Proposal of Benchmark Problem Based on Real-World Car Structure Design Optimization*

Takehisa Kohira
Mazda Motor Corporation
Fuchu-cho, Japan
kohira.t@mazda.co.jp

Hiromasa Kemmotsu
Mazda Motor Corporation
Fuchu-cho, Japan
kemmotsu.h@mazda.co.jp

Oyama Akira
Institute of Space and Astronautical Science,
Japan Aerospace Exploration Agency
Sagamihara, Japan
oyama@flab.isas.jaxa.jp

Tomoaki Tatsukawa
Tokyo University of Science
Katsushika, Japan
tatsukawa@rs.tus.ac.jp

ABSTRACT

A benchmark problem based on a real-world car structure design optimization[1] is proposed. The benchmark problem is constructed by using a response surface method from the design optimization result of a car structure design optimization problem. Because this benchmark problem bases on actual car structure design optimization result conducted by Mazda, it contains features of real-world design optimization problems. Objectives are the minimization of the total weight of the different type of cars and maximization of the number of common gauge (standard plate thickness) parts among the different type of cars. This benchmark problem has 148 discrete design parameters and 36 design constraints for simultaneous design optimization of two types of cars and 222 discrete design parameters and 54 design constraints for simultaneous design optimization of three types of cars. Thus, it is a scalable and multiobjective design optimization problem with many and discrete design parameters and many and severe constraints. The benchmark problem is available on our website (http://ladse.eng.isas.jaxa.jp/benchmark/).

CCS CONCEPTS

• **Theory of computation→Evolutionary algorithms**;

KEYWORDS

Benchmark problem, real-world optimization, multiobjective optimization, constrained optimization, discrete variable optimization.

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1 INTRODUCTION

In [1], the authors conducted simultaneous car structure design optimization of multiple car models, i.e., sport utility vehicle Mazda CX-5 (SUV), large vehicle Mazda 6 (LV), and small vehicle Mazda 3 (SV). While satisfactory result was obtained by using an IBEA-based MOEA, it took several months of computational time supercomputer K [2] due to computationally expensive constraint function evaluations. Therefore, we need more efficient MOEAs that can solve real-world design optimization problems, which have multiple objectives, many constraints and many design parameters. However, there are few benchmark problems that have such features.

Therefore, we propose a benchmark problem from result of [1] using a response surface method (RSM) for evaluating the crashworthiness, body stiffness and three modes natural frequency. The benchmark problem is available on our website[1].

2 BENCHMARK PROBLEM FORMULATION

Three types of cars, i.e., SUV, LV, and SV are simultaneously designed. The design variables are the gauge (standard plate thickness) of parts of the three car types. This problem is Mazda constrained discrete multiobjective optimization benchmark problem (Mazda CdMOBP), because the design variables are discrete.

The design objectives are (1) minimization of the total weight of three car models and (2) maximization of the number of common gauge (standard plate thickness) parts among the three types of cars. The design parameters are the plate gauge of 74 parts of each vehicle model (see Fig. 1). Total number of design parameters is 222. When the gauge of the same part of the three models becomes the same, the part is considered as common. 42 design constraints include crashworthiness in the four crash modes (front 40% offset, full front, side, and rear 70% offset impact), torsional stiffness, and natural frequency (lateral bending, longitudinal bending, and torsion) for each car type (see Fig. 1). For smaller problem, we propose simultaneous optimization of two types of cars (SUV and SV), where the number of design parameters and number of constraints become 148 and 36. The

[1] http://ladse.eng.isas.jaxa.jp/benchmark/

design problem is characterized by two-objective, many variables, and many constraints optimization problem.

The discrete width of the basic plate gauge is 0.05(mm) when it is less than 1.0(mm) and 0.2(mm) when it is 1.0(mm) or more. For example, in the case of a design space of 0.9(mm) to 1.2(mm), the plate gauges can be 0.90(mm), 0.95(mm), 1.0(mm), or 1.2(mm). The search range of design variables is from -0.3(mm) to +0.3(mm) from the initial part gauge of each vehicle model. For details, please refer to the Mazda benchmark website.

