Repairable Systems – No Longer the Step Child of Reliability!!!
Repairable System Reliability Modeling using Proc Reliability in SAS® 9.3

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Abstract

Most assets are repairable in nature. These assets include transportation systems such as Trucks and Locomotives, Oil & Gas drilling equipment and heavy engineering equipment such as the Earthmoving equipment. When assets break down, they are repaired rather than replaced. The measurement and characterization of repairable system reliability requires a different set of statistical techniques as compared to a non-repairable system.

The formulation of repairable system reliability is based on the concept of a non-stationary stochastic point process where as non-repairable systems can be modeled using properties of cumulative distribution function. SAS/QC® Proc Reliability has features to analyze repairable system reliability.

Proc Reliability in SAS/QC ® version 9.2 allowed modeling of repairable system reliability using the non-parametric Mean Cumulative Function. In SAS/QC ® version 9.3, Proc Reliability has a much needed functionality to model recurrent data by fitting a Non–Homogeneous Poisson Process (NHPP).

This paper illustrates the use of Non-parametric Mean Cumulate Function (MCF) and parametric NHPP to model reliability of critical sub-systems of a repairable transportation asset.

Introduction

- Reliability is the ability of a system to perform its required functions under stated conditions for a specific period of time.
- System failure is defined as state of the system when it stops performing its required function.
- To restore a system to an operating condition upon failure, system is either repaired or fully replaced.
- Systems such as **Light bulb, Pacemakers or Flash drives** are replaced upon failure, and are referred to as non-repairable systems.
- Examples of systems which are repaired upon failure include transportation systems such as trucks and locomotives, oil & gas drilling equipment and heavy engineering equipment such as the earthmoving equipment.
- Accurate characterization of system reliability is important for determining **system availability and forecasting the repair events.**

Statistical Theory of Reliability

The statistical models for reliability are different for repairable and non-repairable systems. The statistical theory for non-repairable systems is well researched and published as compared to the repairable systems. Following sections outline the difference between the statistical models for non-repairable vs. the repairable systems.

Models for Non-Repairable Systems

- The models are based on the theory of **Renewal Processes.**
- The times between successive system failures in a renewal process are assumed to be independent and identically distributed, that is, the times arise from a single population.
- The reliability is expressed in terms of properties of distribution functions. Reliability for time t is expressed as

$$R(t) = 1 - F(t)$$

$$F(t) = \int_{t=0}^{t=\infty} f(t)\,dt$$

- $F(t)$ is the cumulative distribution function of the probability distribution with density function f(t). The commonly used probability distributions include **Exponential, Weibull and Log-Normal.**

Models for Repairable Systems

- Repairable systems undergo multiple repairs over their lifetimes. Repairs are not perfect hence they do not renew the system or restore it to a state as good as new. Hence models based on renewal theory are not applicable for modeling Repairable systems reliability.
- The times between successive failures are not independently and identically distributed. There is a non-stationery trend in times between successive failures which needs to be taken into consideration.
- When analyzing data from repairable systems, analysts routinely assume that the observations for times between failures are realizations of a renewal process. With this incorrect assumption, statistical distributions such as Weibull are fitted to model the system reliability.
- **In version 9.3, SAS/QC ® Proc Reliability has provision to apply appropriate parametric and non-parametric models for analyzing repairable system data**

Non-parametric Reliability Model

- Proc Reliability supports non-parametric method based on **Mean Cumulative Function (MCF)**, developed by Nelson (1988, 2003) for characterizing repairable system reliability.
- MCF provides a nonparametric estimate of mean cumulative repair count or repair cost per system versus the age along with the estimate of variance and confidence limits.
- Alternate usage measures, such as mileage can be used to compute the MCF.
- The MCF estimate can be obtained for right and interval censored data.
- Proc Reliability also offers statistical test to check if the difference between two MCF curves is significant or not.

