論　文　の　要　旨

題　目　　A Study on Epistemic Uncertainty Estimation in Reliability Models
（信頼性モデルにおける不確実性推定に関する研究）

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This thesis discusses the epistemic uncertainty estimation in reliability models such as fault trees, Markov models and their hybrid models. The epistemic uncertainty is the uncertainty of output of model propagated from the uncertainty of input parameters. The uncertainty of input parameters are caused by the statistical errors in estimating model parameters due to limited sample size.

In Chapter 2, we develop the moment-based approach for estimating the epistemic uncertainty in hierarchical reliability models. The main point of the epistemic uncertainty estimation is how to determine the distribution of output of model. There are two approaches to obtain the distribution of output. One approach is to get a closed form solution of the distribution based on mathematical analysis. However, it is not always that the solution has a closed form. Another approach is based on sampling. By collecting outputs of model with the changes of input parameters, we obtain the distribution of output of model numerically. But, such approaches require much computation cost, i.e., the computation time tends to be longer when we want to get the highly-accurate distribution. The moment-based approach for the epistemic uncertainty estimation is known as the method to make a balance between computation speed and accuracy. Since the moment-based needs the information on local sensitivity, i.e., the first two derivatives of output of model, it has been discussed in a monolithic Markov chain whose first two derivatives are computed easily. This thesis extends the applicability of moment-based approach to the hierarchical reliability model. The hierarchical reliability model is defined as a hybrid model with fault trees and Markov chains, and they are used in reliability evaluation for complex system. The main idea behind our approach is to use the automatic differentiation for BDD (binary decision diagram) representation of fault trees and Markov chains. Numerical experiments are exhibited to estimate the uncertainty propagation in both simple and complicated hierarchical models. By comparing them with Bayes approach, we discuss the accuracy of moment-based approximation.

In Chapter 3, we focus on the global sensitivity of epistemic uncertainty. Although the local sensitivity is to estimate the magnitude of variation when the input parameters are varied, the global sensitivity is an approach to reveal the main effect to produce the uncertainty. The well-known global sensitivity is the variance-based sensitivity analysis that is similar to the variance analysis in statistical models. Our main idea is to apply the moment-based approach to obtain the variance-based sensitivity measure in Markov models. The presented approach is much faster than the existing approach using Monte Carlo (MC) simulation.

In Chapter 4, we discuss the computation method of information matrix for phase-type (PH)

approximation. The PH approximation is applied in non-exponential models that involve the state transitions following non-exponential distributions, and is to approximate the original model by replacing their non-exponential distributions with PH distributions. Since PH distributions are defined by Markov chains, the approximated model is regarded as a Markov model. In this scheme, we need to determine the model parameters of PH distributions that fits to the non-exponential distribution. Since this is based on the statistical estimation, the determined parameters of PH distribution involve the uncertainty. In the epistemic uncertainty estimation, the uncertainty of input parameters are estimated beforehand. In the context of PH approximation, the uncertainty of PH parameters should also be estimated. One of the approach to estimate the uncertainty is the evaluation of information matrix. By computing the information matrix with the estimated parameters, we obtain the characteristics of uncertainty of parameters. However, the computation of information matrix requires much computation effort. Especially, since PH distributions have a lot of parameters, it is necessary to develop an effective computation approach on information matrix. In Chapter 4, we propose an effective algorithm for computing the information matrix of PH distribution based on the uniformization technique.

Finally, we summary the contributions of this thesis are; (i) enhancement of the moment-based approach for estimating epistemic uncertainty so that it can be applied to in hierarchical models with the automatic differential technique. (ii) application of moment-based approach to obtain the global sensitivity measure of epistemic uncertainty with the variance-based sensitivity analysis. (iii) development of an effective algorithm for computing the information matrix of PH distributions that is useful to estimate the uncertainty of input parameters.