COLLABORATION SUPPORT SYSTEM BASED ON THE ASSESSMENT OF CREATED IDEAS USING DATA ENVELOPMENT ANALYSIS

Masakazu Kobayashi[1], Masatake Higashi[1] and Masataka Yoshimura[2]

[1]Toyota Technological Institute
[2]Kyoto University

ABSTRACT

This paper focuses on the creative aspects of collaboration and proposes a support system consisting of a method for analyzing ideas created by designers during collaborative design projects and a method for visualizing interactive communication processes among designers in order to enhance designers' creativity. The analytical method analyses created ideas using DEA (Data Envelopment Analysis) and reveals characteristics and overall effectiveness of each idea, relationships between ideas from the various viewpoints and potentially fruitful directions for improvement of created ideas or exploration of new ideas. By following these indications, designers can explore more sophisticated ideas efficiently and effectively. Whereas, the visualization method that was originally developed in our previous works makes interactive communication processes among designers visible from the two viewpoints: the flow of its process and the relationships between design goals and created ideas. Using this method, designers can engage in more active discussions, share idea exploration spaces and explore a wider range of ideas. In addition, we also develop a computerized support system to enable smooth operation of above two methods and conduct the case study using the computerized support system in order to confirm the effectiveness of the proposed support system.

Keywords: Design engineering, Creative design, Collaboration, Assessment of ideas, and Data envelopment analysis

1   INTRODUCTION

Collaboration is a process where the efforts of a group of participants are facilitated by sharing expertise, ideas, resources or responsibilities [1]. The advantage of collaboration is the increased ability to achieve complex large-scale and multidisciplinary problems, which no man can achieve alone. In addition to such advantage, collaboration offers an additional potential benefit in terms of enhancing group members' creativity. During the collaboration processes, group members cooperate by exchanging ideas, opinions and various information, which can stimulate their creativity and increase their chances of generating new ideas [2]. Collaboration is not the new concept but its importance is gradually recognized in these days.

Collaboration has been a research subject for many years, and such efforts can be classified into two main categories: theoretical research concerning the mechanism of the collaboration process, and research that addresses the construction of support methods. Theoretical researches are conducted mainly in the fields of psychology and cognitive science. Researches of support methods are conducted in the engineering field and can be roughly organized into the several areas such as (1) communication support [3][4], (2) knowledge management [5][6] and (3) distributed design environments [7][8]. However, there are few researches that focus on the creative side of collaboration and support designers' creativity. In our previous researches [9][10], we focused on the creative side of collaboration and proposed a support system that enhances designers' creativity during collaborative design activities. This system consists of following two visualization procedures. The first procedure makes visible the flow of interactive communication among designers, which enables smooth interactive communication. The second one makes visible the relationships between ideas, design concepts and design goals, which enables sharing of exploration space and wide range of idea exploration.

On the other hand, this paper proposes a new method for analyzing ideas created by designers during collaboration. This method analyzes ideas using DEA (Data Envelopment Analysis) and reveals overall effectiveness of each idea, relationships between ideas from the various viewpoints, and potentially fruitful directions for improvement of existing ideas or exploration of new ideas. By following these indications, designers can efficiently and effectively create more sophisticated ideas. In this paper, we use this analytical method with our visualization method proposed in the previous researches in combination because the function of this method is limited to the analysis of ideas. In such scenarios, exploration of ideas with the support of visualization method and analysis of created ideas are conducted alternately.

The rest of this paper is organized as follows. Section 2 describes the details of data envelopment analysis. Section 3 describes the proposed methods and section 4 describes development of computerized support system that facilitates designers using the proposed methods. To demonstrate the effectiveness of the proposed method, we conduct experiments for the group of undergraduate students, as described in Section 5. Finally, Section 6 summarizes the results of this paper.

2   DATA ENVELOPMENT ANALYSIS

Data Envelopment Analysis (DEA) is a method for measuring and comparing relative efficiency of multiple objects where each object has multiple inputs and outputs, developed by Charnes et al. [11]. Over the past two decades, Data Envelopment Analysis (DEA) has emerged as an important tool in the field of efficiency measurement [12].

In general, efficiency of an object is defined by output/input ratio. However, this calculation method is often inadequate due to the existence of multiple inputs and outputs. In such cases, relative efficiency, defined by the following equation (1), is used.

$$Relative\ efficiency\ \theta = \frac{\sum_{j} u_j \times y_j}{\sum_{i} v_i \times x_i} \tag{1}$$

Where, x_i is amount of input i (i=1,2,…,m), y_j is amount of output j (j=1,2,…,n), v_i is weight given to input i, u_j is weight given to output j. In this measurement, a common set of weights needs to be applied across all objects. However, relative efficiency of objects varies with changes in a common set of weights, so this raises the problem of how such an agreed and appropriate common set of weights can be obtained.

