Optimization of Public Seat Functions to Assure a Comfortable Sitting Posture in Diverse Conditions

Takeshi Kitamura[1]

[1] Graduate School of Science and Technology, Keio University

Received: 9 December 2012 Accepted: 3 January 2013 Published: 15 January 2013

Abstract

Seat functions for public seats, such as those in railway vehicles, have been designed to assure a comfortable sitting posture. However, the importance of these functions is not widely understood. Public seats are used in a variety of conditions because users have diverse physiques and sitting postures. Thus, design solutions that consider only standard conditions, physiques, and sitting postures are insufficient. The objectives of this study are 1) to clarify the relative importance of seat functions in assuring a comfortable sitting posture and 2) to optimize important seat functions in diverse conditions. First, an analytic hierarchy process (AHP) and a fuzzy analytic hierarchy process (Fuzzy AHP) clarified that the forward tilt function of the seatback and seat swing function are necessary to assume a comfortable sitting posture because they contribute to the fitness of the seatback and prevent the hip sliding force, respectively. However, there is trade-off between satisfying the fitness and preventing the hip sliding force. Second, the seat swing function with a forward tilt function was optimized. The solution is the optimal relationship between the seatback and the seat cushion angles adjusted by the seat swing function to prevent the hip sliding force considering diverse conditions and the forward tilt angles. Finally, a sensory experiment confirmed the effectiveness of the optimized design solution.

Index terms— seat design, diverse conditions, robust design, fuzzy AHP.

1 Introduction

o assure a comfortable sitting posture, some seat functions, such as the forward tilt of the seatback or seat swing function (Fig. **??**), are included in public seats in railway vehicles and passenger airplanes [1] to [3]. However, it is unclear how these functions contribute to a comfortable sitting posture. Currently designers select seat functions based on their experience or sensory evaluation experiments [4]. Moreover, the conventional design assumes standard conditions in which all passengers have average physiques and standard sitting positions. Consequently, conventional design solutions are often poorly evaluated for non-standard conditions, including those with nonaverage physiques and varied postures (diverse conditions) [5] and [6].

The objectives of this study are to determine which seat functions assure a comfortable sitting posture and then optimize these seat functions for diverse conditions. To determine the relative importance of the seat functions, we conducted a sensory experiment using evaluation factors to elucidate factors for a comfortable sitting posture. We then analyzed the results of the sensory evaluation experiment via an analytic hierarchy process (AHP) and a fuzzy analytic hierarchy process (Fuzzy AHP) [7] and [8]. Second, we constructed a human-seat model for selected seats and performed simulations to optimize seat functions using the model. In this study, the signal-to-noise (SN) ratio from the Taguchi method [9] and [10] was used to consider variations in user physiques and the diversity of sitting postures. Finally, we conducted a sensory experiment to evaluate the optimized design solution. ?

Examinees: To incorporate passengers with various physiques, we evaluated passengers using combinations of three different heights and weights.

Of the nine possible combinations, two are statistically rare, and consequently eliminated (Table 1). The height and weight levels are defined using their mean values µ h and µ w and standard deviations ? h and ? w ? Sitting posture: Each examinee adjusted the seat to assume the most comfortable sitting posture.

.

? Evaluated seat functions: A sample seat was prepared with five different seat functions: adjustable head rest height, forward tilt, seat swing, seat cushion slide, and footrest. Figure 2 shows the seat functions of the experimental seat. The specifications of the sample seat are identical to an actual public transportation seat found in the Hatsukari express train in Japan. ii.

2 Evaluation method

Based on the results of a previous study [11], we chose two factors to evaluate seat functions: the fitness of the sitting posture and the amount of freedom for various sitting postures with a relative weighting of 7 to 3. The examinees evaluated each factor by answering the following questions using the semantic differential (SD) method on a five-point scale. "Is it possible to achieve a comfortable sitting posture?" and "Is it possible to achieve a variety of sitting postures?" b) Analysis of important seat functions for a comfortable sitting posture i. Application of AHP and Fuzzy AHP To analyze the importance of seat functions in assuring a comfortable sitting posture, the results of the evaluation were analyzed using AHP and Fuzzy AHP.

AHP is a decision-making method that considers subjective human criteria. In AHP, a hierarchal model is initially created. The model consists of three components: the design object, evaluation factors, and alternatives. The factors in the decision-making problems are divided based on the hierarchy model. Then the degree of importance for each evaluation factor is determined using an evaluation matrix based on paired comparisons. Finally, the degree of importance of the alternatives based on the hierarchy model is numerically simulated using the degree of importance of the evaluation factors and the results of SD method.

