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A Proposal of Design Method Based on Hierarchical Design Model and an Application for Automotive Seat Designs

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1. Introduction

1.1. Background

In the early process of design where a conceptual design and a basic design are done, a structural model is often used by designers. On the other hand, in the late process of design where a detailed design is done, a mathematical model is often used by engineers. In the conventional studies, the design methods that contribute to each model have been proposed. However, a design method that has an ability to support the building of both models has not been proposed.

In proposing such a design method, a viewpoint that has an ability to deal comprehensively with the early and the late process of design is necessary. As a design model that provides such viewpoint, the Hierarchical Design Model (Matsuoka, 2005) has been proposed as shown in Figure 1. In addition, as a design method that reflects the features of Hierarchical Design Model, the Quality Function Deployment based on the Hierarchical Design Model (Hierarchical QFD) has been proposed as shown in Figure 2. Therefore, the Hierarchical QFD is expanded into a design method that properly connects the structural model building in the early process of design to the mathematical model building in the late process of design. Consequently, it is possible to propose a new design method that has an ability to support the building of both models.

1.2. Purpose

In this study, firstly, a design method that has an ability to support the building of both structural and mathematical models is proposed by expanding the Hierarchical QFD that reflects the features of Hierarchical Design Model. Secondly, the effectiveness of the proposed design method is verified by applying it to automotive seat designs.

Figure 1. Hierarchical Design Model.

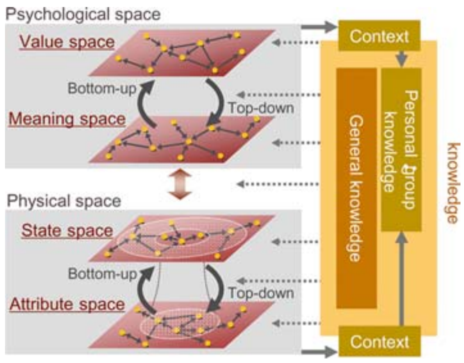


Figure 2. Hierarchical QFD.

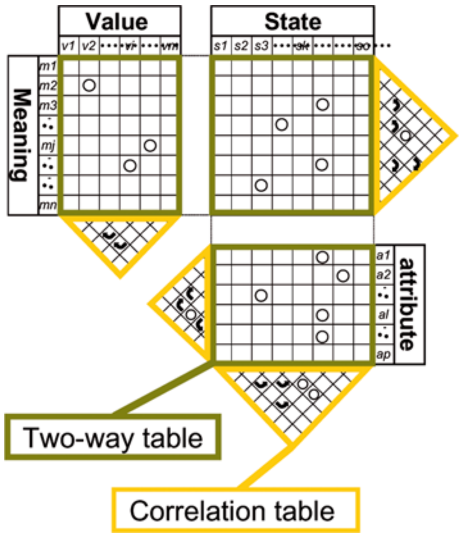
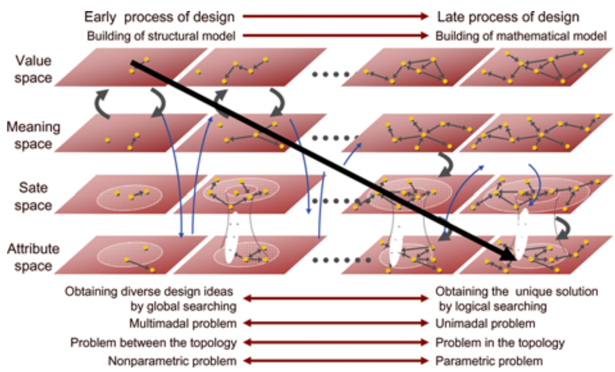


Figure 3. The early process of design to the late process of design.



2. Hierarchical Design Model

This chapter describes the general appearance of the Hierarchical Design Model and the Hierarchical QFD that reflects the features of Hierarchical Design Model.

