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# A change-point based reliability prediction model using field return data ☆

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ABSTRACT

In this study, we propose an accurate reliability prediction model for high-volume complex electronic products throughout their warranty periods by using field return data. Our model has a specific application to electronics boards with given case studies using 36-month warranty data. Our model is constructed on a Weibull-exponential hazard rate scheme by using the proposed change point detection method based on backward and forward data analysis. We consider field return data as short-term and long-term corresponding to early failure and useful life phases of the products, respectively. The proposed model is evaluated by applying it to four different board data sets. Each data set has between 1500 and 4000 board failures. Our prediction model can make a 36-month (full warranty) reliability prediction of a board with using its field data as short as 3 months. The predicted results from our model and the direct results using full warranty data match well. This demonstrates the accuracy of our model. We also evaluate our change point method by applying it to our board data sets as well as to a well-known heart transplant data set.

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## 1. Introduction

The rapid developments in electronics, especially in the last decade, have elevated the importance of electronics reliability [2–4]. Complex electronic systems, spanning almost all large industrial fields, require high reliability that necessitates accurate and early reliability predictions to give feedback for design and warranty precautions. Prediction methods in the literature are mainly based on accelerated life tests, component based numerical and probabilistic simulations, and statistical field data analysis [2,5–7]. Despite their widely usage, accelerated tests do not meet the needs of today's very rapid electronic product cycles; they are time consuming and expensive [8]. To overcome this problem, tests can be supported by simulations. However, in general simulations have severe accuracy limitations especially for complex electronic systems having various failure mechanisms [2,8,9]. Therefore, accelerated test and simulation based predictions can be deceptive for many applications. This underlines the importance of using field return data for reliability prediction that is relatively accurate, cheap, and time saving.

In this study, we perform warranty forecasting of high-volume complex electronic products using their field return data. We have cooperated with one of the Europe's largest household appliance manufacturers and used their well-maintained data sets of four different electronic boards. Each data set has between 1500 and 4000 board failures.

We construct our prediction model on a Weibull-exponential piecewise hazard rate scheme by considering early failure and useful life phases of the products. This scheme is preferred for products not getting into the wear-out region during their warranty times or anticipated lives [10,11]. Electronic products including electronic boards thoroughly studied in this work, fall into these product groups. As shown in Fig. 1, electronic boards are expected to work at least 10–15 years with a warranty period of at most 5 years.

Using a piecewise hazard rate function for our reliability model necessitates to determine the turning/change time distinguishing Weibull and exponential distributions. This problem, often called as the change point problem in the literature, is of fundamental importance in various applications including bio-statistics and medical survival data analysis [13–15]. Different approaches have been proposed to solve the problem [16]. Studies exploiting parametric change point analysis of non-monotonic hazard rate functions consider the change point as a parameter and propose statistical estimation methods including maximum likelihood, least squares, and Bayesian methods [15,17,18]. Additionally, nonparametric methods are studied widely [13,19].

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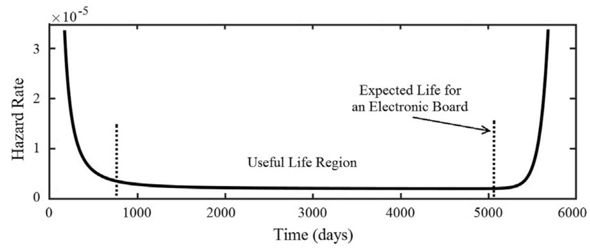


**Fig. 1.** A bathtub curve – hazard rate function over time [12].

Although there are both parametric and non-parametric methods in the literature giving theoretically satisfactory results for the change point problem, they are loosely encountered in engineering areas in the manner of applicability. They are usually evaluated using certain data sets with certain distributions such as biological survival data having exponential-exponential hazard rate scheme [15,16,18]. However, these methods can be deceptive for unevenly distributed data in time domain that needs different approaches and distributions for different time spans. For example, consider our board data sets for which nearly 90% and 10% of the data belong to the early failure (Weibull distribution) and the useful life (exponential distribution) regions, respectively. With the above discussed methods, the change point that separates the regions can not be determined accurately. Motivated by this, we propose a practical yet accurate change point detection method by performing forward and backward data analysis with left and right truncated data. We exploit both parametric and non-parametric techniques by using maximum likelihood and rank regression estimations.