The degree of importance for AHP is an additive measure because the sum is equal to one. However, an additive measure cannot evaluate substitutability and complementarity of a sensory evaluation. Substitutability states that even if there is only one excellent evaluation among a number of evaluations, the overall evaluation is Figure 2 : Specification of the sample seat good evaluation. In contrast, complementarity means that one inferior evaluation lowers the overall evaluation. Because AHP emphasizes overall balance, herein we employ Fuzzy AHP uses non-additive measures (possibility and necessity measures), which are described below.

First, we expressed the additive measure generally used in AHP, the degree of importance y of the alternatives as a weighted sum of the degrees of importance w i (0 ? w i ? 1) of the evaluation factors x i , and the evaluation value f j (x i) of j th alternative of x i . Then y can be expressed as = + + = ? = n n i i j i j w w x f w y (1)

evaluation factors. Fuzzy AHP normalizes the degrees of importance w i (0 ? w i ? 1) for cases where w i = 1 for more than one i. For example, wi can be normalized by their maximum value. The classes A l of the number of n is established using w i ' (r 1 <r 2 <?<r n { }X x n l r w x A l i i l ? = = , ,..., 1 , ' | _=1)

, which is the modified degree of importance, X is the class of = = ? = ? r n l r r A m l l l is allocated as (3)

The possibility measure expectation E* (upper limited expectation), which adopts the maximum evaluation value f(x) for evaluation factors x included in each class A l , while the necessity measure expectation E* (lower limited expectation), which adopts the minimum evaluation value, using probabilities m l)) (max) (max) ( ) (1 1 1 x f r r x f A m f E n l A x l l n l A x l l l ? ? = ? ? = ? * ? = = (

)) (min) (min) ( ) (1 1 1 x f r r x f A m f E n l A x l l n l A x l l l ? ? = ? ? = ? * ? = = (4)) (max * * j j f E y = (5)

Thus, the most favorable degrees of importance of alternatives (y*, y*) in the possibility and necessity measures are expressed as measures followed by the seat cushion slide, footrest, and headrest height adjustment functions, in that order. These findings can be explained by the body pressure distribution. In general, the lower the pressure on the body from the seat is thought to be more desirable [12].

It is possible that the forward tilt and the seat swing functions distribute the pressure to large regions of the body by increasing the pressure on the back. Thus, we expect these functions to be highly rated. In summary, we selected the forward tilt and the seat swing functions, which were highly rated in the three measures - possibility, additivity, and necessity -as the necessary seat functions to assure a comfortable sitting posture for varied conditions.

3 (7)

The seat functions were selected by applying these degrees of importance of the alternatives.

4 Data analysis and the selection of alternatives

Figure 3 shows the hierarchy model employed in this study. To determine the compound degree of importance of each measure and alternative, we applied three types of values: the degree of importance of the evaluation factors, the evaluation value assigned by each examinee, and the results of equations (**??**), (6), and (7).

Figure 4 shows the average of the compound degree of importance, as well as the measures for possibility, additivity, and necessity. The forward tilt and the seat swing functions are the most highly rated III. Optimization of Seat Functions for a Comfortable Sitting Posture

Here we focus on the forward tilt and seat swing functions as the functions necessary to realize a comfortable sitting posture. Because we optimized the forward tilt function in a previous study [13], we briefly summarize the optimization. Then we clarified the optimization of a seat swing function with and without a The forward tilt function is the function that bends the seatback between the thorax and the lumbar regions. This function contributes to fitness of the Figure **??** : Forward tilt pivot position seatback for assuming a comfortable sitting posture. We have determined the optimal pivot point of the forward tilt and the movement range of the forward tilt angle (FA) based on a sensory experiment with diverse users in a previous study. These results are summarized below.

Previously a sensory experiment involving 16 Japanese participants (8 male and 8 female) with varying physiques (height percentile from 10% to 99%) determined the optimal forward tilt position for diverse users. The pivot point of forward tilt function is behind the 10th vertebra (Fig. **??**) because the point of largest movement in the spine (except the thorax) is between the 10th and 11th vertebrae.

