INTERNATIONAL DESIGN CONFERENCE - DESIGN 2002
Dubrovnik, May 14 - 17, 2002.

DESIGN 2002

Strategic Design: a Design Method to Manage the Design Framework

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Design, Strategic Design, Problem Framework, Evaluation Function, Knapsack Problem

1. Introduction

Engineering design can be generally described as “Generate and Evaluation” which means generating solution candidatures, and carrying out their evaluation[Cross 1996]. From this point of view, the method of design support can be divided into two kinds of support. One is for generating solution candidatures and another is for establishing the evaluation criterion. Many previous methods of design support were focused on generating candidatures for the design solution[Nagano et al. 1998]. In these studies, the evaluation criterion is fixed throughout the entire design process. The evaluation is decided according to whether the final solution meets the required specifications or not. On the other hand, the method of varying the evaluation criterion depending on the circumstances is also expected to yield a good design solution. For example, in the case of designing a machine which has a number of functions, it is better to improve the design solution to meet each requirement separately to consider all requirements at one time[Gero 1996]. This means that the evaluation criterion of solution candidatures must be changed dynamically as the process proceeds, which is the new design support method.

Next we take notice of the problem framework in the design process in order to generalize the above discussion. In engineering design, it is thought that the designer repeats two steps. One is to establish the problem framework for generating the design solution. Another is to search for and generate design solutions within the problem framework generated in the former step. Here we define the problem framework as a framework which contains the evaluation criterions of the design solution, varieties and scopes of parameters and constraints for the design. In other studies on engineering design, for example, optimization problems, the latter step has been discussed[Moire at el. 1998]. And the former step is discussed in the area of creative design[Oka et al. 2001][Kokodner et al. 1996][Haag et al. 2001][Nakakoji et al. 2000]. In those discussions, however, the framework is considered unchangeable throughout the entire design process. The idea of changing the problem framework dynamically has been employed in very few studies. In previous studies, the former problem and the latter problems have been discussed separately, but it is essential to combine them in the interests of generating better solutions more effectively.

In this study, we define “strategic design ” as the method of controlling the problem framework aggressively and purposely for effective design. We aim to establishing a methodology for “strategic design”.

In this paper, as the first step, we verify the efficiency of changing the evaluation criterion of the design solution in the design process through a computer simulation. Concretely, we suggest the hypothesis that there is a specific pattern for changing the problem framework through the design process for searching for solutions effectively.

2. Method of Study

2.1 Simulation Flow

Fig.1 shows the flow of the simulation in this study.

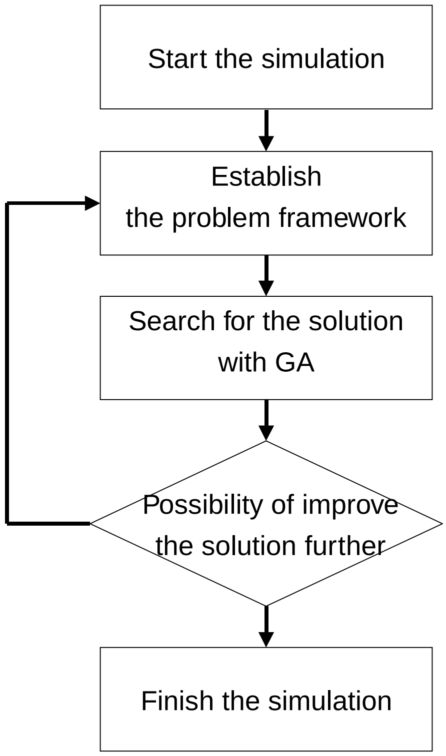


Fig. 1 Flow of the simulation

In this study, the evaluation function is the linear sum of a number of criterions with weights. The evaluation function is shown below.

$$E = \sum (Vi \times Wi)$$

E: Evaluation Function, Vi: ith Evaluation Criterion Wi: ith Weight

Wi is changed as the problem framework changes. The central criterion within the problem framework is given the weight of 1.0, and a criterion which is not centeral is given a wight according to the interval from the center of the problem framework. The weight is reduced by 0.1, as the interval from the center increases. If a criterion is outside the problem framework, the weight is 0 (zero).
Here, selecting a evaluation function is equivalent to selecting a problem framework. The design solution is searched for to fit the evaluation function with the genetic algorithm(GA). Searching for the solution with GA is continued until the value reached at 1.5 times of the initial value or it saturates.

2.2 Changing the Problem Frame

In this study, the propriety of the problem framework is evaluated by the total evaluation function as shown below.

