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A fuzzy TOPSIS and Rough Set based approach for mechanism analysis of product infant failure

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ABSTRACT

Root causes identification of product infant failure is nowadays one of the critical topics in product quality improvements. This paper puts forward a novel technical approach for mechanism analysis of product infant failure based on domain mapping in Axiomatic Design and the quality and reliability data from product lifecycle in the form of relational tree. The proposed method could intelligently decompose the early fault symptoms into root causes of critical functional parameters in function domain, design parameters in physical domain and process parameters in process domain successively. More specifically, both qualitative and quantitative attributes of quality and reliability types are considered for solving the root causes weight computation problem of product infant failure, this approach emphasizes the integrated application of artificial intelligence techniques of Rough Set and fuzzy TOPSIS to compute the weight of root causes. In order to enumerate the latent root causes of product infant failure, connotation of product infant failure based on the product reliability evolution model in the life cycle and data integration model of quality and reliability in production based on the extended QR chain are presented firstly. Then, a decomposition method for relational tree of product infant failure is studied based on domains of functional, physical and process in Axiomatic Design. The failure relation weight computation of root causes (nodes of relational tree) is considered as multi-criteria decision making problem (MCDM) by integrated application of Rough Set and fuzzy TOPSIS (Technique for Order Preference by Similarity to Ideal Solution), which the Rough Set is used to mining the quality data and fuzzy TOPSIS is adopted to model the computation process of failure relation weight. Finally, the validity of the proposed method is verified by a case study of analyzing a car infant failure about body noise vibration harshness complaint, and the result proves that the proposed approach is conducive to improve the intelligent level of root causes identification for complex product infant failure.

1. Introduction

Quality improvement is a routine mission of the product engineering, and the optimization of product infant failure rate is the most important and difficult task (Köksal et al., 2011; Gall et al., 2001). Infant failures have often been referred to the quality problems occurred in the "infant" region of leftmost of bathtub curve of product life (Roesch, 2012), and infant failures are assumed to be caused mainly by design vulnerabilities and manufacturing defects (Jiang and Murthy, 2009). Because of the high occurrence possibility of early failures in infant life, the infant failure rate always keeps unexpectedly high and received extensive attention.

In order to accelerate the decrease of the infant failure rate, the burn-in test is employed for screening potential early life defects. By testing the manufactured items under accelerated stress conditions (that is increased temperature, voltage stress etc.), early failures are weeded out. Therefore, high reliability of the delivered products could be ensured (Kurz et al., 2014). Despite the widespread application of the burn-in test to detect infant failures in product reliability engineering, research on the analysis approach of product infant failure mechanism is few. Most current researches are focused on the estimation of lifetime distributions from perspectives of traditionally statistical inferences.

It is a basic assumption that every failure has explainable physical or functional causes related to hardware, software and service (Nakao et al., 2009). The goal of failure mechanism analysis is to identify the root causes, determine what the sensitive factors including design, manufacturing and usage are involved, and quantify the results (Bernstein, 2014). The root cause is the most basic causal factor or factors that, if corrected or removed, will

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prevent the recurrence of the failure. Identifying root causes is the key task of failure mechanism analysis, and the correctness of the results is crucial to preventing similar failure occurrences in the future (Kapur and Pecht, 2014).

In the age of big data (Gil et al., 2014; Einav and Levin, 2014), with advances in automation and computer systems, intelligent quality improvement of industrial products and processes requires integration and analysis of big data to solve quality related manufacturing problems (Montgomery, 2014; Meeker and Hong, 2014; Köksal et al., 2011). How to identify and confirm the accurate root causes set of product infant failure from the lifecycle quality and reliability data is a prerequisite to develop continuous in-process quality improvement (Shi, 2013). Traditional methods such as Failure Mode and Effect Analysis (FMEA) and Fault Tree Analysis (FTA) (O'Connor and Kleyner, 2012) are always confined to reliability data and statistical analysis. Still, the general analysis approach for product infant failures in the context of big data and artificial intelligence methodology has not drawn the attention it deserves. Driven by these requirements, the paper puts forward a general technical approach for mechanism analysis for engineering product infant failures by integration the lifecycle quality and reliability data and artificial intelligence techniques of Rough Set and fuzzy TOPSIS for the first time, which could intelligently decompose early fault symptoms into critical functional, design and production parameters in the form of relational tree based on the domain mapping in Axiomatic Design (Suh, 2001). Specifically, this approach emphasizes the integrated application of the artificial intelligence techniques in dealing with this type of problems, in which the Rough Set is used to mining the quality data and fuzzy TOPSIS is adopted to model the computation process of failure relation weight of root causes.