A sensory experiment evaluated the comfort of a sitting posture and determined the optimum movement range of FA using the same conditions as above. Figure **??** shows the acceptable comfort range of FA for each examinee. Based on the results, we selected an FA movement range between 0 and 30 degrees.

The previous section demonstrates that the forward tilt function can assure a comfortable sitting posture by tilting the seatback at a pivot point behind the 10th thorax vertebra and a 0 to 30 degree movement range. Moreover, the design solution of the seat swing Figure **??** : Suitable forward tilt angle range for different builds function is related to FA because the seat swing function sinks the back end of the seat cushion on the axis of the front edge of the seat cushion in tandem when adjusting the seatback to prevent the hip sliding force. The force is usually generated on the buttocks in an anterior direction from the human body dynamics varied from the seat angles. The hip sliding force is one cause of uncomfortable sitting [14], and varies as a function of the back angle (BA), which is the angle between the seatback and the vertical direction, and the cushion angle (CA), which is the angle between the seat cushion and the horizontal. BA and CA are adjusted by the seat swing function. In addition, the hip sliding force varies with FA as adjusted by the forward tilt function.

5 b) Optimization of the seat swing function

The optimal combination between BA and CA minimizes the hip sliding force and optimizes the seat swing function. In this study, the seat swing functions with and without the forward tilt function were optimized. Here users adjusted FA to a certain value.

6 i. Design method

The seat swing function was optimized using the SN ratio, which is the measure from the Taguchi method to evaluate the stability of the functional value of a design objective with respect to the variance of a variety of factors. When data is divided into a functional characteristic value S (signal) and variance N (noise), the ratio of these values is the SN ratio [15], and indicates the stability of a functional value. Maximizing the SN ratio improves the performance of the design objective; thus, selecting a design solution that Figure 7 shows the procedure to optimize the seat swing function. First the hip sliding force is estimated, and then simulations analyze the results. There are three steps to construct the hip sliding force estimation equation: (1) select the design objective and measure its characteristics, (2) model the design factor, and (3) estimate the hip sliding force.

The seat swing function reduces the hip sliding force. Therefore, the design objective is for the hip sliding force to be 0 N.

To model the factors that influence the hip sliding force, initially a human model and seat model must be separately constructed. Then a human-seat model, which depicts their relationship, is constructed. Because the human model needs to be split into parts, we selected division points based on both human anatomy and sitting posture [16]. Our twodimensional model includes the thoracic, lumbar, and pelvic regions as well as the thigh and lower thigh regions. For each body region measurement, we used the statistical average of the human body measurements [17].

For each body region weight, we renormalized the weights from an earlier study to match the models used in this study [18]. We considered three types of sitting postures: the standard one and two types of hip sliding postures (stretched waist and bent waist) [19]. In the standard sitting posture, a passenger sits such that the buttocks are positioned deep on the seat cushion and the waist is in contact with the seatback. In the hip sliding posture, the passenger sits with the buttocks slid forward and the pelvis rotated such that waist does not come into contact with the seatback. The stretched waist sitting posture stretches both the pelvis and the waist, while the bent waist posture bends both the pelvis and the waist. The greater trochanter point of the hip sliding sitting posture is set 100 mm forward from the standard sitting posture, based on an earlier study [19].

The two-dimensional seat model consists of three parts: upper seatback, lower seatback, and seat cushion, which are rigid-body link structure. As shown in Section 2.1.1, the forward tilt function rotates around a pivot point behind the 10th thorax vertebrae. The size and adjustability of the sample seat are based on a reallife Hatsukari public seat (Section 1.1.1).

We constructed the human-seat model using the above human and seat models (Fig. 8). Because the hip sliding force estimate and the features of the sitting position can be viewed from the sagittal plane of the human body, the human-seat model in this study is constructed in the sagittal plane. Forces include friction between the human body and the seat, where the vertical component of force from each seat part (the upper seatback, the lower seatback, and the seat cushion) is multiplied by the friction coefficient, which is assumed to be 0.3 [20].

Then we constructed human-seat models with respect to varied sitting postures to estimate the hip sliding equation for all postures (Figs. 9-11, equations 8-10). Table 2 explains the variables in these equations [21].