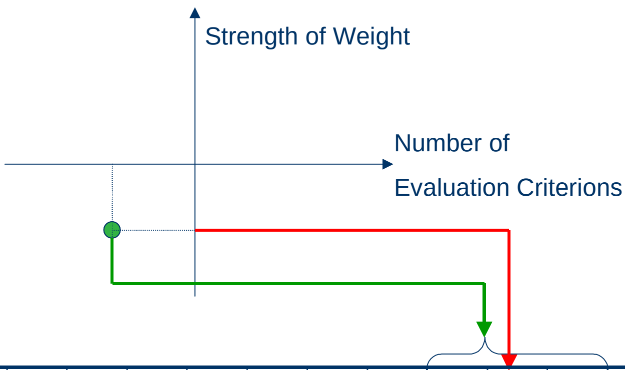
$$E_T = \sum (Vi \times W_{Ti})$$

E_T: Total Evaluation Function Vi: ith Evaluation Criterion W_T i: ith Weight for Total Value

After searching for the solution, the total evaluation function judges whether changing the problem framework will contribute to the improvement of the solution. If an improvement is expected, a new problem framework is generated. If not, the simulation is finished. The total evaluation function is used only to evaluate the problem framework, not to search for the solution.

2.3 Expression of the Problem Framework

In this study, the problem framework is presented by a coordinate with two axes. The vertical axis stands for the strength of the weights to be searched primarily. The lateral axis stands for the number of evaluation criterions to be selected. The origin is the averages of both the strength of weights and the number of evaluation criterions. For example, the point on the third quadrant in Fig.2 indicates a problem framework which includes few and weaker criterions than average.Here, Criterions A to K in order of strength are presumed. In this case, the problem framework has three criterions and the primary criterion to be searched aggressively is 0.2 of Criterion I.



Criterions	A	B	C	D	E	F	G	H	I	J	K
Weight (Wi)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	1.0	0.9	0.0
Weight for Total Evaluation (Wti)	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.0

Fig.2 Expression of the Problem Framework

3. Computer Experiment

3.1 Experiment 1

3.1.1 Experiment Conditions

We consider the knapsack problem, that is, to select proper PC parts. In this simulation, we prepare 40 parts which are classified according to information such as their performance, price and type (Tab.1).

Tab.1 Example of Parts

Type	Name	Performance	Price
CPU	Athlon 1.5G	63.60	15780
CPU	Pentium2 600	26.64	5000
Video Card	Monster 3DII	38.90	7590
Hard Disk	30G	37.50	11280
Drive	DVD	75.00	7980
Memory	64MB	2.72	1300
:	:	:	:

The evaluation criterions for evaluating the total PC performance are processing speed, graphic performance, capacity of hard disks, expansion, sound performance, multimedia performance, price and size in order of weight, as shown in Tab.2.

Tab.2 Evaluation Criterions

Evaluation Criterion	Processing Speed	Graphic	Capacity of HDD	Expansion	Sound performance	Multi media	Price	Size
Weight for Total Evaluation	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3

Under this condition, the processing speed is regarded as the most important, and the CPU and memory related to the processing speed are to be searched aggressively. In this experiment, the problem frameworks are set at random. The purpose of this experiment is to identify a certain pattern for changing the problem framework which leads to a highly evaluated result.

3.1.2 Result

We made 50000 patterns by changing the problem framework at random. After all of the simulations, each result is arranged in descending order of its total value (Fig.3). The lateral axis shows the simulation numbers, and the vertical axis shows the percentage of the total evaluation of each simulation against the maximum total evaluation. For convenience, results are classified into four classes, depending on their total evaluation. The difference between a highly evaluated pattern and a poorly evaluated one is shown in Fig.4.

