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Quality Control Problem in Printed Circuit Board Manufacturing—An Extended Rough Set Theory Approach

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Abstract

This paper presents a new heuristic algorithm, called extended rough set theory, for reduct selection in rough set theory (RST) applications. This algorithm is efficient and quick in selecting reducts especially if the problem size is large. The algorithm is able to derive the rules and identify the most significant features simultaneously, which is unique and useful in solving quality control problems. A detailed comparison between traditional statistical methods, the RST approach, and the extended RST approach is presented. The developed algorithm is applied to an industrial case study involving quality control of printed circuit boards (PCBs). The case study addresses one of the common quality problems faced in the PCB manufacturing, namely, solder ball defects. Several features that cause solder ball defects were identified and the features that significantly impact the quality were considered in this case study. Two experiments with equal and unequal weights were conducted and the results were compared. The end result of the extended RST investigation is a set of decision rules that shows the cause for the solder ball defects. The rules help to discriminate the good and bad parts to predict defective PCBs. A large sample of 3,568 PCBs was used to derive the set of rules. Results from the extended RST are very encouraging compared to statistical approaches. The rules derived from the data set provide an indication of how to effectively study this problem in further investigations. This paper forms the basis for solving many other similar problems that occur in manufacturing and service industries.

Keywords: *Data Mining, Rough Set Theory, PCB Assembly, Quality Engineering, Manufacturing Fault Detection*

Introduction

In modern manufacturing environments, vast amounts of data are collected in database management systems and data warehouses from all involved areas, such as product and process design, assembly, materials planning and control, order entry and scheduling, maintenance, recycling, and so on. Many knowledge-based components have also been added to (semi)-automate certain steps. Examples are expert systems for decision support, intelligent scheduling systems for concurrent production, fuzzy controllers, etc. A persistent problem is the gathering of required expert knowledge to implement knowledge-based components. Data mining provides some solutions to this knowledge acquisition problem. Data mining is the process of extracting and refining knowledge from large databases (Berry and Linoff 1997; Dhar and Stein 1997; Cheung et al. 1996). It is a process that uses a variety of data analysis tools to discover patterns and relationships in data. The extracted information can be used to predict, classify, model, and summarize the data being mined.

There is a wide range of scenarios within manufacturing environments in which data mining has been applied successfully. Fault diagnosis is one area where data mining is applied more often. Error rates at a manufacturing process are used as input to identify knowledge for further assistance to engineers. Identifying patterns, which indicate the potential failure of a component or machine, is another potential exercise of data mining. Other relevant areas include machine maintenance, process and quality control, and process analysis. Texas Instruments has isolated faults during semiconductor manufacturing using automated discovery from wafer tracking databases (Saxena 1993). Associations are created to identify interrelationships among processing steps, which can isolate faults during the manufacturing processes.

Apte, Weiss, and Grout (1993) facilitated five classification methods to predict defects in hard drive manufacturing.

In this paper, a data mining technique using a new heuristic algorithm for reduct selection in rough set theory (RST), called extended RST, will be applied to solve a quality control problem in the printed circuit board (PCB) manufacturing process. Literature review suggests that RST has not been widely applied to quality control problems, thus making this research novel. In RST, each object is characterized by attributes, and RST discovers the dependencies between them. Compared to the usual statistical tools with a population-based approach, RST uses an individual object model based approach that provides a very good tool for analyzing quality control problems (Kusiak 2001). While promising, the RST approach is computationally intensive in selecting the required reducts. The proposed extended rough set theory approach addresses this challenge of reduct selection by using a weighed approach. Furthermore, the extended RST is able to identify "defective" and "significant factors" simultaneously, which is unique and useful in solving quality control problems. The efficiency of this algorithm is tested with an industrial case study.

Approaches to the Quality Control Problem

Three commonly used statistical approaches in quality control problems are illustrated along with RST in *Table 1*. The common approaches to identify defects from a lot (batch) are control charts (classic and p). The use of control charts assumes that data are available before the control operation. Design of experiment (DOE) and regression analysis (RA) are used to identify significant "root causes" whenever the defective information is provided. For DOE, the experiment is designed and data are collected for the significant variables, and for RA the data are collected and are readily available. None of the approaches is able to identify "defectives" and "significant factors" simultaneously. Most statistical tools must respect several statistical assumptions, such as normality of distribution of the variables, constant variance of the variables, and so on. It is hard to meet all of these assumptions in practice. Furthermore, a data transformation phase is critical for statistical approaches, and some of these statistical methodologies require that the data be linearly related to an objective variable, normally distributed, and contain no outliers.

Table 1
Comparison of Statistical Approaches and Rough Set Theory in Quality Control

	Control Chart[1]	Design of Experiment	Regression Analysis[2, 3]	Rough Set Theory
Purpose	Identify individual defectives	Identify significant factors (root causes)	Identify significant factors (root causes)	Identify individual defectives and Identify significant factors simultaneously
Data type	Continuous/Discrete	Continuous	Continuous/Discrete	Continuous/Discrete
Assumption required	Constant variance	Normal distribution Constant variance	Normal distribution Constant variance	None
Solution approach	(1) μ +/− 3σ (2) p +/− $z\sigma$ p (3) c +/− z $\sqrt{c}$	Design matrix for factors (A, B, C...)	$Y = \beta 0 + \beta 1x + \beta 2x^2 + \varepsilon$	Reduct generation algorithm
Mechanism of defective identification	Control limits	ANOVA	ANOVA	Verified decision rules
Perspective (paradigm)	Population	Population	Population	Individual

Note: [1]Control chart for variable requires normal distribution assumption while control chart for attribute does not requires normal distribution assumption. [2]Logistic regression analysis for discrete responses requires only Bernoulli distribution. [3]Generalized linear regression analysis for discrete responses, the distributions are required only discrete exponential family distributions.