On the other side, Data Envelopment Analysis dose not use a common set of weights to determine relative efficiency of multiple objects. Instead of a common set of weights, DEA allows each object to individually have a set of weights that shows it in the most favorable light in comparison to the other objects. This enables fair comparison between multiple objects. The details of calculation procedure are described in the following section.

2.1   Calculation procedure of DEA

In DEA, each object is called decision making unit (DMU). Now, we assumed that there are s number of decision making units DMU_k (k=1,2,…s) having m number of inputs x_{ik} (i=1,2,…,m), n number of outputs v_{ik} (i=1,2,…,n), m number of weights given to input i v_{ik} (i=1,2,…,m) and n number of weight given to output j u_{jk} (j=1,2,…,n). Under these assumptions, efficiency of DMU_p can be calculated as:

$$Maximize\ \theta_p = \frac{\sum_{j} u_{jp} \times y_{jp}}{\sum_{i} v_{ip} \times x_{ip}} \tag{2}$$

Subject to:

$$\frac{\sum_{j} u_{jp} \times y_{jk}}{\sum_{i} v_{ip} \times x_{ik}} \le 1 \quad (k=1,2,...s) \tag{3}$$

$$v_{1p}, v_{2p}, ...v_{mp} \ge 0, \ u_{1p}, u_{2p}, ...u_{np} \ge 0 \tag{4}$$

The variables of the above problem are input and output weights. This calculation produces the weights most favorable to DMU$_p$ and measures its efficiency. Because of equation (3), maximum efficiency is limited to 1.

The DEA model described above is a fractional linear program. To calculate quickly and efficiently, this model is converted into linear form as described below and then is solved as linear program.

Primal objective function:

$$Minimize \ \theta_p \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad (5)$$

Secondary objective function:

$$Minimize -\mathbf{es_x}-\mathbf{es_y} \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad (6)$$

Subject to:

$$\theta_p \ \boldsymbol{x_p} = \boldsymbol{X\lambda} + \boldsymbol{s_x} \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad (7)$$

$$\boldsymbol{y_p} = \boldsymbol{Y\lambda} - \boldsymbol{s_y} \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad (8)$$

$$\theta_p \geq 0 \ , \ \ \lambda \geq 0 \ , \ \ s_x \geq 0 \ , \ \ s_y \geq 0 \qquad\qquad\qquad\qquad\qquad\qquad (9)$$

Where $\boldsymbol{X}$ and $\boldsymbol{Y}$ are respectively input and output matrix consisting of x_{ik} and y_{ik}, $\boldsymbol{s_x} = (s_{x1}, s_{x2}, \ldots, s_{xm})$ and $\boldsymbol{s_y} = (s_{y1}, s_{y2}, \ldots, s_{yn})$ are the slack variables of input and output, $\boldsymbol{\lambda} = (\lambda_1, \lambda_2, \ldots, \lambda_s)$ are also variables and $\boldsymbol{e} = (1,1,\ldots 1)$. If the solutions to above problem are $\theta_p^* = 1$, $\boldsymbol{s_x}^* = \boldsymbol{0}$ and $\boldsymbol{s_y}^* = \boldsymbol{0}$, DMU$_p$ is indeed efficient. In other cases, DMU$_p$ is inefficient even if θ_p equals 1. Efficient DMUs can be enveloped by line or surface, they are called as efficiency frontier in DEA. Fig.1 illustrates efficient and inefficient DMUs and efficiency frontier. This example is one input and two outputs model and output1/input is plotted on the X-axis as criteria1 and output2/input is plotted on the Y-axis as criteria2. In this example, DMU1, 2 and 3 are efficient and the convex line that connects these DMUs is efficiency frontier.
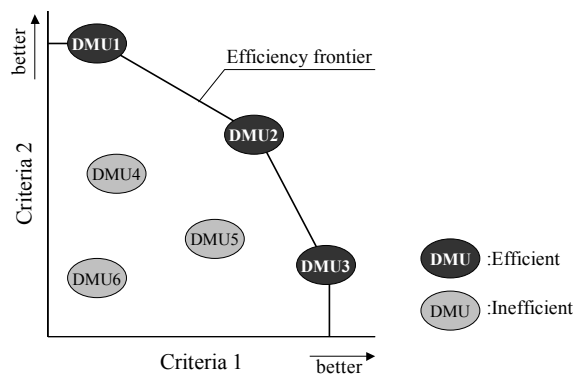

Figure 1. Efficiency frontier

If DMU$_p$ is inefficient, there are DMUs that are superior to DMU$_p$. The set of these DMUs is called reference set E$_p$. Whether a certain DMU belongs to E$_p$ or not can be identified according to the following equation (10). All of DMUs belonging to E$_p$ are efficient.