Similar to the estimation of the hip sliding force, the simulation analysis consists of three parts: (1) select the control and noise factors as well as their levels, (2) determine the simulation conditions, and (3) calculate the SN ratio and optimal design solution. ? Select the control and noise factors as well as their levels First, we defined the factors influencing the design objective. Then these factors are ( ) ( ) ( ) ( )( ) ( )( ) ( ) ( ) ( ) { } ( ) ( ) ( ) { } ( ) ( ) ? + °? + ? + °= ? ? + °= ? + ? °+ = ? °= = ? ? ? = ? + ? + = ? ? ? + + = ? + = + + ? + = + ? = + ? ? ? ? = ? ? ? C B 2 2 h 2 3 C B h C B 3 1 F B C Ab Hi 1 1 An F B F B b 5 5 5 F F 5 B B b 4 4 a 5 5 4 Ab Ab B B b 3 3 a 4 4 5 4 3 An C C a 2 2 b 1 1 2 a 3 3 b 2 2 C Hi 3 C 2 v C Hi 3 C 2 h C v C h C v C hF 3+4 ? An ? Hi H ? L' L 3 +L 4 L h ? L' L 3 +L 4 L h ? L' L 3 +L 4 L h F 5 F HS F h F v F 2 ? T ? ? ? ? ? ? F ? F ? C ? C( ) ( ) ( ) ( ) ( ) ( ) ( ) ( ) ( ) ( ) ( ) ( ) ( ) ( ) { } ( ) [ ] ( ) ( ) ( ) ? + °? + + ? + °= ? ? + °+ = ? + ? °+ = ? °= = ? ? ? = + ? ? ? ? + + + = ? + = + + + + + = + + = + ? ? ? ? = ? ? + + + C B 2 2 h 2 4 3 C B h C B 4 3 1 F B C T Hi 1 1 An F B F B 5b 5 5 T T F B F B mb 4 3 a 5 5 5 4 3 An C C a 2 2 1b 1 2 ma 4 3 b 2 2 C Hi 4 3 C 2 v C Hi 4 3 C 2 C v C h C v C hL L L L L L L L L H g l M F g l M M g l M F F g l M g l M F g l M M g l M F F F F F F F F F os F F h{ } ( ) ( ) ( ) ( ) ? °? °? + = ? ? ? ? + °? ? ? ? ? + ? + °= ? ? + °? ? ? ? = + ? + ? °+ = + ? °= = ? ? ? = ? + ? ? ? ? ? ? + + + = ? + = + + + ? + + = ? + + = + ? ? ? ? = ? ? ? + ? + + 24 180**) ( ) ( ) ( ) ( ) ( ) ( ) ( ) ( ) ( ) ( ) ( ) ( ) (( ) ( ) ( )**2 4 2 3 C B 2 2 h 2 C B h C B 1 F B C T Hi 1 1 An F B F B b 5 5 5 T T F B F B b m 4 3 a 5 5 5 4 3 An C C a 2 2 1b 1 2 a m 4 3 b 2 2 C Hi 4 3 C 2 v C Hi 4 3 C 2 h C v C h C v C h HS3 L L L L L L L L L L L H g l M F g l M M g l M F F g l M g l M F g l M M g l M F F F F F F

Table **??** : Conditions of Each Simulation divided into control and noise factors. A designer can determine the level of influence of a control factor, but not that of a noise factor. We identified the following factors: a. CA (control factor) b. BA (control factor) c. FA (noise factor) d. Physiques (noise factor) e. Sitting postures (noise factor)

The level of each factor was determined, as described below. CA has 51 different values from 0 to 50 degrees in one-degree increments. In this study, physique, sitting posture, and FA, are noise factors with seven, three, and three levels, respectively. FA is set to 0, 15, or 30 degrees.

We used three different conditions in the simulation analysis (Table **??**).

? Simulation 1: The seat swing function is optimized for the standard condition. In particular, CA minimizes the hip sliding force Y (equation 8) for each BA value. ? Simulation 2: The single seat swing function is optimized by determining the levels of physique and sitting posture.

? Simulation 3: The seat swing function with the forward tilt function is optimized by determining the levels of physique, sitting posture, and FA. In the simulations, the SN ratios of the hip sliding force are estimated for each combination of BA and CA. The SN ratio is the ratio of the signal factor to the noise factor. Then the optimal design solution is selected by the combination of BA and CA that maximized the SN ratio against each BA. (0 deg) The equation for the SN ratio differs according to the type of measurement characteristic. In this study, iv. Calculate the SN ratio and Optimal Design Solution the target value of hip sliding force is 0 N. When the SN ratio is minimized, it is defined as where FHSi is the hip sliding force and n is the number of the measurement? = ? = n i H Si F n 1 2 1 log 10 ? (11)

characteristics (Yi). If the mean of the hip sliding force is ?, and its variance is ?2, then the expected value of the SN ratio (?) is( ) [ ] 2 2 log 10 E ? µ ? + ? =**(12)**

Therefore, the true value of the SN ratio includes both the mean value of the hip sliding force and variance due to the noise factor.