Parametric Reliability Models

- **Nonhomogeneous Poisson Process (NHPP)** is widely used for modeling repairable system reliability (see Cox and Lewis 1966, Crow 1974, 1990, 1993; Lawless 2003; Bain and Englehardt 1991; Rigdon and Basu 1989).
- NHPP allows modeling the non-stationery trend in time between failures by allowing the repair rate or event recurrence rate to be a function of age t. The event recurrence rate is denoted by λ(t) and based on the functional form of λ(t) different models for NHPP have been developed.
- Starting version 9.3, Proc Reliability allows modeling of repair data using NHPP. Following functional forms of λ(t) are supported.

Model	Recurrence Rate
Crow-AMSAA	$\lambda(t) = \beta\eta t^{\beta-1}$
Homogeneous	$\lambda(t) = \exp(\eta)$
Log-Linear	$\lambda(t) = \exp(\eta + \beta t)$
Power	$\lambda(t) = \frac{\beta}{\eta}\frac{t}{\eta}^{\beta-1}$
Proportional Intensity	$\lambda(t) = \exp(\eta)\beta t^{\beta-1}$

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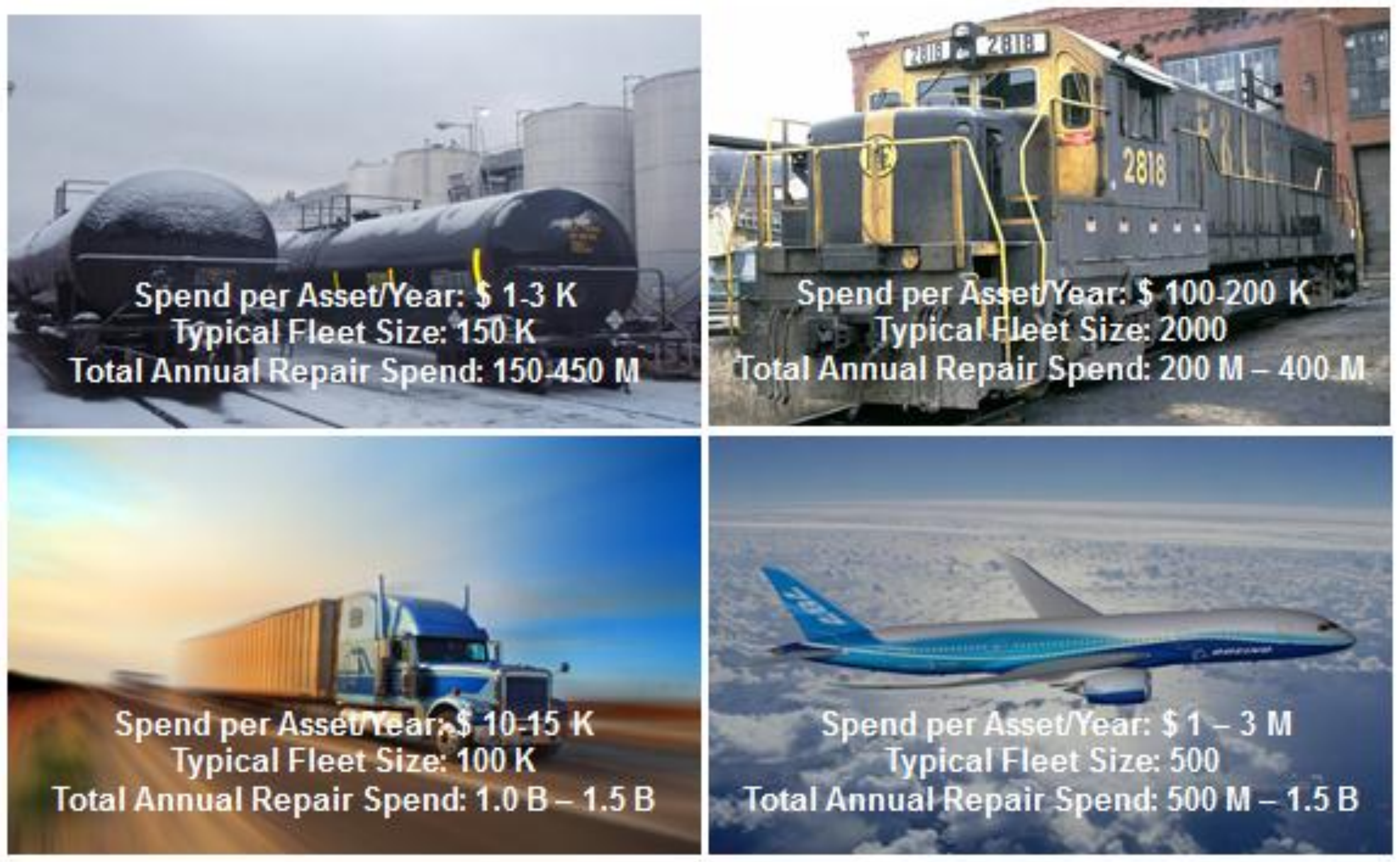
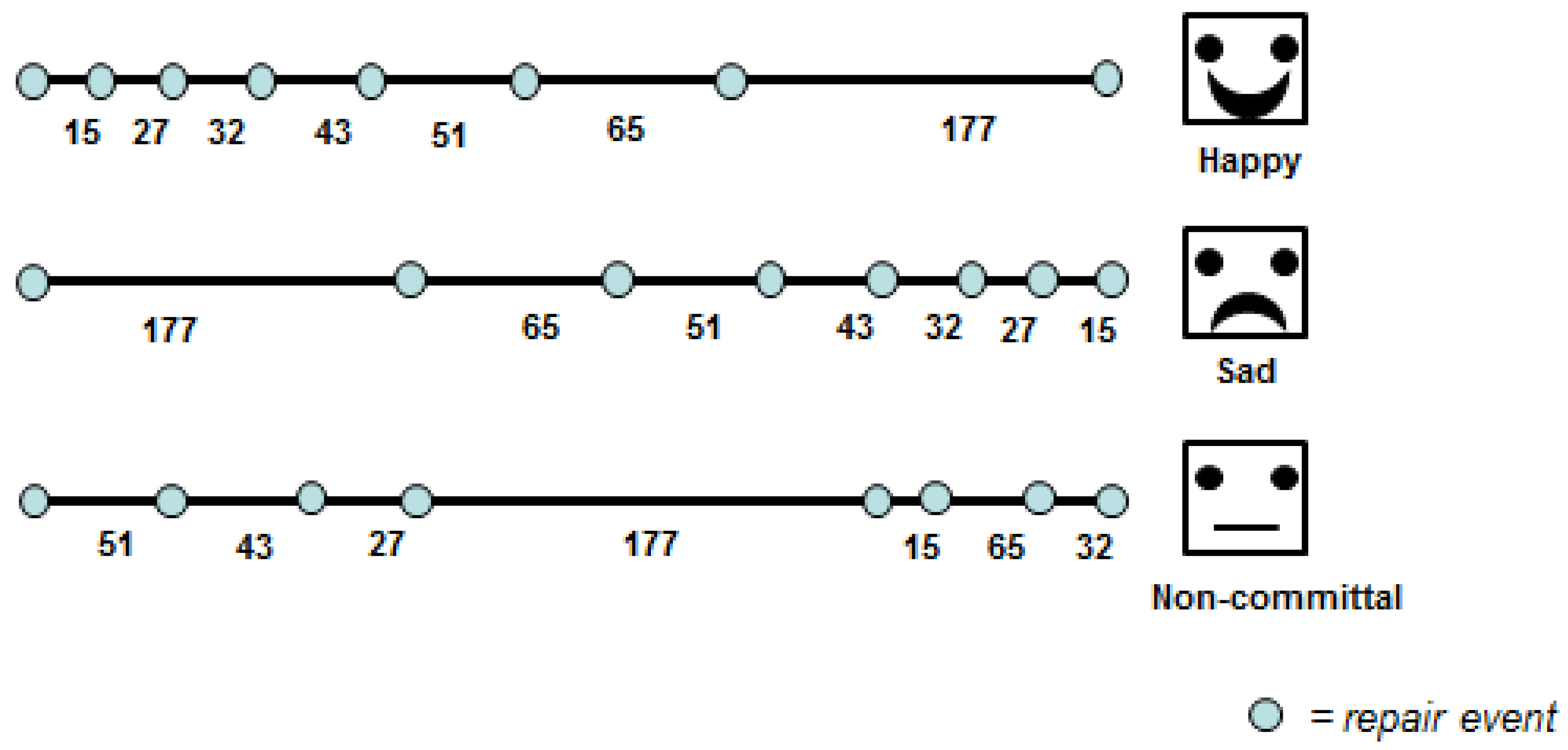