2.1. The General Appearance of Hierarchical Design Model

As a design theory expanded from General Design Theory (Yoshikawa, 1979), the Hierarchical Design Model has been proposed by Matsuoka as shown in Figure 1. The Hierarchical Design Model consists of design spaces with hierarchical structure, knowledge used for reasoning, and context. Design spaces are divided into the following four hierarchies: value space, meaning space, state space, and attribute space. Each space has design elements. The Hierarchical Design Model has an ability to deal comprehensively with the early and the late process of design by defining the design practice as a practice of reasoning the relationship between design elements in different hierarchies (the modeling between different hierarchies) and a practice of reasoning the relationship between design elements in the same hierarchy (the modeling in the same hierarchy). In addition, as shown in Figure 3, the Hierarchical Design Model describes a transition from the early process of design to the late process of design as a change in repetition of reasoning in each same hierarchy and between different hierarchies.

As described above, the Hierarchical Design Model has an ability to describe the early and the late process of design by the same model. Therefore, it is possible to propose a design method that has an ability to support the building of both the structural model in the early process of design and the mathematical model in the late process of design by proposing a design method that reflects the features of Hierarchical Design Model.

2.2. Hierarchical QFD

As a design method that reflects the features of Hierarchical Design Model, the Hierarchical QFD that has an ability to build a structural model has been proposed as shown in Figure 2. The Hierarchical QFD is an expanded design method by reflecting the features of Hierarchical Design Model to QFD that has been widely used in quality management. The Hierarchical QFD consists of three two-way tables describing each modeling between different hierarchies and four correlation tables describing each modeling in the same hierarchy.

Besides, the Hierarchical QFD has an ability to build a structural model by describing the relationship between design elements in the tables. In addition, QFD (Anders, 2001) is a design method that has an ability to clear the relationship between ciental quality requirements and quality elements of products.

3. A proposal of a Design Method Based on Hierarchical Design Model

This chapter describes an expansion of the Hierarchical QFD, which is necessary for connecting the structural model building in the early process of design to the mathematical model building in the late process of design properly, and proposes a design method that has an ability to support the building of both models.

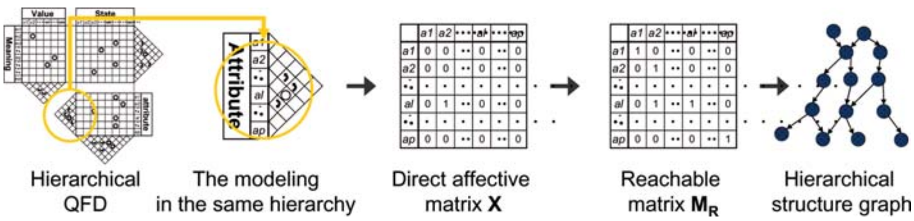
It is necessary for mathematical model building to decide objective characteristic and related design factors from design elements that the design consists of. However, design elements complexly intertwine, and have not only direct impact but also sidebar impact each other. Fault Tree Analysis (FTA), Failure Model and Effect Analysis (FMEA), and so forth, the conventional design methods for building a structural model does not has an ability to grasp sidebar impacts of design elements. In addition, a selection method of objective characteristic and related design factors, which is necessary for building a mathematical model from a structural model, has not been proposed. In this study, therefore, the Hierarchical QFD is expanded in the following two aspects in order to solve the above two aspects. Firstly, the Hierarchical QFD is expanded into the method that has an ability to grasp clearly sidebar impacts by introducing ISM method. Secondly, a selection method of objective characteristic and related design factors necessary for building a mathematical model based on the Hierarchical QFD is proposed.

Consequently, a design method that supports to build both structural and mathematical model is proposed.