This simulation yields the optimal CA with the maximum SN ratio for each BA, which prevents the hip sliding force (the hip sliding prevention curve).

Figure 12 shows the results of simulations 1, 2, and 3 (the hip sliding prevention curves). The curve of simulation 3 lies between those of simulation 1 and simulation 2. This observation can be explained by the interplay of two forces: a decrease in the hip sliding force with the hip sliding posture (calculated from eq. 9), and an increase in the hip sliding force with the forward tilt (calculated from eq. 8).

7 IV.

8 Sensory Experiment

To confirm the effectiveness of the optimized design solution for the seat swing function with a forward tilt (simulation 3), we performed a sensory experiment to compare the optimal design solution (simulation 3) and the standard solution (simulation 1).

9 a) Sensory experiment i. Conditions

The sensory experiment included seven different physiques, two types of sitting postures, and the seat described in Section 1.1.1. BA and CA were selected such that CA clearly affected the hip sliding force prevention curves; that is, the experiment included simulations 1 and 3. For each BA (30, 35, and 40 degrees), simulation 1 used CA = 20, 23, and 25 degrees, while simulation 3 used CA = 19, 21, and 23 degrees respectively.

10 ii. Method

Examinees sat in two different sitting postures (standard and hip sliding sitting posture) on the seat using the previously mentioned combinations of CA and BA, and then evaluated the extent to which they "did not feel the hip sliding force" using the SD method on a fivepoint scale. b) Analysis of the effectiveness of the optimal design solution i. Estimate of the SN ratio

The SN ratios of the design solutions from simulations 1 and 3 were estimated using the ratings from the sensory experiment on a five-Figure 13 : Increment in SN ratio from conventional solutions (simulation 1) to the proposed solution (simulation 3) point scale. The SN ratio ? is then calculated as? = ? = n i i y n 1 2 1 1 log 10 ? (**13**)

where yi is the rating from a given experiment, and n is the number of combinations of CA and BA. The total number of ratings is 14 because examinees evaluated two different sitting postures.

ii. Analysis of the Sensory Experiment Figure 13 indicates that simulation 3 has a larger SN ratio than simulation 1 for all BAs. The solution for simulation 3 prevents the hip sliding force for diverse physiques, sitting postures, and FAs. Thus, the sensory experiment confirms the effectiveness of our optimized solution using diverse conditions (simulation 3).

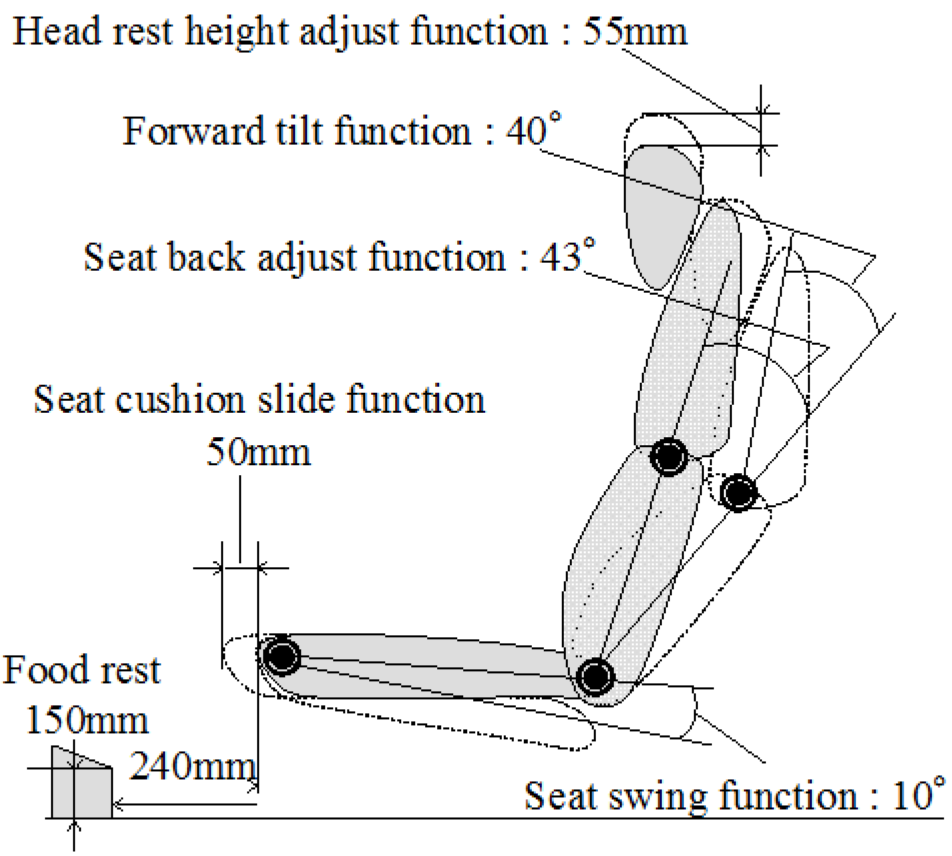
V.

