationships [3]. In the future, there will be a trend toward more profound quality management knowledge [4]. Existing and acquired organizational quality management knowledge must be preserved and integrated into the organization to increase knowledge availability. Thus, the focus of IQM is to use data mining and knowledge discovery technology to provide support for quality management [5]. Some scholars studying how to use knowledge in quality management to better service quality management constructed an IQM

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https://doi.org/10.1016/j.aei.2018.08.013
Received 20 April 2018; Received in revised form 15 August 2018; Accepted 22 August 2018
1474-0346/

Nomenclature

QPS	quality problem-solving
IQM	intelligent quality management
IQPSS	intelligent quality problem-solving system
KTM	knowledge transformation module
QPSKB	the quality problem-solving knowledge base
OGM	ontology generation module
KIM	knowledge inference module
CFRMM	component and fault relational matrix mining
C	The set of components, $C=[c_1,c_2,\cdots,c_n]$, where c_i indicates the i_{th} component, $i=1,2,\cdots,n$
F	The set of faults, $F=[f_1,f_2,\cdots,f_m]$, where f_j represents the j_{th} fault, $j=1,2,\cdots,m$
T	The set of problem titles, $T=[t_1,t_2,\cdots,t_l]$. where t_s represents the s_{th} problem title, $s=1,2,\cdots,l$
W	An indexed word set made up of words contained in the text of the component, fault, and problem title. $W=[w_1,w_2,\cdots,w_e]$, where w_τ represents the τ_{th} index word, $\tau=1,2,\cdots,e$.
CW_{ne}	The document-term matrix of components, $CW_{ne}=(cw_{i\tau})_{n\times e}$, where $cw_{i\tau}=1$ indicates that component c_i contains index word w_τ, and $cw_{i\tau}=0$ indicates the opposite.
FW_{me}	The document-term matrix of faults, $FW_{me}=(fw_{j\tau})_{m\times e}$, where $fw_{j\tau}=1$ indicates that fault f_j contains index word w_τ, $fw_{j\tau}=0$ indicates the opposite.
TW_{le}	The document-term matrix of problem titles, $TW_{le}=(tw_{s\tau})_{l\times e}$, where $tw_{s\tau}=1$ indicates that problem title t_s contains index word w_τ, and $tw_{s\tau}=0$ indicates the opposite.
CF_{nm}	The relational matrix of Component and faults, $CF_{nm}=(cf_{ij})_{n\times m}$, where $cf_{ij}=1$ indicates that the component c_i has experienced the fault f_j, and $cf_{ij}=0$ indicates that the component c_i has not experienced the fault f_j.
X	The set of causes, $X=[x_1,x_2,\cdots,x_\lambda]$, where x_k represents k_{th} cause, $k=1,2,\cdots,\lambda$.
Y	The set of classes, $Y=[1,2,\cdots,\psi]$.
TR	The training set of causes, $TR=\{(x_1,y_1),(x_2,y_2),\cdots,(x_{tr},y_{tr})\}$, where $x_\varepsilon\in X, y_\varepsilon\in Y$, $\varepsilon=1,2,\cdots,tr$.
TE	The test set of causes, $TE=\{(x_1',y_1'),(x_2',y_2'),\cdots,(x_{te}',y_{te}')\}$, where, $y_o'\in Y$, $o=1,2,\cdots,te$.

framework with data mining feature based on knowledge management [5–7]. However, these studies did not analyze the knowledge representation of the knowledge base or reveal the specific implementation details of each module in the frameworks. Besides, the scope of quality management covered by these studies is too broad due to the lack of in-depth study of the detailed activities of quality management. At the same time, some scholars have paid close attention to performing quality inspections to improve or predict quality through process flow parameters and on applying intelligent technologies to quality management tools [12–17]. However, few scholars have studied the application of intelligent technologies in quality problem-solving activities, such as causal analysis and the formulation of measures.

From the practical perspective of applying intelligent technology in quality management, to tackle the problem that traditional QPS relies heavily on human experience and ignores historical data, some quality management information systems have added a search function to make better use of the available historical data. When a new quality problem occurs, a user can search for relevant data and information in the system by entering keywords related to the problem. This type of search-engine-like function can provide pertinent data and information. Unfortunately, it cannot directly and accurately provide relevant knowledge concerning quality problems, which makes finding the required information difficult.

Given the limitations of existing research and practice, this paper proposes a framework, a method and a system for knowledge-driven automotive intelligent quality problem-solving at the macro level. At the same time, the analysis of the knowledge representation of the knowledge base, as well as the specific implementation details of each module in the framework at the micro level, are provided. In particular, this paper makes the following main contributions; they are as follows:

1. This paper proposes a novel data mining method to extract the relationship matrix of components and fault types from a large number of quality problem texts, making it possible to understand all the fault types that occur on each component.
2. This paper first proposes a new digital fishbone diagram method for causal analysis, subverting the method of fishbone diagrams obtained through brainstorming. In the field where the fishbone diagram can be used for causal analysis, this digital fishbone diagram can provide true and reliable historical causes of the problem and greatly reduce the time and cost of the causal analysis.
3. Different from the existing quality management information system with a search function, the intelligent quality problem-solving system (IQPSS) proposed in this paper, which works like a question-answering system, can provide relevant knowledge to problem-solving staff in a structured way.

The remainder of this paper is organized as follows: Section 2 provides a review of prior literature related to this research. In Section 3, the architecture of the IQPSS and introduce the main functions of each IQPSS module is proposed. In Section 4, the ontology generation module (OGM) and the corresponding ontology generation method in the IQPSS framework are introduced. Section 5 describes the knowledge transformation module (KTM) and data mining method in IQPSS framework. Section 6 presents the knowledge inference module (KIM) and knowledge inference method in the IQPSS framework. Section 7 contains a case study describing a pilot run of the system conducted in a real company. Section 8 includes a discussion of IQPSS. The final section concludes the paper by presenting the key findings and future work.

2. Related work

With the in-depth development of quality management and the emergence of knowledge management theory, some quality management scholars revealed that a certain relationship between quality management and knowledge management exists. At the macro level, IQM mainly considers the introduction of knowledge management into quality management. Some scholars studying how to use knowledge in quality management to better service quality management constructed an IQM framework based on knowledge management. Wang [5] brought forward an intelligent TQM expert system that included knowledge discovery from databases. This IQM system is equipped with a "data mining" feature to provide quality knowledge and fosters the ability to understand the relationships between enterprise management processes. Ch et al. [6] proposed a model of knowledge management to support quality management and introduced an intelligent quality management process model. This model differs from traditional quality management in that it contains a new component: knowledge management. Srikanth et al. [7] proposed an IQM expert system with a post analysis of actionable knowledge discovery framework, which both develops relationships between the enterprise and management