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Flowgraph models: a Bayesian case study in construction engineering

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Abstract

Flowgraph models are useful in a wide variety of systems engineering and survival analysis problems. They are especially useful for analyzing time-to-event data and constructing corresponding Bayes predictive distributions. When a continuous time semi-Markov process defines transition times between a finite number of states and interest focuses on estimating densities, survival/reliability and hazard functions, or predictive distributions, flowgraph models provide a way of presenting the model and an associated method for data analysis. The method is illustrated using data from a construction engineering project.

Keywords: Hazard; Predictive distribution; Reliability; Semi-Markov process; Time-to-event data

1. Introduction

Flowgraph models are useful for modeling time to event data that result from a stochastic process. A flowgraph models potential outcomes, probabilities of outcomes, and waiting times for those outcomes to occur. Flowgraphs model semi-Markov processes and provide a practical alternative methodology for data analysis. They are useful when a continuous time semi-Markov process defines the transition times between states and interest focuses on estimating the density, reliability or survival function, or hazard function of the process. Given a stochastic process with conditionally independent states, a flowgraph model allows for the use of most standard waiting time distributions to model the different states. It provides

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a method for accessing the waiting time distribution for any partial or total waiting time. Flowgraph models operate on moment generating functions (MGFs) and use saddlepoint approximations (cf. Daniels, 1954) to convert the MGFs to waiting time probability density functions (pdfs), cumulative distribution functions (CDFs), reliability or survival functions, and hazard functions. As a data analytic method, flowgraphs have distinct advantages over other methods for semi-Markov processes (cf. Ouhbi and Limnios, 1999, 2003). Flowgraphs handle censoring and can be used in either a frequentist or a Bayesian framework.

Block diagrams and signal flowgraphs are widely used to represent engineering systems, especially in circuit analysis. Basic flowgraph ideas were developed in engineering, but they never incorporated probabilities, waiting times, or data analysis. The literature on flowgraph methods is vast. Introductions to flowgraph methods are contained in most circuit analysis or control systems textbooks such as Dorf and Bishop (1995), Gajic and Lelic (1996), and Whitehouse (1973). Statistical flowgraph models are based on flowgraph ideas but unlike their antecedents, flowgraph models can also be used to model and analyze data from complex stochastic systems. For literature on statistical flowgraph models see Butler and Huzurbazar (1997) and Huzurbazar (1999, 2000). This article focuses on an application of flowgraph modeling to a real data project involving planning in construction engineering. Section 2 provides a brief introduction to flowgraph models for engineering systems and Section 2.1 shows how to solve a flowgraph model. Section 3 describes the construction engineering project. Section 4 presents conclusions.

2. A brief introduction to flowgraph models for engineering systems

Fig. 1 shows a complex system consisting of outcomes in series and cascaded in parallel with feedback loops. The system is an assembly line for a manufacturing process for car stereos. State 0 represents an initial detection of a problem with a stereo. The problem is categorized into one of two types of severity. If the severity is of type I, the system is in state 1 for repair of the item. Eventually, the problem is fixed and the item moves to state 3 where it is specifically inspected to make sure that the type I problem is fixed. If the problem is

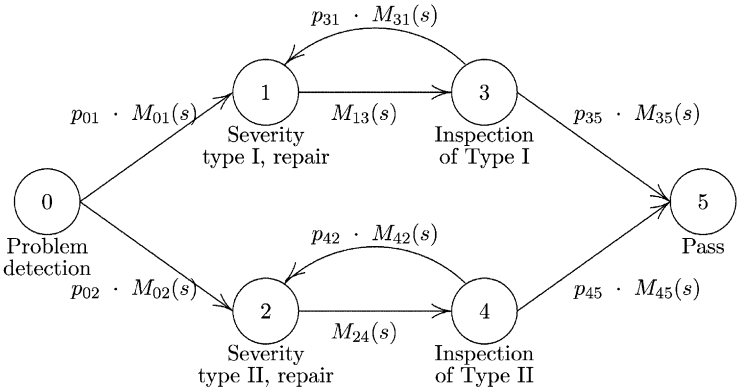

Fig. 1. Flowgraph model for manufacturing system.