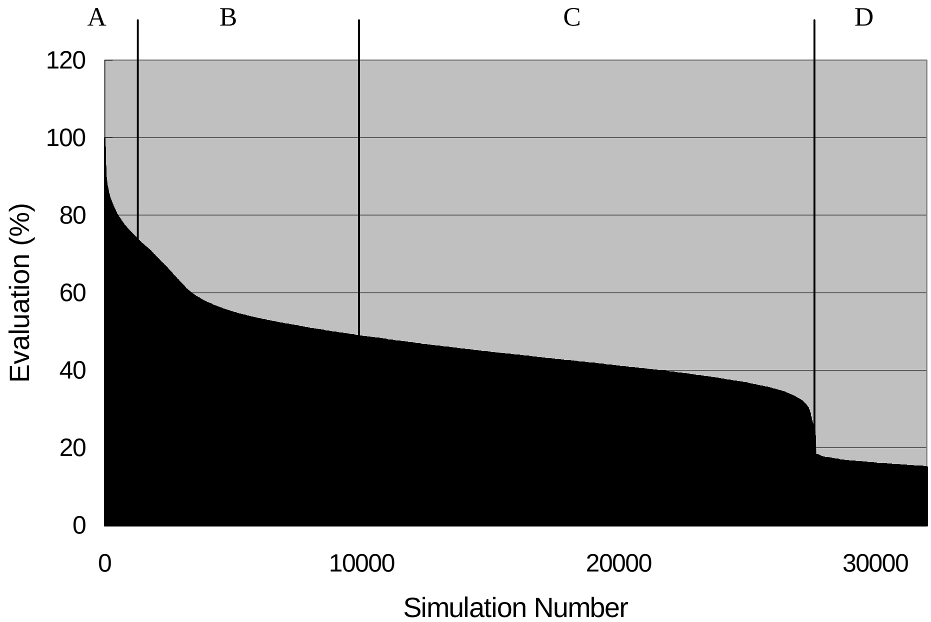
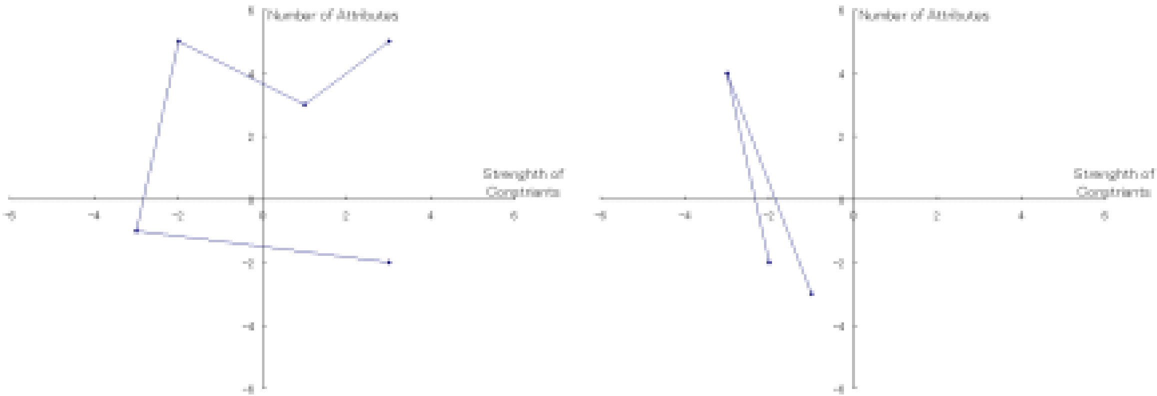


Fig.3 Evaluation and Class



a)Highly evaluated pattern **b)Poorly evaluated pattern**

Fig.4 Patterns of the Problem Frameworks

3.1.3 Analysis of Results

In this study, we analyze the result from next three viewpoints: 1) at which problem framework the design process begins, 2)the scope of the trace of the problem framework on the graph, 3)whether the trace of the problem framework on the graph has a certain pattern (clockwise or counterclockwise) Tabs.1~3 show the percentages.

Table 1 Beginning point of the traces

	1st quadrant	2nd quadrant	3rd quadrant	4th quadrant
A Class	19.6	8.3	29.6	42.5
B Class	42.3	17.1	9.6	31.0
C Class	18.0	3.1	27.8	46.8
D Class	24.6	42.2	25.7	4.4

Table 2 Scope of the traces

	1st quadrant	2nd quadrant	3rd quadrant	4th quadrant	All
A Class	72.7	60.1	72.9	83.2	15.9
B Class	71.0	55.5	62.0	83.8	9.6
C Class	60.9	54.8	72.2	89.2	3.8
D Class	30.6	57.5	40.4	8.0	0.0

Table 3 Pattern of the traces

	Clockwise	Counterclockwise	None
A Class	51.2	22.1	26.7
B Class	50.8	41.5	50.2
C Class	57.6	23.0	20.4
D Class	26.3	25.6	49.9

Considering the patterns on changing the problem framework in Class A and B, of which the results were highly evaluated, it is suggested that the following three characteristics contribute to the efficiency of searching for the design solution.

The trace of the problem framework
-starts in the 4th quadrant.
-covers all of the quadrants.
-proceeds clockwise.