The main contributions of this paper are

a) A general decomposition method of root causes based on relational tree for product infant failure is brought forth. This approach could intelligently decompose the early fault symptoms into root causes of critical functional, design and production parameters systematically.
b) The failure relation weight computation of root causes is formulated as multi-criteria decision making problem (MCDM) for considering both quantitative and qualitative attributes. Fuzzy is incorporated to remove the vagueness of the decision process. Although, the fuzzy TOPSIS method used to solve the problem is not novel, its application in the mechanism analysis of product infant failure is proposed for the first time here.
c) New attributes to compute the weight of root causes are proposed after several rounds of discussions with the industries.
d) Rough Set is adopted to mine the value of each criterion directly from historical quality evaluation data. Decision makers are indirectly involved for setting the mining rules for identification of weight values.

The rest of the paper is organized as follows: in Section 2 we give brief literature review of infant failure analysis and fuzzy MCDM. Section 3 expounds the connotation of product infant failure. In Section 4 we focus on preliminary definitions of Rough Set and fuzzy TOPSIS. Section 5 presents the intelligent analysis method of product infant failure mechanism based on the relational tree. Section 6 offers a case study of an infant failure analysis of car NVH. Finally, Section 7 provides conclusions and perspectives.

2. State of the art

A number of researchers about infant failure have focused on the estimation method of lifetime distributions from perspectives of traditionally statistical inferences (Kuo and Kim, 1999; Gall et al., 2001; Bebbington et al., 2009). However, only a few research works have been done on the mechanism analysis and root causes identification of product infant failure so far. In this section, some important analysis works about infant failure mechanisms and root causes are summarized.

We have used fuzzy TOPSIS, a fuzzy MCDM methodology to compute the failure relation weight of root causes. A brief overview and applications of Rough Set and fuzzy TOPSIS is also provided in this section.

2.1. Analysis of infant failure mechanisms and root causes

Kuo and Kim (1999) presented an overview of yield, reliability, burn-in, cost factors, and fault coverage as practiced in the semiconductor manufacturing industry, both yield–reliability relationships and relation models between yield and reliability were thoroughly analyzed in regard to their importance to semiconductor products, concluded that product reliability during the early production stage could be estimated through a relation model of yield and reliability. Gall et al. (2001) conducted statistical analysis of early failures in electromigration, and found the electromigration failure mechanism following perfect lognormal behavior down to the four sigma level. Kim et al. (2005) investigated the effect of the defect density distributions on the predicted reliability and emphasized that for any device, reliability functions preserve an ordering of yield functions. Bebbington et al. (2009) presented a polynomial functions of degree three or four to revisit the natural approach of modeling N- and W-shaped hazard rate functions when considering non-conforming components and assembly errors of manufacturing. Jiang and Murthy (2009) put forward a statistical method to model the effect of quality variations in manufacturing on product reliability based on Weibull distribution. Roesch (2012) proposed a new bathtub curve to reveal quality and reliability correlations, and he emphasized that the relationship can predict future experiences in reliability based on manufacturing quality data. Kim (2013) investigated the effect of manufacturing defects on the infant failure rate and observed that for any product, the failure rate decreases if the device-to-device variability of the number of defects is large enough. Kurz et al. (2014) presented an advanced Bayesian estimation models for the Weibull distribution handling both early time-to-failure and discrete failure count data.

In addition to the works of infant failure mechanisms above, there are a few researches of root causes analysis recently. Liao (2004) proposed a hybrid case-based reasoning method that integrates a multi-layer perceptron (MLP) neural network with case-based reasoning (CBR) for the automatic identification of failure mechanisms. Ransom (2007) provided a practical guide to root cause failure analysis process which including three steps of data collection causes analysis and solution phase. Nakao et al. (2009) adopted the Axiomatic Design to analyze failure data for the first time, and stated that coupled and complex design is major root cause of engineering failures. Bhaumik (2010) recommended a general approach for a successful failure investigation, and emphasized that majority of the investigations stop after the primary cause determination because of lack of initiative and/or information from the customer/client. Calderaro et al. (2011) presented a method to identify and localize failures in smart grids, the method is based on a carefully designed Petri net (PN) that captures the modeling details of the protection system of the distribution network and allows the detection/identification of failures in data transmission and faults in the distribution network by means of simple matrix operations. O'Connor and Kleyner (2012) emphasized failure reporting and analysis is an important part of the QA (Quality Assurance) function, and the key task is to analyze failure patterns and trends by Production Failure Reporting Analysis and Corrective Action System (FRACAS). Motamedi et al. (2014)