An Efficient Variable Screening Method for Effective Surrogate Models for Reliability-Based Design Optimization

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In the reliability-based design optimization (RBDO) process, surrogate models are frequently used to reduce the number of the simulations since analysis of a simulation model takes a great deal of computational time. On the other hand, to mitigate the curse of dimension and obtain accurate surrogate models, we have to limit the dimension of the RBDO problem. Therefore, it is desirable to develop an efficient and effective variable screening method for reducing the dimension of the RBDO problem. In this paper, requirements of the variable screening method for deterministic design optimization (DDO) and RBDO are compared, and it is found that output variance is critical for identifying important variables in the RBDO process. For DDO, design sensitivity of constraints can be used to determine importance of design variables as input variables have no uncertainty. In RBDO, output variability should be considered to count the effect of input randomness and to satisfy probabilistic constraints. However, once variable screening is carried out, total variability of the output decreases as the dimension of surrogate model is reduced. Therefore, variable screening for RBDO is better to identify variables which induce large output variability so that output variability is kept as much as possible after variable screening is carried out. An efficient approximated method based on the univariate dimension reduction method (DRM) is proposed to calculate output variance efficiently. Using the univariate DRM, the output variance can be computed with three point quadratic approximations for each variable, which requires much less simulations than multi-dimensional surrogate models. To determine which variable induces larger output variance, a hypothesis testing is applied to the proposed method. Hence, possible errors are contained in a user-specified error level. Also, an appropriate number of samples required for calculating output variance is proposed. Using a car noise & vibration crash safety RBDO problem, the effectiveness of the proposed method is verified. The problem has 44 input random input design variables and 11 constraints. Considering output variances of the constraints, 14 input random variables are identified as important variables using the proposed method. It is shown that the same 14 variables are selected by the global sensitivity indices method. However, the proposed method requires only 89 (88+1) simulation analyses to create quadratic approximation models; whereas global sensitivity indices method uses Monte Carlo method with many simulations or requires 44-D surrogate models. Hence, the efficiency of proposed method has been demonstrated. With identified 14 variables, RBDO is performed using the I-RBDO program and an optimum is found reducing 3.6% of cost, satisfying first 10 probabilistic constraints and violating 11th probabilistic constraint by 12.3% of the target probability of failure. For comparison, 14 variables are selected based on engineer's experience and RBDO is carried out as well. With selection by experience, 11th probabilistic constraint is violated by 77% of the target value which is a significant. To further reduce cost value, four more design variables are selected using the design sensitivity of cost function and added to the previously selected 14 variables by the proposed method. With 18 variables, RBDO optimum is found reducing 7.6% of the cost and violating only 11.7% of 11th constraint. Therefore, performance of proposed method is demonstrated.