A Bayesian Analysis Framework for Multi-state Component Degradation Model Parameter Inference with Multi-source Uncertain Evidence

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Maintenance optimization and cost reduction have drawn increasing attention in the nuclear industry. Maintenance optimization for a component relies largely on an accurate degradation model of the component. An accurate model enables us to predict the evolution of the component accurately and hence to make optimal maintenance decisions. Development of an accurate model usually requires a large amount of relevant data, and this becomes feasible with the increasing effort of nuclear power plant utilities in data collection. In particular, to ensure the safe operation of nuclear power plants, plant utilities have made a significant effort in monitoring, surveillance, and inspection activities, which can be periodic or non-periodic. These activities lead to the collection of a large amount of data related to component performance. These data contain useful information about the degradation and reliability of relevant components, and therefore can be used to guide the maintenance activities in the plants. However, nuclear power plants have not managed the full use of this data. In this research, we attempt to bridge this gap and aim to develop a Bayesian analysis framework that will use the data introduced above to infer component reliability model parameters. The updated reliability model can then be used to optimize maintenance activities. Specifically, we model component degradation and state observation as a hidden Markov process. In the hidden Markov model, the component can be in one of multiple states, from normal state through one or more degraded states to failed state. Using a multi-state degradation model provides two major benefits. First, a multi-state model provides a more realistic representation of component degradation. Second, it provides more opportunities for maintenance optimization. The component state can be monitored using different means. For example for a pump, the state can be monitored through vibration signal, noise magnitude, etc. However, the observations obtained using these means usually only serve as uncertain evidence of the component state. In the Bayesian analysis framework, we use these observations as evidence to update our prior belief about the distributions for the transition intensities in the hidden Markov model, which leads to the posterior distributions for the transition intensities. The analysis for a pump used in nuclear power plants is performed to demonstrate the capability of the Bayesian analysis framework.