3.1. A Method of Building a Structural Model

The Hierarchical QFD has been expanded into a design method that has an ability to grasp clearly sidebar impacts by introducing Interpretive Structural Modeling method (ISM method) that visually expresses the complex relationship of effects between design elements. Therefore, as shown in Figure 4, it is contemplated that the relationship included sidebar impacts in the same hierarchy could be visualized by introducing ISM method into correlation tables. Consequently, the Hierarchical QFD has been expanded into a design method that is possible to grasp clearly sidebar impacts.

Figure 4. ISM method.



3.2. A Method of Building a Mathematical Model

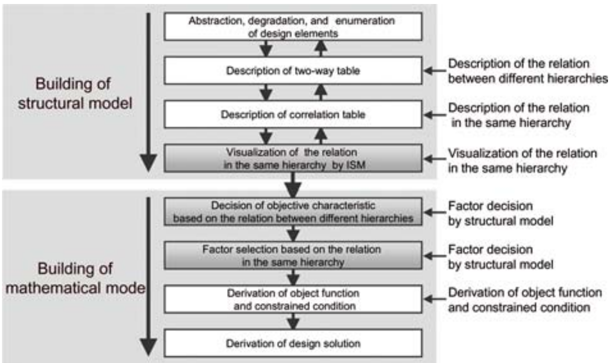
A selection method of objective characteristic and related design factors necessary for building a mathematical model from the Hierarchical QFD is proposed. For this purpose, as shown in Table 1, a selection method of factors has been proposed by paying attention to the following three aspects of a structural model built by the Hierarchical QFD expanded in the previous paragraph: the modeling in the same hierarchy visualized by ISM method, the modeling between different hierarchies shown in correlation tables of the Hierarchical QFD, and natures of factors based on the Hierarchical Design Model. Consequently, it is contemplated that design factors could be properly and effectively decided. Then, depending on the case, a mathematical model is built based on the decided design factors. In addition, a control factor and a noise factor are used in the robust design (Takeo, 2005a) that ensures robust performance in considering variation of products. In usual optimization, a control factor is called a design variable, and a noise factor is not considered.

As described above, firstly, the Hierarchical QFD has been expanded into a design method that has an ability to grasp clearly sidebar impacts. Secondly, a selection method of design factors by using the Hierarchical QFD properly has been proposed. Consequently, as shown in Figure 5, a design method that has an ability to support the building of both the structural model in the early process of design and the mathematical model in the late process of design has been proposed.

Table 1. Selection Method of Design Factors

		Nature	Selection method
Objective characteristic		Physical quantity that porperly expresses design target	In state space, design element that icorresponds to design target
Design factors that relates to an objective characteristic	Control factor	Physical quantity that controls an objective	In attribute space, design element that relates to objective characteristic and has no interactions with the other
	Noise factor	Design element that flutuates objective characteristic	Design element that relates to objective characteristic and is not controlled by designer
	Limiting factor	Design element that limits control factor	Design element that relates to control factor in elements with constraint of limiting value and so

Figure 5. The proposed design method.



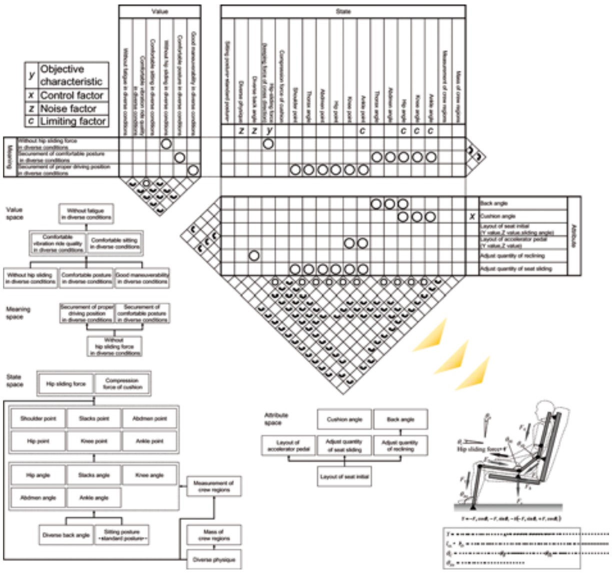
4. Case of Automotive Seat Designs

This chapter describes the application of the proposed design method to automotive seat designs in order to verify the effectiveness of the method. The automotive seats are usually categorized into two: driver seat and passenger seat. The driver seat is a work seat for pedal operation and so forth, while passenger seat is a comfort seat. Therefore, it is preferable that both design solutions is different in considering each usage environments. The proposed design method is applied to each of the driver and the passenger seat.

