

## A Framework of Statistical Model Validation for Virtual Product Testing

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### Abstract

Increased customer expectations have resulted in new product developments at an ever increasing pace. The product development process is traditionally conceived of as a cost-intensive and time-consuming process because it requires repeated product prototyping and testing to improve product performances and reliability. As products are becoming more complex with a shorter product lifecycle, virtual product testing using computer simulation has become more important to design and evaluate a new engineering product. Virtual testing can significantly save time and cost to design and evaluate a new engineering product. However, developing an accurate simulation model is not an easy task because no standard framework has been developed yet. This difficulty becomes worse when taking into account model uncertainties in boundary condition, material properties, loading condition, experimental error, and manufacturing tolerances. This research proposes a framework of statistical model validation for virtual product testing following three successive steps: (i) a framework for statistical model calibration, (ii) hypothesis test for validity check and (iii) virtual qualification in a statistical manner. Statistical model calibration adjusts a set of unknown model variables so that the agreement is maximized between the predicted and observed results. This step improves the predictive capability of a computational model in a calibration domain. Then, hypothesis test for validity check is performed to investigate if a calibrated model is eligible for virtual testing of a new design. For validity check of a computational model, many experimental data from multiple samples are generally required; however, it is impractical to manufacture lots of prototypes due to expensive manufacturing cost. There are two challenges for validity check due to the lack of experimental data. First, the experiments for validity check are normally conducted with samples of different designs or under various operating conditions in a validation domain. When few sets of experimental data are collected at different operating conditions, it is beneficial to integrate the evidence from all the observations over the entire validation domain into a single measure of overall mismatch. Second, the small sample size of experiments will produce another layer of uncertainty in a validity check metric, of which the effect on model validity must be carefully analyzed. To overcome these challenges, an area metric with a u-pooling method is employed for the hypothesis test to measure the degree of mismatch between predicted and observed results while considering uncertainty in the u-pooling metric due to the lack of experimental data. If the null hypothesis is rejected, the model should be refined through model verification and calibration activities. Otherwise, the virtual qualification process can be executed with a qualified model for new product developments. Lastly, the qualification process builds a design decision matrix to aid in rational decision-making on the product developments. A computational model of a tire tread block was used to demonstrate the effectiveness of the proposed framework.

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