$$E_p = \{DMU_k \ | \ \lambda_k^* > 0, \ k=1,2,\ldots s\} \qquad\qquad\qquad\qquad\qquad (10)$$

If DMU$_p$ is inefficient, DMU$_p$ can become efficient by modify its inputs $\boldsymbol{x_p}$ and outputs $\boldsymbol{y_p}$ according to equations (11) and (12).

$$\boldsymbol{x_p} \Rightarrow \theta_p^* \boldsymbol{x_p} - \boldsymbol{s_x}^* \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad (11)$$

$$\boldsymbol{y_p} \Rightarrow \boldsymbol{y_p} - \boldsymbol{s_y}^* \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad (12)$$

In fact, there are innumerable solutions to improve DMU$_p$ to efficient, but the solution as described in equation (11) and (12) can improve DMU$_p$ to efficient with minimum effort.

2.2 Hierarchization of DMUs based on the efficiency

When DEA is executed, all DMUs can be classified into efficient and inefficient. Then, the second DEA is executed using DMUs that are classified into inefficient in the first DEA, these DMUs are also classified into efficient and inefficient. If DEA is repeatedly executed using DMUs that are classified into inefficient in the previous DEA, all DMUs can be hierarchized based on the efficiency. Fig.2 illustrates the concept of this operation. DEA also can calculate reference set that shows the relationships between efficient DMUs and inefficient ones so hierarchical diagram as shown in Fig.3 is finally obtained.
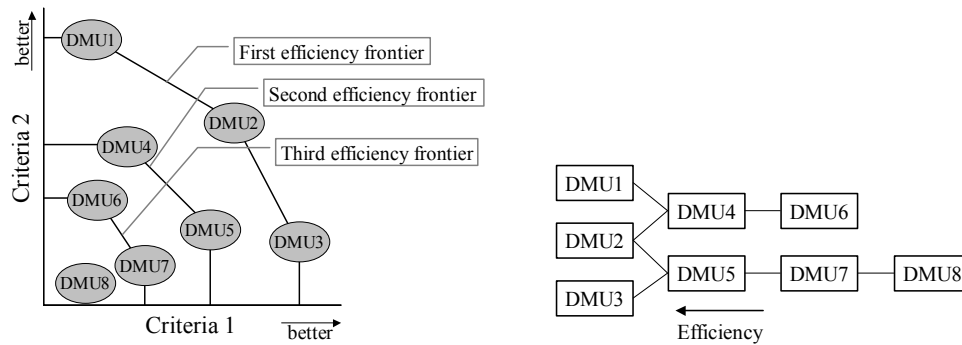
Figure 2. Hierarchization of DMUs (left) and Figure 3. Hierarchical diagram (right)

2.3 Application of DEA into the assessment of ideas

To apply DEA into the assessment of ideas, we make the connection between items of DEA and items of idea assessment.

(1) DMUs

We apply ideas created by the designers during collaboration to DMUs. Each idea is applied into each DMU so the number of DMUs equals to the number of ideas.

(2) Input

When assessing ideas, there is no item that needs be applied into input, so each idea has one input having fixed value equal to 1.

(3) Output

In this paper we assumed that collaborative activity is the process where multiple performances of the product is required to be improved and designers cooperatively explore promising ideas that improves product's performances. In such scenario, the worth of an idea is based on how the idea contributes to improvement of each product's performance. Therefore, when assessing ideas using DEA, created ideas are evaluated from such viewpoint and their results are used as outputs. There are multiple performances that need to be improved, so each idea has multiple outputs that equal to the number of performances needs to be improved. The details of evaluation procedure are described in section 3.2.

(4) Efficiency

The efficiency of the idea is defined as an overall contribution to improvement of product's performances. The higher efficiency of the idea, the better the idea totally.

3.COLLABORATION SUPPORT SYSTEM BASED ON IDEA ANALYSIS

Idea exploration is the inefficient activity where designers try to find out promising ideas that solve given problems from the vast exploration space by their trial and error processes. In such vast exploration space, there is no guarantee that designers can find out superior ideas without any hint or suggestion.

To overcome these difficulties, this paper proposes the method that assesses created ideas and indicates potentially fruitful directions for improvement of created ideas or exploration of new ideas. By following these indications, designers can effectively and efficiently explore promising ideas from such vast exploration space. To assess ideas, DEA, as described in Section2, is used in this method.