4.1. A Driver Seat Design

4.1.1. A structural model and a mathematical model of a driver seat design. The aim of a driver seat design has been the improvement of pedal operation that is considered most important in driver performance (Haruhiko, 2002). Therefore, it has been contemplated that a movement of operating pedal could become simplicity by lowering the cushion angle (C.A.) of a current seat. However, C.A. is concerned with a phenomenon that the hip slides forward (hip-sliding). Consequently, in a driver seat design, a structural and a mathematical model with respect to hip-sliding have been built by the proposed design method in order to confirm whether the above measure is pertinence or not as shown in Figure 6.

Figure 6. A structural model and a mathematical model in a driver seat.

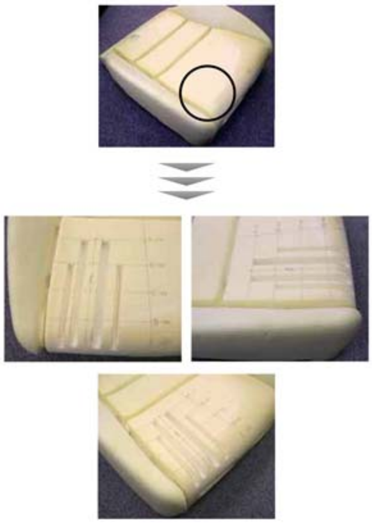


4.1.2. A design solution of a driver seat design. It has been recognized that the measure lowering the C.A. could cause a cranky pedal operation for increasing sip-sliding force that cause sip-sliding by reference to a structural and a mathematical model shown in Figure 6. Therefore, as an alternative, it has been contemplated to reduce "compression force of cushion" that could become a load on the thigh of a driver in operating pedals.

However, reducing "compression force of cushion" increases hip-sliding force by reference to a structural and a mathematical model shown in Figure 6. Therefore, it has been contemplated that distributing "compression force of cushion" could turn the movement of operating pedals into simplicity by reducing a load on the thigh of a driver without increasing hip-sliding force.

As described above, a cushion pad has been slit up in order to distribute "compression force of cushion".
Consequently, in a driver seat design, a design solution has been obtained as shown in Figure 7.

Figure 7. A design solution in a driver seat.



4.2. A Passenger Seat Design

4.2.1. A structural model and a mathematical model of a passenger seat design. Front-seat passengers have diverse postures that are likely to curse hip-sliding (Yoshiyuki, 1988). Therefore, it has been contemplated that hip-sliding is prevented by raising C.A. of a current seat. However, Front-seat passengers are to have cramped posture. The aim of passenger seat design has been not only the improvement in preventing hip-sliding but also keeping the passenger comfortable (Toshimiti, 1987).

Consequently, in a passenger seat design, a structural and a mathematical model with respect to hip-sliding have been built by the proposed design method in order to obtain guidelines of such a measure as shown in Figure 8.