Figure 1: Maintenance Spend for Transportation Assets



Repairable system reliability theory differentiates between Happy, Sad or Non-committal repairable systems .

Figure 2: Happy, Sad and Non-committal Systems

(Source: Ascher, H. & Feingold, H. (1984). Repairable Systems Reliability. New York, NY: Marcel Dekker, Inc.)

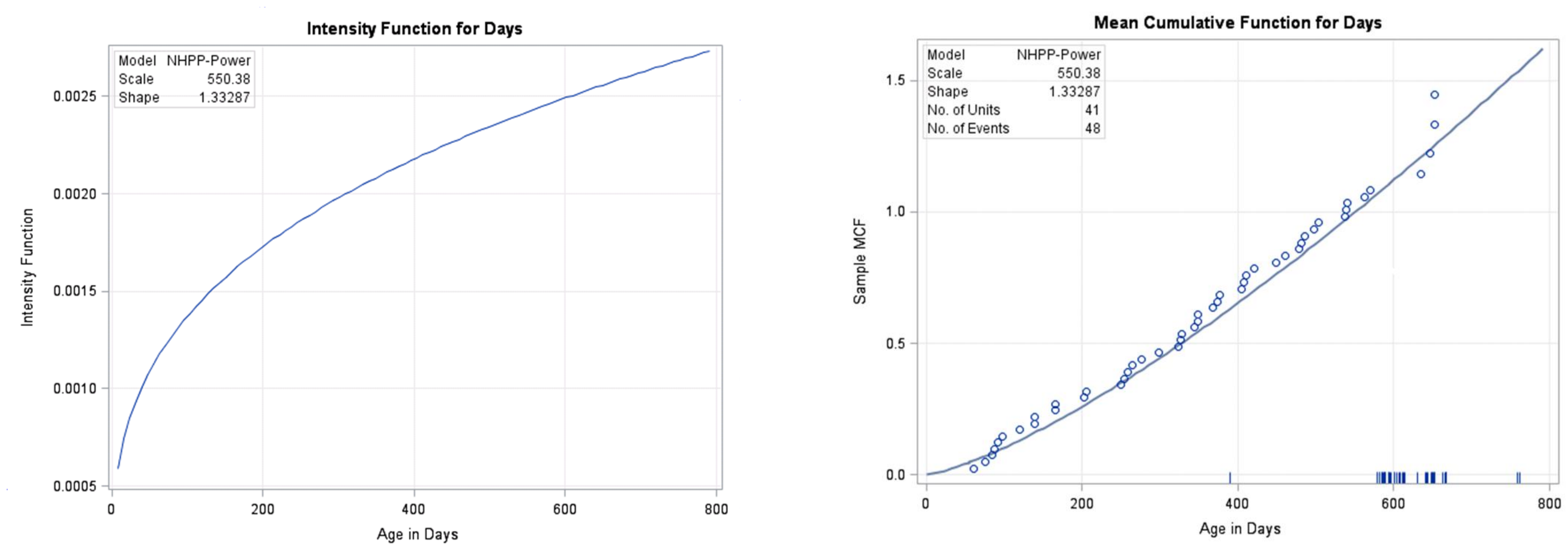


Figure 3: Proc Reliability Output Graphs.

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