Idea exploration activity using this method consists of two processes, (1) idea exploration process and (2) idea assessment process, where designers gradually explore promising ideas by alternating these two processes, as shown in Fig.4. The following sections explain the details of each process.
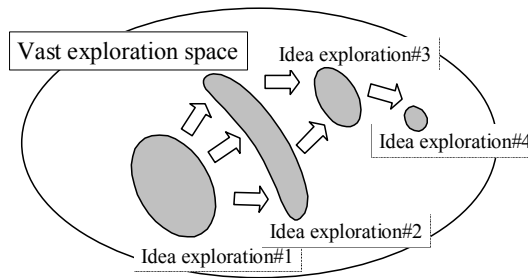

Figure4. Evolutional idea exploration processes

3.1 Exploration of ideas

In this process, designers cooperatively explore as many ideas as possible. To support the idea exploration process, communication support method, developed in our previous researches [9][10], is used. This method consists of following two visualization procedures. The first procedure makes visible the flow of interactive communication among designers during idea exploration processes in the form of session tree structures, whereas the second one makes visible the relationships between ideas, design concepts and design goals in the form of a relational tree diagram. We provide a brief explanation about these visualization procedures here because of space limitation. Please see the details in our previous works [9][10].

(1) Visualization of interactive communication flow

This procedure makes visible interactive communication flow in the form of session tree structures. In this procedure, the designers' actions during idea exploration are classified into two types: presentation of ideas and discussion of ideas. Using these two types of basic actions, interactive communication flow can be represented as a collection of elements that consist of a presentation of a new idea and a sequence of discussion. Here, each element that has several related actions is treated as a basic unit of interactive communication process and is termed a "session". Each session consists of a single initiating action, such as the presentation of a new idea, and several subsequent actions related to or triggered by the initial action, such as discussion of the idea. The former is called a trigger action, the latter a response action. New response actions can occur in response to a trigger action or to any previously presented response action that develops during a session. The relationship between a given trigger action and the subsequent sequence of response actions can thus be visualized as a tree structure, as shown in fig.5. Explicit visualization method, as described here, helps designers manage the flow of intercommunication processes during creative group activity, so that designers can engage in more active discussions that stimulate creative thinking.
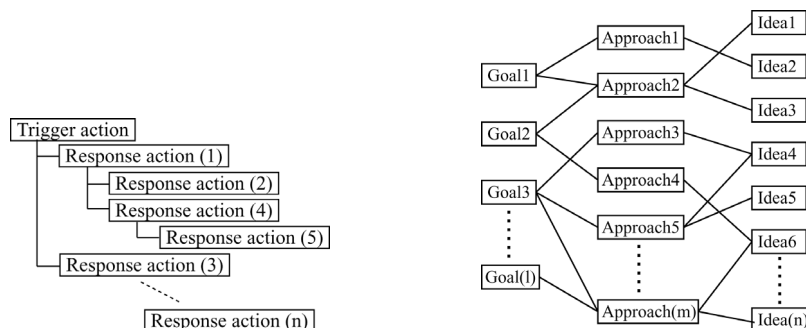

Figure 5. Session tree structure (left) and Figure 6. Relational tree diagram (right)

(2) Visualization of relationships between ideas, design concepts and design goals

Generally, when people explore a new idea during problem solving or creative activity, they begin by unconsciously or consciously considering a general direction that would help solve the creative problem, and then specific details concerning the new idea are fleshed out. A general direction can be

translated in a concept or an outline of a new idea. In this paper, this type of general direction is termed an "approach". When an approach is defined, the relationships between design goals, approaches and ideas can be visualized as a relational tree diagram, as shown in fig.6. The use of the relational tree diagram enables designers to share idea exploration space and to explicitly explore conceptual approaches and then create concrete ideas, so they can explore a wider range of ideas than when not using such a diagram.

3.2 Assessment of ideas using DEA

In this process, ideas created during the idea exploration process are assessed and potentially fruitful directions for further exploration are revealed. These indications are utilized in the further idea exploration process. Assessment procedure consists of three steps, (1) evaluation of ideas by designers, (2) execution of DEA and (3) analysis of the results of DEA. The following sections explain the details of each step.

3.2.1 Evaluation of ideas by designers

In the first step, contribution of ideas to improvement of each performance is evaluated. Specifically, designers individually grade all ideas on a scale of 1 to 5 from the viewpoint of how each idea can improve each product's performance. The results of grading executed by each designer are then tallied and used as outputs of DMUs (ideas) in the next step. Contribution of each idea to improvement of each performance is evaluated individually, so the number of evaluations that needs to be executed by each designer equals to the total number of ideas multiplied by the total number of evaluated performance.

3.2.2 Execution of DEA

In the second step, DEA is executed and the efficiency of each idea is calculated.

3.2.3 Analysis of the results of DEA

In the third step, designers analyze the results of DEA and reveal the potentially fruitful directions for improvement of created ideas and exploration of new ideas, which enable effective improvement of performances, from four viewpoints. The following section explains the details of these viewpoints.

