Safety Corner

What is the Application of Bayes' Theorem in Safety Engineering?

In the traditional frequentist world, we are taught that the frequency of an event is the number of observed success (or failures) over a specified period of time. However, in conducting a QRA for emerging technologies or advanced systems with few or no observed failures, it is not trivial to determine the failure rates of these systems.

We have learnt to use Bayes' Theorem in calculating conditional probabilities: P(B|A) = P(A|B) P(B) / P(A), where P(A|B) denotes the probability of event A occurring, given that event B occurs. However, the Bayes' Theorem also reflects the dynamics of learning and accumulation of knowledge with the above expression rewritten as: P(Posterior|Evidence) = P(Prior) P(Evidence|Prior)/ P(Evidence).

The "Prior" probability expresses the state of our current knowledge or uncertainties of an event (such as a component failure rate). This prior knowledge can be generic knowledge that includes general engineering knowledge of the component in question, and historical performance of the same or similar component used in other systems. When we are presented with evidence (such as the past experience of the component being analysed; and this includes nil failure over a specified period of time), the "Posterior" distribution then reflects our updated knowledge or uncertainties of the component failure rate after we treat the data through a process called Bayesian Data Update. When we observe another set of evidence, our current posterior distribution becomes the prior distribution for this new experiment and our state of knowledge is again updated. We should note that the mathematical manipulation involved in Bayesian Data Update is not trivial and should be conducted by experienced risk analysts.

In a risk analysis where failure data are scarce, the sequential nature of Bayes' Theorem can elegantly reflect the process of updating our knowledge on the uncertainties of parameters. To date, the Bayesian Data Update process is commonly used in assessing events such as hardware failure rates, human error rates, expert opinion, abnormal environmental events (e.g., fire, flood, seismic) frequencies, etc.

The application of Bayes' Theorem in treating uncertainties is indeed the foundation of modern risk analyses. Without using the Bayesian Data Update process, the validity of a QRA would be questionable.

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The Safety Corner is contributed by Ir Dr. Vincent Ho, who can be contacted at vsho.hkarms@gmail.com