

Development of MBD Method for Global Design Optimization Using Cross-Domain Model

-Part II: Module-Aware Contribution Analysis and Specification Decision-Making Using Compromise Programming-

Aoto Utsumi¹⁾ Shigemitsu Takahashi¹⁾ Mayuka Ojima¹⁾ Masayuki Kiyono¹⁾

*1) Nissan Motor Co., Ltd.
560-2 Okatsukoku, Atsugi-shi, Kanagawa 243-0126, Japan*

KEY WORDS: vehicle development, computer aided engineering, performance plan, MBD, multi-objective design optimization [B2]

This paper proposes a specification decision-making method for the planning stage as Part II of the study on the CAEM (Collective Automotive Engineering Model). Part I constructed an integrated 1D physical cross-domain model that predicts multiple performance attributes from common design information, and narrowed down the design variables for each performance cluster by DMM (Domain Mapping Matrix) sensitivity analysis and DSM (Design Structure Matrix) clustering. Two problems remained. First, because the final selection was carried out by tightening the target values on a parallel plot, in cases where no solution satisfies all the targets (which occur frequently at the planning stage) engineers had no choice but to compromise the targets through repeated trial and error, and the selection required a great deal of time. Second, the flow presumed quantitative variables, so modules, which are discrete design variables that switch several parameters simultaneously, could not be compared on a unified contribution scale and were excluded from dimension reduction. In this paper, modules are handled on the same scale as quantitative variables, and the degree of compromise is quantified as the distance from the ideal point.

Fig. 1 shows the workflow. A Latin Hypercube DOE (Design of Experiments) is generated for the search ranges of the quantitative variables and the module ID sets defined in the relational database of CAEM, and is evaluated by CAEM. In the variance-based sensitivity analysis, each objective variable is approximated by a univariate Fourier series, and the resulting reduction in the standard deviation is defined as its contribution. By assigning a unique integer label to each module type and fixing the scaling coefficient at 1, the modules are placed on the same "per one switching step" scale as the quantitative variables, and by normalizing the contributions by the design unit, objective variables with different physical units can share a single DMM. DSM clustering extracts the performance groups that should be studied together and reduces the number of dimensions of the optimization. The costly CAEM evaluation is replaced by a GPR (Gaussian Process Regression) surrogate, and the Pareto front is extracted by NSGA-II. Next, compromise programming selects the unique specification that minimizes the Euclidean distance of the deviations, which are mapped by the directional attribute and normalized by the design unit.

When the method was applied to specification study of an HEV, the objective functions were consolidated into four performance attributes by DMM/DSM. Although the several thousand non-dominated solutions cannot be ranked as long as they remain a Pareto front, compromise programming was able to narrow them down quantitatively to a unique candidate (Fig. 2, Table 1). Case A, obtained for the initial ideal point, satisfied the targets of fuel economy and handling stability, but did not satisfy acceleration performance and ride comfort. When the ride comfort component of the ideal point was relaxed, the compromise solution switched to Case B, which satisfied all four relaxed targets.

Both cases are valid candidates derived quantitatively for different ideal points, and the method can make the rationale for selection explicit, including module selection. The combinations obtained were counter-intuitive with respect to conventional engineering judgement; that is, combinations that are difficult to reach by experience-based manual screening can be explained by their physical causality, namely the contribution relations of the modules and parameters. The screening therefore shifts from judgement that relies on experience and intuition to discussion based on quantitative evidence. Because a compromise solution is obtained within seconds, repeated studies with different ideal points can be conducted interactively, greatly shortening the time required to reach a trade-off agreement among the engineers responsible for each performance attribute. The selected specification is returned to the physical model via the CAEM API to verify its consistency with the surrogate prediction and its physical validity.

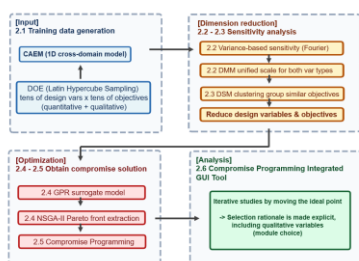


Fig. 1 Overall workflow of the proposed specification decision-making method

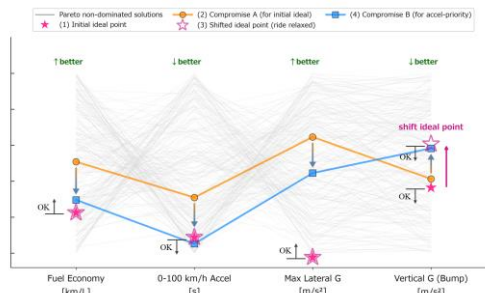


Fig. 2 Compromise-solution switch by ideal-point move (A to B).

Selected module	Case A	Case B
ENG (engine)	mid-size	small
Fr MOT (front motor)	low power	high power
BAT (battery)	large capacity	large capacity
Tire	standard	standard
Suspension	standard	standard
Mass (result)	heavy (BAT)	moderate

Table 1 Module selection: Case A vs Case B