(1) Efficiency

The efficiency of the idea indicates how the idea is good. Designers can explore more promising ideas with less effort by improving existing high efficiency ideas or exploring new ideas based on them.

(2) Improvement of inefficient ideas

As described in Section 2.1 a solution to modify inefficient ideas into efficient with minimum effort can be obtained quantitatively. Therefore designers can explore efficient ideas effectively by modifying the inefficient ideas according to the calculated solution.

(3) Hierarchization of ideas based on the efficiency

Hierarchical diagram based on the efficiency, as described in Section 2.2, helps designers to understand the relationships between the quality of ideas and the relationships between characteristics of ideas. Hierarchical diagram shows the relationships between ideas having similar contribution to improvement of product's performances, independently of their physical content i.e. similarity of mechanisms, structures or devices. Therefore, designers can get a hint for new ideas or improvement of existing ideas by analyzing similarities and differences between ideas from hierarchical diagram.

(4) Relationships between the efficiency and contribution of ideas to each design goal

When the designers try to modify existing ideas or explore new ideas based on existing ideas, the success of designers' trial largely depends on not only which idea designers focus on but also which performance of the focused idea designers try to improve. Therefore, as the fourth viewpoint, the relationships between the efficiency and contribution of ideas to improvement of each design goal are visualized, which reveals that which ideas and which performance designers should focus on.

Fig.7 is a graph with the efficiency on the y-axis and contribution to a specific design goal$_i$ on the x-axis. One graph shows the relationships between the efficiency and the contribution to one design goal,

so same number of graphs as the number of design goal need to be drawn in order to analyze ideas from all aspects.

When designers focus on improvement of a specific design goal and try to modify existing ideas or create new ideas, the graph that shows the relationships between the efficiency and the contribution to a specific design goal can be utilized. We'll explain about how to utilize the graph by taking Fig.7 as an example. This graph shows the relationships the efficiency and contribution to design goal$_i$. According to Fig.7, the efficiency of idea 1, 2 and 3 is approximately 1. Contribution of idea 1 to design goal$_i$ is high, so idea 1 has strong relation to design goal$_i$, whereas, contribution of idea 3 to design goal$_i$ is zero, so idea 3 has no relation to design goal$_i$. There is certain design goal except design goal$_i$ that has strong relation to idea 3 because the efficiency of idea 3 is approximately 1 though the contribution to design goal$_i$ is zero. Idea 2 is intermediate between idea 1 and 3.
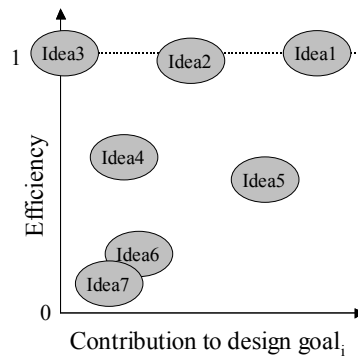
Figure 7. Relationships between efficiency and contribution to design goal$_i$

Next, we analyze fruitful directions for enhancing contribution of ideas to the improvement of design goal$_i$, based on above consideration. In Fig.7, the efficiency of idea 1, 2 and 3 is approximately 1, so it is better to focus on these ideas, according to the viewpoint of (1). However, idea 3 has no relation to design goal$_i$, as described above, so it is pretty difficult to modify idea 3 for enhancing its contribution to design goal$_i$. Therefore, it is better to modify idea 3 for enhancing the other design goal. Modifications of ideas that have already high contribution to improvement of design goal$_i$ like idea 1 are also difficult and ineffective. However, the success of such modification greatly improves their efficiency, so if designers have some sort of ideas, such challenges are worth being done. In contrast, concerning ideas that have moderate contribution like idea 2, there is a lot of alternatives and room for improvement. However, compared to the modification of ideas like idea 1, the amount of improvement of their efficiency by enhancing their contribution is small. Therefore, it is better to balance modification of ideas like 1 and 2. Here, we focus on one graph, but in practice designers try to improve existing ideas or explore new ideas using all graphs in parallel.

This paper shows four viewpoints, as described above, but these viewpoints only reveal fruitful directions for further idea exploration. Idea exploration itself is the task of designers, so designers cooperatively discuss the result of idea assessment from the above viewpoints and work on the further idea exploration using visualization procedures, as described in 3.1.

4. COMPUTERIZED SUPPORT SYSTEM

When the method proposed in this paper is used in practical collaboration, there are two difficulties. The first difficulty concerns the management and the visualization of interactive communication processes as a collection of tree structures and a relational tree diagram, which would be cumbersome if attempted manually. The second concerns execution of DEA and visualization of the results for analyzing created ideas during idea exploration. To calculate the efficiency of each idea, dozen of linear programming problems need to be solved. To resolve these problems and enable smooth collaboration, we construct a computerized support system. This system is programmed using Microsoft Excel and Visual Basic for Applications (VBA). Excel is used for recording interactive communication processes and solving DEA, whereas VBA programs provide GUI of this system. In addition, this system also contains Web server, so designers can access this system via a computer network.

