Comparison of Parametric NHPP-based Software Reliability Models

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1. Introduction

This paper summarizes a few dozen of novel parametric non-homogeneous Poisson process (NHPP)-based software reliability models (SRMs). The software fault-detection time distributions of these SRMs were assumed to follow several continuous distribution families, including generalized exponential, extreme-value , Lindley-type and Burr-type distribution families. Two NHPP-based modeling assumptions were considered; finite-failure (type-I) NHPP and infinite-failure (type-II) NHPP. In numerical studies, we compare our SRMs with the existing NHPP-based SRMs in terms of goodness-of-fit and predictive performances.

2. NHPP-based Software Reliability Modeling

Let $N(t)$ denote the cumulative number of software faults detected up to the system testing time t (≥ 0). The software fault counting process $\{N(t), t \geq 0\}$ can be considered as an NHPP where the probability mass function is given by

$$P_n(t) = \frac{M(t)^n}{n!} e^{-M(t)}, \quad n = 0, 1, 2, \cdots . \qquad (1)$$

The function $M(t)$ is the mean value function.

The NHPP-based SRMs are generally classified into two categories; *type-I NHPP* and *type-II NHPP* with the mean value functions.

In the type-I NHPP, the remaining number of software faults is assumed to obey a Poisson distribution with a positive mean ω. For any $t \in (0, +\infty)$, the c.d.f., $F(t; \boldsymbol{\alpha})$, is applied to describe the distribution of each fault detection time, and $\boldsymbol{\alpha}$ is a free parameter vector. The mean value function of type-I NHPP is derived as

$$M(t; \boldsymbol{\theta}) = \omega F(t; \boldsymbol{\alpha}), \qquad (2)$$

$\boldsymbol{\theta} = (\omega, \boldsymbol{\alpha})$ and $\lim_{t\to\infty} M(t; \boldsymbol{\theta}) = \omega$ (> 0). Okamura and Dohi [1] implemented the existing NHPP-based SRMs with 11 fault-detection time c.d.f.s in the software reliability assessment tool on the spreadsheet (SRATS), such as, exponential SRM, gamma SRM, truncated/log normal SRMs, truncated/log logistic SRMs, truncated/log extreme-value maximum/minimum SRMs, and Pareto SRM.

On the other hand, the type-II NHPP assumes that if each software failure is *minimally* repaired through the debugging, then, the mean value function is unbounded and is given by

$$M(t; \boldsymbol{\alpha}) = -\ln(1 - F(t; \boldsymbol{\alpha})), \qquad (3)$$

where $\lim_{t\to\infty} M(t; \boldsymbol{\alpha}) \to \infty$. In [2], Li et al. used the 11 fault-detection time c.d.f.s in SRATS for the type-II NHPP and obtained 11 new type-II SRMs, called type-II SRATS.

3. Lindley-type NHPP-based SRMs

The *Lindley distribution* is a meaningful one-parameter continuous probability distribution proposed by D. V. Lindley. Based on the contribution of the original Lindley distribution, several Lindley-type distributions have been proposed in recent years and been widely used in various fields In [3], Li et al. have introduced 6 Lindley-type distributions; gamma Lindley, exponentiated Lindley, power Lindley, exponentiated power Lindley, Gompertz Lindley, and

表 1: Goodness-of-fit performances based on **AIC** (group data).

	Best SRATS	Best type-II SRATS	Best Lindley	Best Burr
TIDS1	73.053	85.339	84.490	**72.500**
TIDS2	61.694	60.674	63.840	**54.632**
TIDS3	87.275	91.919	87.270	**85.873**
TIDS4	51.052	63.556	51.050	**50.256**
TIDS5	29.911	27.953	31.22	**29.132**
TIDS6	108.831	107.211	104.280	**102.871**
TIDS7	**123.256**	138.029	126.930	124.767
TIDS8	117.470	148.438	120.630	**117.234**

表 2: Predictive performances based on **PMSE** (group data from 20% observation point).

	Best SRATS	Best type-II SRATS	Best Lindley	Best Burr
TIDS1	220.732	218.763	**93.000**	205.956
TIDS2	29.244	47.377	36.260	**5.784**
TIDS3	820.049	171.702	**123.010**	300.014
TIDS4	142.854	86.083	**66.570**	129.764
TIDS5	2.628	2.625	0.330	**0.275**
TIDS6	98.903	**25.613**	117.590	30.2254
TIDS7	387.694	67.730	**52.320**	233.833
TIDS8	448.935	423.360	**311.520**	423.360

weighted Lindley distribution into the type-I and type-II NHPP software reliability modeling.

4. Burr-type NHPP-based SRMs

By considering the relation between c.d.f. and probability density function, I. W. Burr proposed 12 *Burr-type distributions*; Burr-type I ∼ Burr-type XII. In recent, Li et al. [4] introduced the seven Burr-type distributions; Burr-type III, VI, VII, VIII, IX, X and XII into type-I and type-II NHPP. Since the domains of random variable X of Burr-type VI, VII, VIII, IX are $(-\infty, +\infty)$, they transformed the c.d.f.s with support $(-\infty, +\infty)$ to the log Burr-type distributions and the truncated Burr-type distributions with the support $(0, \infty)$.

5. Numerical Studies

In numerical experiments, we analyzed eight software fault count group data. Suppose that the parameters of the SRMs have been estimated bymeans of maximum likelihood estimation. Then, we utilize the Akaike information criterion (AIC) for evaluating the goodness-of-fit performance of SRMs. To validate the fault prediction capability of SRMs, we set the observation point at 20% of testing length in each data set, and applied predictive mean squares error (PMSE) to investigate the predictive performance of each SRM.

By comparing with the existing NHPP-based SRMs in SRATS [1], we confirmed that the Burr-type NHPP-based SRMs could provide the better goodness-of-fit performances than the other NHPP-based SRMs in most data sets (see Table 1), and the Lindley-type NHPP-based SRMs had the better potential for accurate prediction of unknown future fault detection in many cases (see Table 2).

参考文献

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