3.2 Experiment 2

3.2.1 Experiment Conditions

The results of Experiment 1 suggest that a specific pattern of the problem framework leads to the solution being highly evaluated. Therefore we carried out the next experiment. In this experiment, the fundamental conditions are the same as for Experiment 1, however, the pattern of the problem framework is set not at random, but it is given arbitrarily based on Experiment 1.

Here we prepare four cases based on Experiment 1.

Case 1: The pattern of which the trace begins in the 4th quadrant and proceeds through the 3rd, 2^{nd} and 1st quadrants clockwise.

Case 2: The pattern of which the trace covers the same scope as for Case 1, but begins in the 1st quadrant and proceeds through the 2nd, 3rd, 4th quadrants counterclockwise.

Case 3: The pattern of which the trace covers the same scope as for Case1, but begins in the 2nd quadrant and proceeds through the 1st, 4th, 3rd quadrants clockwise.

Case 4: The pattern of which the trace begins in the 3rd quadrant and proceeds through the 2nd, 1st quadrants, but does not cover the 4th quadrant.

3.2.2 Result

Variations of the total evaluation in each class are shown in Fig.5.The vertical axis stands for the percentages of total evaluations in comparison with the final total evaluation in Case 1. The lateral axis stands for steps of changing the problem framework in each simulation.

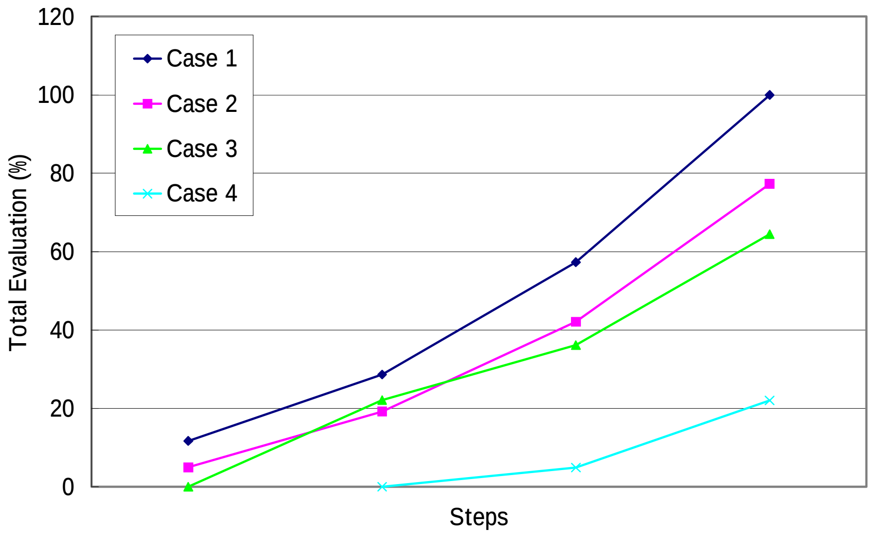


Fig.5 Variation of evaluations in each class

3.3 Summary of Experiments

Through Experiment 2, we verified that the three conditions suggested in Experiment 1 are valid for increasing the efficiency for searching for the solution. This is summarized below.

-The trace of the problem framework starts in the 4th quadrant.

If the designer starts to search for the solution, looking at only evaluation criterions which have strong weights, the search space becomes smaller in the initial design process, which may cause him/her to miss good solutions throughout the entire design process. Therefore, for an effective solution-search, the designer should start with a problem framework which includes many evaluation criterions of weak weights, as is presented in the 4th quadrant.

-The trace of the problem framework covers all of the quadrants.

Each quadrant has different characteristics to present to the problem framework which affect the solution-search, so every quadrant is important for high efficiency.

-The trace of the problem framework proceeds clockwise

It may be efficient for the problem framework not only to cover all of the quadrants but also to change with a certain pattern. First, many evaluation criterions of smaller weights should be considered. After the solution has been improved to a certain degree, the considered evaluation criterions should be diminished gradually, transiting to evaluation criterions of strong weights. Finally, as many evaluation criterions as possible should be considered in order to obtain the solution.

In addition to the above, we found that transiting between the 1st quadrant and the 4th quadrant does not contribute to an efficient solution search. Doing so would change the design target while looking at many criterions. This could result in redesigning which ignores the first design.

4. Conclusion

In this study, we suggested a method of strategic design which changes the problem framework deliberately. For the knapsack problem which we considered in this study, changing the problem framework dynamically in each design process lead us effectively to a solution. We also suggest that there are specific patterns for changing the problem framework. As a further study, we must discuss in detail the relationship between the pattern for changing the problem framework and the efficiency of design, in order to generally describe the theory.

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