4.1 Visualization of interactive communication processes

Fig.8 shows a screenshot of Excel that displays communication processes from two viewpoints and input window. Figs. 9 and 10 zoom in examples of visualized communication flow and visualized relationships between ideas, design concepts and design goals, respectively. All of interactive communications among designers are recorded and displayed in these manners. Fig.11 shows a screenshot of a Web browser when designers access the visualization program via network. Designers can input their ideas, opinions and comments into the visualized program and browse visualized communication processes via a Web browser.
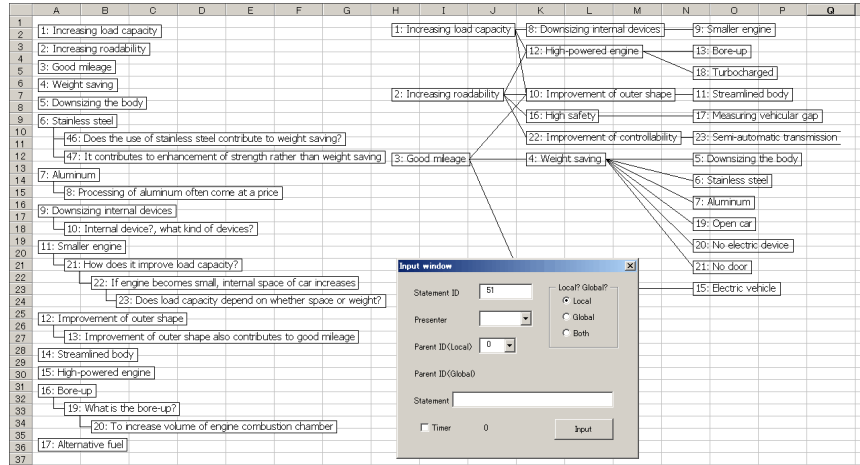

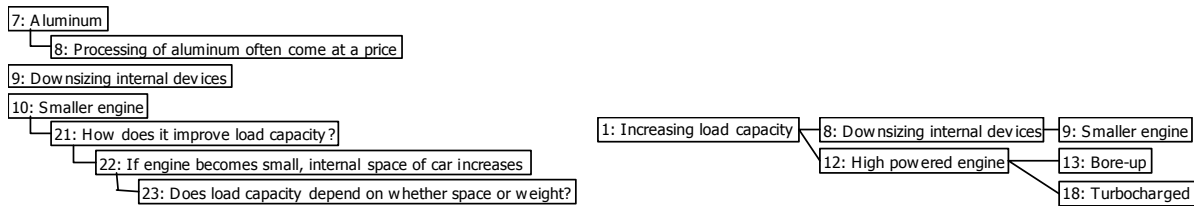*Figure 8. Display of communication processes from two viewpoints*

Figure 9. Examples of visualized communication flow (left), and Figure 10. Examples of visualized relationships between ideas, design concepts and design goals (right)
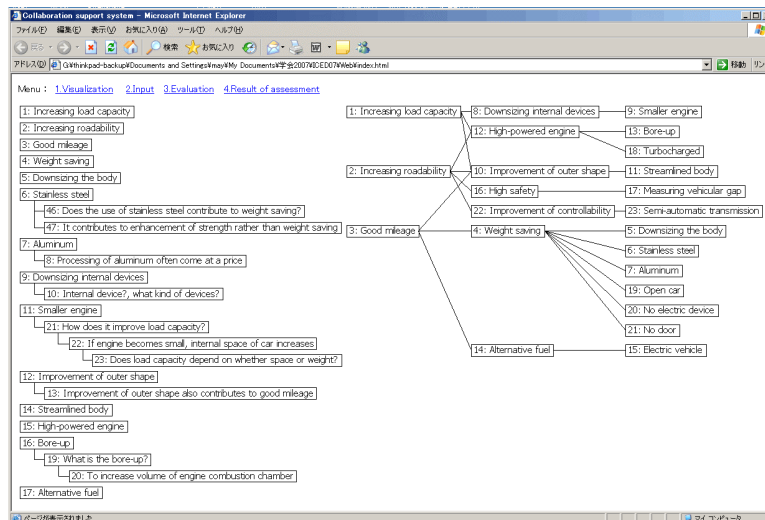

Figure 11. Display of communication processes (via Web browser)