11 Conclusion

Two seat functions, forward tilt function and seat swing function, are necessary to assure a comfortable sitting posture. Thus, we optimized these functions using the SN ratio, which was obtained by the Taguchi method by considering users' diverse physiques and sitting postures. Moreover, we conducted a sensory experiment to confirm the effectiveness of the optimal design solution. The key findings are summarized below. 1. AHP and Fuzzy AHP analyses reveal that the forward tilt and seat swing functions are most highly rated to assure a comfortable sitting position for diverse conditions, physiques, and sitting postures. Thus, these are the key functions to a comfortable sitting posture. 2. A comparison of the design solutions for standard conditions (standard physique, sitting posture, and FA = 0 degrees) and the seat swing function with a forward tilt (varied physiques, sitting postures, and FAs) reveals that the CA for each BA is lower for the seat swing function with a forward tilt than the standard condition. Although the hip sliding force increases as FA increases, the hip sliding posture decreases the overall force. 3. To compare the optimal design solution of the seat swing function with the forward tilt function to standard solution, we conducted a sensory experiment for varied physiques and sitting postures. The SN ratio of the optimal design solution is higher than that of the standard one, confirming the effectiveness of the design solution in assuring a comfortable sitting posture under diverse conditions. Herein we have designed a public seat that combines the seat swing function with a forward tilt to assure a comfortable sitting posture. In the future, we plan to optimize public seats based not only on pressure minimization, but also on other aspects of human physiology, such as muscle activity and blood flow. [1] [2] [3]

11

Figure 1: T 1)Figure 1 :



2

Figure 2: (2)

1

II.	Seat Functions that Assure a Comfortable Sitting Posture
a) Sensory Experiment	

Figure 3: Table 1 :

2

Sign Sign	Meaning Meaning	Sign Sign	Meaning Meaning	Sign Sign	Meaning Meaning
F HS F HS	Hip sliding force Hip sliding force	H H	Height of seat cushion Height of seat cushion	i=1 i=1	Thorax region Thorax region
F h F h	Horizontal force on Horizontal force on trochanter major trochanter major	M M	Body weight Body weight	i=2 i=2	Lumber region Lumber region
F v F v	Vertical force on Vertical force on trochanter major trochanter major	M i M i	Weight of i th body Weight of i th body section section	i=3 i=3	Pelvis region Pelvis region
F i F i	Force on i th human Force on i th human body section body section	l ia l ia	Ratio of L i and the Ratio of L i and the length from i th body length from i th body section upper-edge to section upper-edge to gravity-center gravity-center	i=4 i=4	Thigh region Thigh region
L L	Body height Body height	l ib l ib	1 -l ia 1 -l ia	i=5 i=5	Lower thigh region Lower thigh region
L i L i	Length of i th body Length of i th body section section	l ma l ma	Composite ratio of 3rd Composite ratio of 3rd and 4th body section in and 4th body section in stretched waist sitting stretched waist sitting posture posture	k k	Coefficient of frictional Coefficient of frictional resistance resistance
L h L h	Buttock-trochanterion Buttock-trochanterion length length	l m'a l m'a	l ma in bent waist sitting l ma in bent waist sitting posture. posture.		

