Contribution ID: **27** Type: **not specified**

System reliability modeling with dependent degradation paths: a review of models including clustering and machine learning

Models are reviewed for systems of degrading components that exhibit dependent degradation paths, including distinct clusters of components which have similar behaviors. When component degradation models are extended to complex systems with multiple components, more complex reliability behaviors are often exhibited. As an example, consider a smart railway station, which exhibits multiple dependent failure processes and cluster of components. The main functionality of the railway station is to supply the electricity demand from the loads in the railway station and trains. Component degradation paths can form clusters because of external stresses that influence only a subset of components or physical proximity of a subset of components or many different reasons. For the railroad system, to reduce the CO2 emission, two additional external energy sources can be used, e.g., a breaking power recuperation system that recuperates the electricity generated during the breaking of the trains, and a photovoltaic generation system that produce renewable energy supplies to the system. The energy storage system degrades as the battery in the system ages, and concurrently, the photovoltaic generation systems suffer from performance degradation. These two components form a cluster because the degradation of the photovoltaic system are accelerated by the degradation of the energy storage system, as when the energy storage system degrades, the power generated from the photovoltaic system cannot be absorbed rapidly, creating additional stresses to the photovoltaic system that could increase its aging rate.

Different approaches for modeling the reliability for systems with dependent failure processes or degradation processes are reviewed, and stochastically dependent component degradation processes are specifically studied and extended. Models for dependent failure and/or degradation processes can be formulated by approximating joint multivariate distributions using copula functions. The copula function can be applied directly to the joint distribution of the degradation measures or to a joint distribution of the parameters of a degradation model. Alternatively, in the new model, gamma or Weiner process parameters are defined as a function of a vector of random variables and sensitivity coefficients, with specific random variables within the vector corresponding to individual clusters. Furthermore, machine learning models will be beneficial or even necessary when there are dynamic data sets and changing conditions.

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Session Classification: Invited speaker: David Coit