In benchmark problem, Radial Basis Function (RBF) implemented in commercial software Isight is used for constraint evaluations. For details, please refer to references [3, 4].

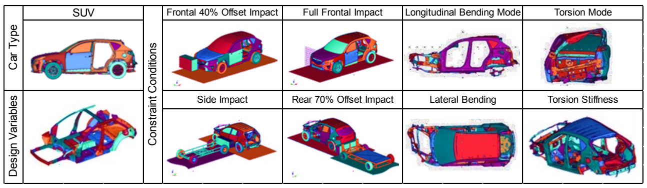

Figure 1: Car type is SUV, design variables and vehicles performance as constraints [1]. LV and SV are the same as SUV.

3 RESULTS AND DISCUSSION

Here, we present optimization result of Mazda CdMOBP by using NSGA-II implemented in Isight. The population size is 300, and maximum number of generation is 100 (total number of evaluations is 30000). The other parameters are the default value of Isight. Here we consider simultaneous design optimization of three types of cars.

Figure 2 shows the distribution of solutions in the objective function space. We can find a trade-off between objective functions. However, NSGA-II implemented in Isight find only 8 Pareto optimal solutions. Also, since the initial individuals of NSGA-II are random searches, the number of common gauge parts is small. Pareto optimal solutions can be improved more by setting the initial individual of optimization near the initial value. Figure 3 shows the percentage of infeasible solutions in each generation. More than 70% of the populations violate 20 or more constraints simultaneously in the initial optimization process. Even after 15 generations more than 50% of the population violates multiple constraints. Roughly speaking, 20% of populations violate two or more constraints even after 20 generations. The results in Fig. 2 and 3 are one trial experiment using NSGA-II.

4 CONCLUSION

We proposed a benchmark problem based on a real-world car structure design optimization (Mazda CdMOBP). This benchmark problem has two objectives, many discrete variables, and many constraints. We can consider simultaneous design optimization of two types of cars or three types of cars. In order to evaluate design candidates quickly, the constraint functions are approximated by a response surface method.

Computational result of NSGA-II implemented in Isight showed that Mazda CdMOBP has severe constraints and it is hard to find good Pareto-optimal solutions. We also found that feasible solutions and infeasible solutions distribute in mixture in objective function space. Optimization calculation of 300 individuals and 100 generations is possible in about 8 minutes by using RSM [1] We can verify many optimization methods in a short period of time.

In order to evaluate performance of optimization algorithms using Mazda CdMOBP, Hypervolume (HV)[3] can be a good indicator. We recommend normalizing the objective functions. For details, please refer to the Mazda benchmark website.

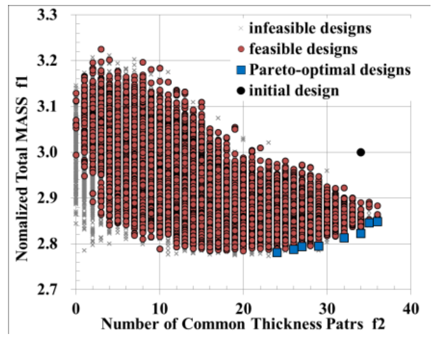

Figure 2: Distribution of solutions.

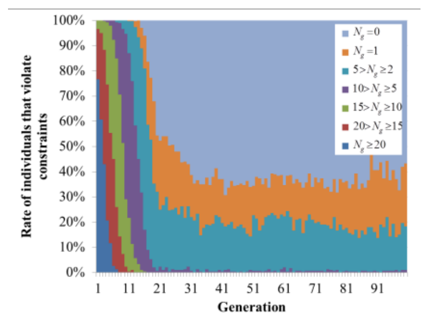

Figure 3: Percentage of individuals who violated constraint conditions in each generation

5 ACKNOWLEDGMENTS

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[3] https://www.3ds.com/products-services/simulia/products/isight-simulia-execution-engine/, accessed in January, 2017.

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[2] 2.6GHz, Intel Xeon, 32GB RAM and OS is 64bit Windows 7

[3] http://lopez-ibanez.eu/hypervolume