4.2 Assessment of ideas

During idea assessment process, designers access individually evaluation form via Web browser, as shown in Fig.12, and evaluate the contribution of each idea to the improvement of each performance

on a scale of 1 to 5 by checking a radio button. The assessment program then counts the scores, executes DEA and displays the results of DEA in several forms, as described in Section 3.2.2. Fig.13 shows an example of such report. In Fig.13, three graphs that represent relationships between the efficiency and contribution to the improvement of one design goal and a graph that represents hierarchical relationships between ideas based on the efficiency are displayed. Numbers displayed in these graphs stand for ideas' ID. Fig.14 shows magnified view of one of the graphs displayed in Fig.13. Designers can also browse these results via Web browser.
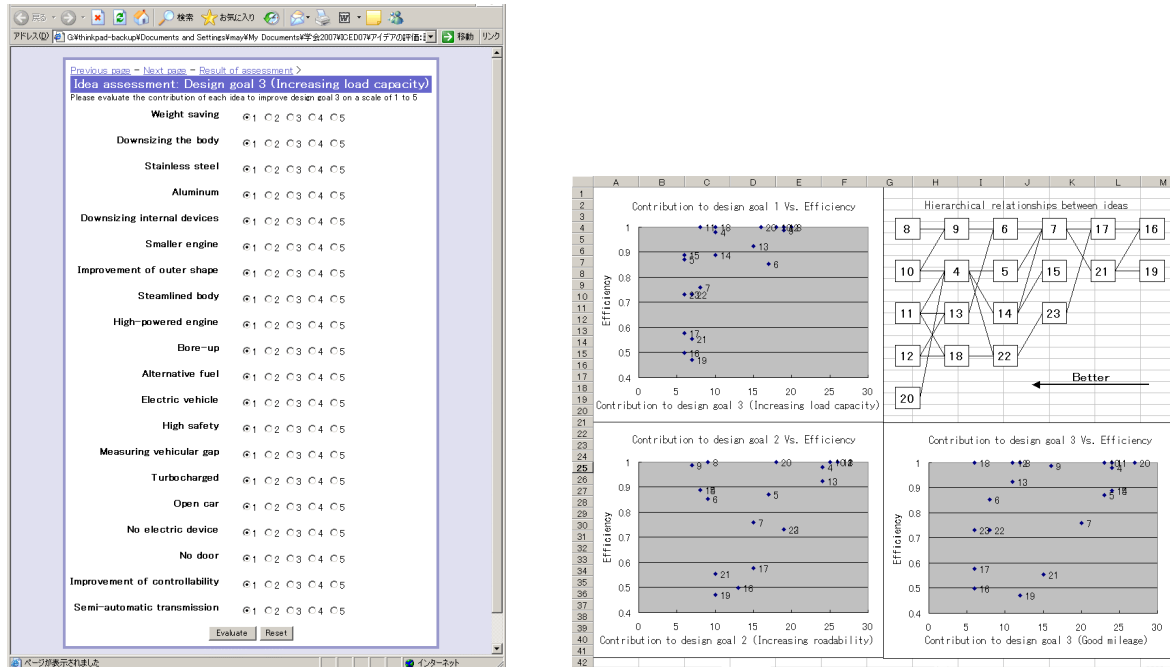

*Figure 12. Entry display for evaluating ideas (via Web browser) (left),
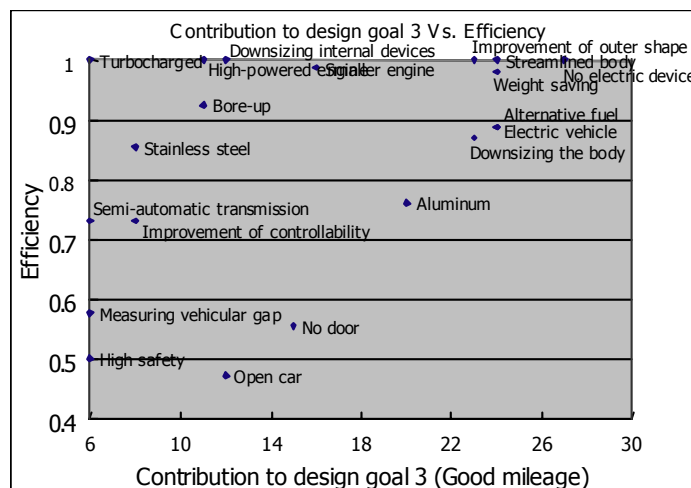and Figure 13. DEA report display (right)*

Figure 14. Example of graphs

5.CASE STUDY

To test the effectiveness of the proposed method, a case study is conducted. To enable comparison, two experiments are performed, one where the proposed method and the computerized support system are used, the other where they are not used.