Figure 4: Table 2 :

Simulation 1 : Optimization of seat swing function considering standard condition Simulation No. Simulation 2 : Optimization of seat swing function Simulation 1 : Optimization of seat swing function considering standard condition Simulation No. Simulation 2 : Optimization of seat swing function	BA, CA Control factor BA, CA BA, CA Control factor BA, CA
considering diverse condition Simulation 3 : Optimization of seat swing function with forward tilt function considering standard condition considering diverse condition Simulation 3 : Optimization of seat swing function with forward tilt function considering standard condition	BA, CA BA, CA
iii. Determine the simulation conditions	Cushion angle [deg] 20 10 30 0 0

Figure 5:

[Yamazaki et al. ()] , N Yamazaki , S Satoh , R Tachikawa . 1994.

[Sommer ()] *A Brief Guide to Sources of Fiber and Textile Information*, H Sommer . 1973. Information Resources Press.

[Cudney et al. ()] *A Comparison of Techniques to Forecast Consumer Satisfaction for Vehicle Ride*, E Cudney , D Drain , K Ragsdell . 2007. 2078 p. .

[Goonetilleke and Feizhou ()] 'A methodology to determine the optimum seat depth'. R S Goonetilleke , S Feizhou . *International journal of industrial ergonomics* 2001. 27 (4) p. .

[Hendrik and Goossens ()] *A Study of load distribution Shear decubitus risk and form of the spine*, R Hendrik , M Goossens . 1994. Biomechanics of Body Support.

[Suzuki et al. ()] 'A study on the factors influencing comfort evaluation of the train'. H Suzuki , H Shiroto , K Omino . *The Japanese Journal of Ergonomics* 1998. 34 p. .

[Shinomiya ()] 'Analysis of passengers' evaluation of amenities offered in coach'. A Shinomiya . *Railway Technical Research Institute* 1990. 4 (3) p. .

[Hisao and Sugiyama ()] 'Application of Fuzzy Integral to the Hierarchized Decision-making Method'. S Hisao , T Sugiyama . Fuzzy System Symposium 1992. 8 p. .

[Adem et al. ()] 'Application of Taguchi Method for Surface Roughness and Roundness Error in Drilling of AISI 316 Stainless Steel'. Ç Adem , K Turgay , S Gürcan . *Journal of Mechanical Engineering* 2011. 58 (3) p. .

[Satoh ()] 'Biomechanical evaluation of a bed cushion by a segmented body model'. S Satoh . *Biomedical Engineering thesis* 1992.

[Biomechanical Fitting of Bed Mattresses Society of Biomechanisms Japan] 'Biomechanical Fitting of Bed Mattresses'. *Society of Biomechanisms Japan* 61 (71) p. .

[Winter ()] *Biomechanics of Human Movement*, D Winter . 1979.

[Matsuoka ()] *Design Science ~"Six Viewpoints" for the Creation of Future~*, Y Matsuoka . 2010. (Design Juku)

[Saito and Wakabayashi ()] 'Development and verification of railway seat for long term sitting'. M Saito , H Wakabayashi . *JSME Centennial Grand Congress-the 6th Transportation and Logistics Conference*, 1997.

[Fujinami ()] 'Developments in ergonomic research on railway passenger seats in Japan'. K Fujinami . *Railway Technical Research Institute* 1997. 11 (11) p. .

[Yu and Keyserling ()] 'Evaluation of a new work seat for industrial sewing operations. Results of three field studies'. C-Y Yu , W Keyserling . *Applied Ergonomics* 1989. 20 (1) p. .

[Hashizume ()] *International symposium lecture meeting on rolling stock seat. Recent rolling stock seats. Rolling stock and machinery*, S Hashizume . 1993. 7 p. .

[Investigation of Inertial Properties of the Human Body. National Technical Information Service Aerospace Medical Research Lab 'Investigation of Inertial Properties of the Human Body. National Technical Information Service'. *Aerospace Medical Research Laboratory* 1976.

[Hashimoto ()] *Present situation and problems of seats for railcars*, J Hashimoto . 1993. 7 p. . (Rolling stock & machinery)

[Matsuoka and Hanai ()] *Study of comfortable sitting posture. SAE technical paper series*, Y Matsuoka , T Hanai . 1988. p. 880054.

[Inoue et al. ()] 'The Way and Features of Design Evaluation in Design Process'. K Inoue , M Tsuchiya , T Anzai . *The Science of Design* 1996. 42 (6) p. .

[Wu and Wu ()] Y Wu , Wu . *Taguchi Methods for*, 2000. ASME Press.