4.2.2. A design solution of passenger seat design. The mathematical model shown in Figure 8 has been optimized by the robust design (Takeo, 2005b). Consequently, it has been recognized that each back angle (B.A.) has an optimum C.A. for not only preventing hip-sliding but also keeping comfort. Besides, as shown in Figure 9, the locus has been drawn by plotting an optimum C.A. against each B.A. Consequently, as guidelines of a measure for not only preventing hip-sliding but also keeping comfort, it has been obtained that C.A. becomes movable against a change of B.A. like the locus shown in Figure 9. As such a function, there is a seat-swing function shown in Figure 10. However, when the seat-swing function introduced to passenger, it has been contemplated that frontseat passengers may not keep enough forward sight by reclining the seat back greatly. Therefore, during long term sitting, it has been contemplated that front-seat passengers could feel repugnant by having hunched posture and so forth. As described above, a passenger seat has been introduced a forward-tilt function that turns the upper parts of a seat back into movable in order to keep forward sight even where front-seat passengers greatly recline seat back.

Consequently, in a passenger seat design, a design solution introduced a forward-tilt function in conjunction with a seat-swing function has been obtained as shown in Figure 11.

Figure 8. A structural model and a mathematical model in a passenger seat.

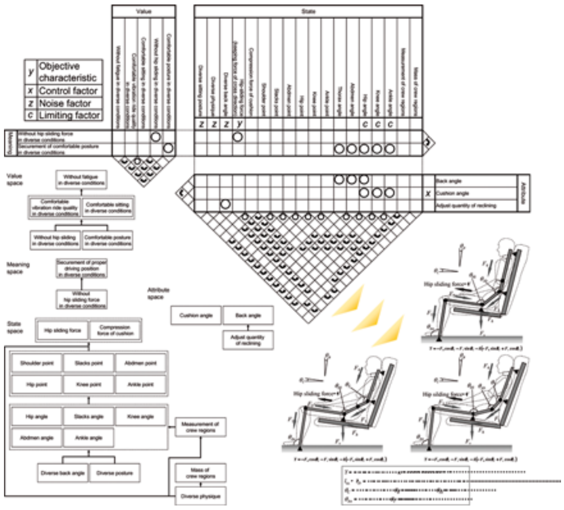


Figure 9. The locus drawn by an optimum C.A. against each B.A.

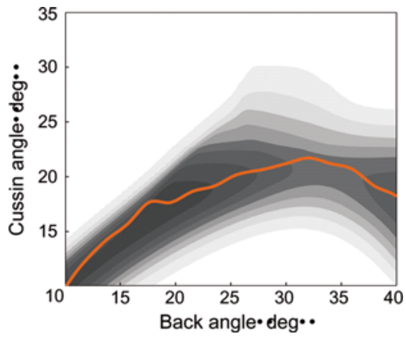
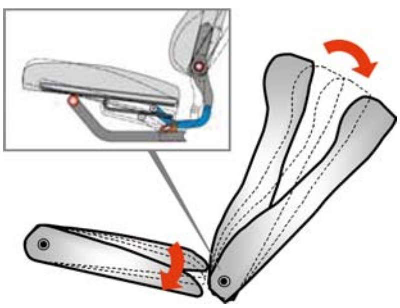


Figure 10. A seat-swing function.



4.3. Comparison of a Driver Seat with a Passenger Seat

As shown in Figure 7 and Figure 11, the design solution of a driver seat design and the design solution of a passenger seat design have been two different solutions by comparing both design solutions by using the proposed design method. The reason why the structural and the mathematical model by using the proposed design method has an ability to consider properly usage environments of each of the driver seat and the passenger seat.

Consequently, the effectiveness of the proposed design method has been confirmed.

Figure 11. A design solution in a passenger seat.

5. Conclusion

In this study, firstly, the Hierarchical QFD that reflects features of a Hierarchical Design Model has been expanded into the method that has an ability to grasp clearly sidebar impacts by introducing ISM method into itself. Secondly, a selection method of objective characteristic and related design factors necessary for building a mathematical model based on the Hierarchical QFD has been proposed. Consequently, the design method that supports the building of both structural and mathematical models has been proposed. Then the proposed design method has been applied to each of the driver and the passenger seat design.

Consequently, two different design solutions that properly considered usage environments of each seat have been obtained by using the proposed design method. As a result, the effectiveness of the proposed design method has been confirmed.

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