5.1 Experimental conditions

In this case study, sixteen undergraduate students, of department of science and engineering in Waseda University, are organized into two experimental groups (Group1 and Group2). This case study consists

of two experiments, so each group conducts one experiment. In each experiment, Group1 did not use the proposed method and the computerized support system, whereas Group2 use them. In this paper, we describe the experiment conducted by group1 as "Exp.1" and the experiment conducted by group2 as "Exp.2."

The design subject of both experiments is a cellular phone and the design goals are (1) to provide functions in addition to a basic verbal communication function, (2) to improve usability and (3) to provide extended battery life. In both experiments, participants are asked to cooperatively create and discuss as many ideas that can achieve the design goals as possible within a limited time frame. The duration of Exp.1 (the proposed method is not used) is limited to 40 minutes, whereas Exp.2 (the proposed method is used) consists of (Step.1) 30 minutes first idea exploration, (Step.2) first assessment of ideas, (Step.3) 10 minutes second idea exploration and (Step.4) second assessment of ideas. Note that second assessment process is only conducted for analysis of experimental results, as described in the next section, so its results are not used for idea exploration during Exp.2. Total duration of idea exploration process during Exp.2 is 40 minutes, which equals to the duration of Exp.1. All processes of both experiments are recorded with a voice recorder.

5.2 Analysis of experimental results

The purpose of the proposed method is to help designers explore sophisticated ideas effectively, so we analyze the results of two experiments from the viewpoint of the quality of the created ideas, based on the following hypotheses.

Hypothesis 1: Proposed method is not used (Exp.1)
The quality of created ideas does not vary throughout an experiment.

Hypothesis 2: Proposed method is used (Exp.2)
Ideas explored during 10 minute second exploration process is superior to ideas explored during 30 minute first exploration process.

Concerning ideas explored during Exp.2, the efficiency of ideas are calculated by DEA during the experiment, so we use their efficiency for evaluating the quality of ideas and verify above two hypotheses. Concerning ideas explored during Exp.1, these ideas are not assessed during Exp.1, so we evaluate these ideas on a scale of 1 to 5 after the experiment and calculate their efficiency using DEA, which is the same way as the proposed method described in Section 3.2.1 and Exp.2.

Table 1. Results of evaluation of ideas

	Group1: Proposed method not used		Group2: Proposed method used	
	# of ideas	Mean value	# of ideas	Mean value
1st half	20	0.8334	24	0.8324
2nd half	12	0.7183	11	0.8860
Variations		-13.82%		6.44%

Table 1 shows the number of ideas created during 1st and 2nd halves of idea exploration process, the average efficiency of ideas explored during each half and the rate of change of the average efficiency between 1st and 2nd halves. Exp.1 consists of only 40 minutes idea exploration, so we divide into first 30 minutes exploration process and second 10 minutes process and calculate each item.

Table 1 shows that the average efficiency during second 10 minutes process is lower than the one during first 30 minutes process in Exp.1, where the proposed method is not used. We guess that this is why (a) participants have explored most of promising ideas during first 30 minutes so they cannot find additional promising ideas during second 10 minutes and (b) participants continue to explore new ideas for a total of 40 minutes without break time in Exp.1 so their concentration decreases with time. Although this result slightly differs from the hypothesis 1, but the average efficiency does not increased with time at least. Therefore, we consider the hypothesis 1 is verified.

In contrast, concerning Exp.2, where the proposed method is used, table 1 shows that the average efficiency of ideas explored during 2nd half of exploration process is higher than the one during 1st half. This fact shows that the hypothesis 2 is true.

These analyses show the effectiveness of the proposed method and the computerized support system.

6.CONCLUSION

This paper proposes a collaboration support system based on assessment of ideas using DEA and visualization of interactive communication processes. The following points were addressed.

(1) To help designers to explore promising ideas effectively and efficiently, the method for assessing created ideas is proposed. This method analyzes ideas using DEA, and reveals potentially fruitful directions for improvement of created ideas or exploration of new ideas. Such indications is utilized in further idea exploration process.

(2) To support interactive communication processes among designers, visualization method is used with the method for assessing ideas. This method was originally developed in our previous researches and visualizes interactive communication processes from viewpoints.

(3) To enable smooth operation of above two methods, the computerized support method is developed. This system contains Web server, so designers can individually access the system via network.

(4) To confirm the effectiveness of the proposed method, a case study is conducted. Two experiments are performed, one where the proposed method is used, the other where it is not used. By comparing the results of two experiments, the effectiveness of the proposed method is confirmed.

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Contact:
Masakazu Kobayashi

Toyota Technological Institute
Department of Information-aided Technology
2-12-1, Hisakata, Tempaku-ku, Nagoya City, 468-8511, Japan
TEL: +81-52-802-1784
FAX: +81-52-809-1789
kobayashi@toyota-ti.ac.jp