Constructed on the proposed change point detection method, we develop an early reliability prediction methodology. In our case studies, we accurately predict 36-month reliability of electronic boards by using their 3-month field data. Investigating the related studies in the literature, we see the inappropriateness of non-parametric methods since they can only predict near future reliability of a new product [20–23]. Parametric methods using time dependent parameters are more suitable in this regard. In general, parametric methods including a standard Bayesian estimation, use a prior parameter distribution assuming that the distribution is same for an old product from which we get prior knowledge and a new product for which we perform reliability estimation [24–27]. This assumption is satisfied if the parameter is defined for a specific failure in a specific material/component. However, for complex systems having various components including electronic products targeted in this study, the assumption looses its validity.

There are also studies using empirical findings to find distributions of the parameters [28,29]. Here, the main problem is that to obtain sufficient accuracy, high amount of data is needed for a new product that can kill the idea of early prediction. Some recent works aim to solve this problem by using data from pass-fail reliability tests and having field data from multiple products [30–32]. In Ref. [31], field data of 17 different products are used for early prediction with an assumption that these products have similar failure distributions. Another solution is performing degradation tests and condition monitoring to have more data [33–35]. Of course, these techniques are considerably costly compared to the techniques, including ours, that just use field data. Additionally, physics of failure based simulations are exploited for reliability prediction [36]. Although this technique gives satisfactory results for individual components having certain failure mechanisms, its accuracy is susceptible for systems having hundreds of components including electronic products targeted in this study.

As opposed to the mentioned studies in the literature, our reliability prediction model uses only field data and deals with a single new product. Our model combines predetermined parameter distributions and empirical findings, and performs data fitting. It has an input of either short-term or long-term field data corresponding to early failure and useful life phases of products, respectively. The output of the model is the reliability prediction covering the full warranty period. In case of having long-term data, we directly apply our change point method to depict a hazard rate curve with Weibull and exponential distributions using maximum likelihood and rank regression methods. In case of having short-term data, we first investigate how the Weibull shape parameter $\beta$ varies with different time intervals of the field data. For this purpose, we use full warranty field data belonging to previous and/or current versions of the products. We develop a mathematical function of $\beta$ in terms of time and product dependent parameters. Additionally, we use empirical findings and iteration methods to estimate other distribution parameters. We finally construct our prediction model based on the developed Weibull-exponential scheme.

The paper is organized as follows. In Section 2, we introduce our reliability prediction methodology with a flowchart. In the following sections we elaborate on the flowchart step by step. In Section 3, we represent our forward and backward data analysis method to achieve a Weibull-exponential piecewise hazard rate scheme. We evaluate our method by applying it to our field data as well as to a well-known heart transplant data. In Section 4, we represent our reliability prediction model with long-term and short-term data. The proposed model is evaluated by applying it to different electronic board families. In Section 5, conclusion remarks and inferences about future works are given.

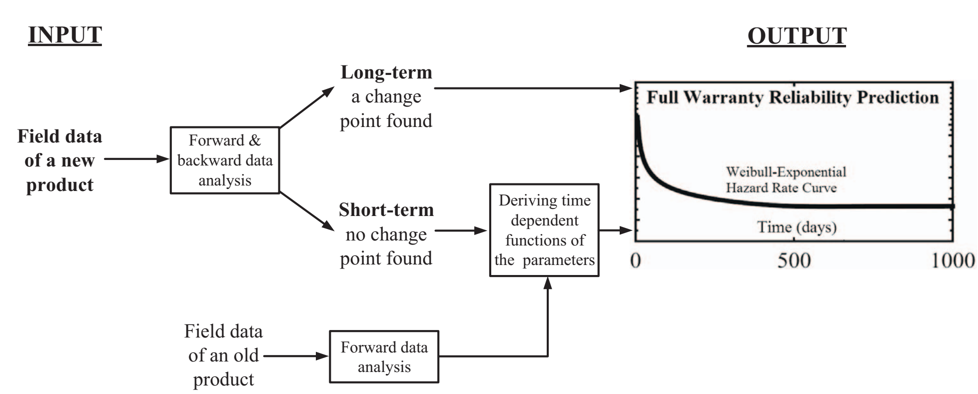


**Fig. 2.** Flow of the proposed reliability prediction methodology.

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