An Intelligent Comfort-Evaluating (ICE) Model for Child Car Seat Design

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Abstract: This essay attempts to explore an intelligent design evaluation system dealing with the ergonomic comfort problems for the child car seat designers. The new intelligent comfort-evaluating (abbreviated as ICE) model is developed through two stages. The first stage is to perform an ergonomic experiment to find out the relations between the comfort and the interface pressures on the child subjects. The second stage is to construct an ICE model by applying the method of gray conjunction analysis with programming languages, such as Visual Basic and C++. Final results show that the new ICE model is very effective for the car seat designers to solve the complex problems of ergonomic comfort. Therefore, the new model can provide designers a scientific method supporting decisions on the new product design of child car seats.

Key words: Design Methodology Design Evaluation, Ergonomics in Design, Child Car Seat Design

1. Introduction

According to the survey from the Nation Highway Traffic Safety Administration (NHTSA) of US in 1992, there were 600 children losing their lives in car accidents every year. Among them, about 250 children lost lives due to not adopting safety restrain devices [1]. With so high death rate, we know that if not using child car seat, the child will increase higher risks of serious injuries in car accidents.

To ensure the security of children’s sitting in passenger cars and to avoid or diminish possible injuries caused by traffic accidents, several advanced industrial developed countries have recently passed the related laws concerning the safety of child car seat. In Taiwan, the child weighed under 20 kilograms will be enforced to use car safety seat next year. Therefore, the design problems of using child car seat are becoming important issues in this country.

The most vital design issues for using child car seats are safety and comfort. Current related studies of child car seats are mostly focused on the surveys of safety. For examples: Lawrence and Kathleen (1996) had surveyed generally misusing situations of child car seats on some districts of the America; Miller et. al. (1998) investigated the situations of using restrain safety devices for children and drivers during car crash[2]; and Glass and Graham (1999) had studied the related situations of using child car seats during car collision in the U.S. from 1985 to 1996[3].

There are fewer studies focused on child car seats than general chair seats in the aspects of comfort issues. The comfort-measuring method of general chair seats mostly adopt physiological measurements for a basis and accompanying with the aid of subjective aptitude measurements [4-6].
The purpose of this study aims to search for the comfort relations of child car seat by performing an experiment of physiological measures, and applying a scientific effective algorithm to build an ICE model for designing optimal child car seat.

The fundamental theory of the new ICE model is based on an artificial intelligent technique, which is the analysis method of gray conjunction [7-8]. The gray conjunction analysis (abbreviated as GCA in this article) is one kind of measuring method to analyze the relations among discrete series in the theory of gray system. It depends upon the geometric shape of serial curve to judge whether they are extensively related or not. In the current study, to build a comfort-evaluating model by applying GCA is quite suitable. The main reasons are depicted as follows:

1. Gray system theory is suitable for the situations where the external message is clear, but the internal message is not clear. Man-machine system is a typical gray system. This study attempts to employ the clear physiological information acquired from the ergonomic experiment to explore the unclear message of children’s comfort.

2. In treating information with the GCA, designers don’t need a lot of data as well as any typical functional relations among data. In an ideal comfort-evaluating system, designers have to assess the children’s comfort levels only depending upon very few and discrete physiological information. Thus, GCA is suitable for this kind of application.

3. The traditional regression method in treating the relations among variables cannot have too many various factors, while the factors affecting human comforts are frequently complicate and diversified. So, using the benefits of GCA, designer can solve this problem.

4. By applying the method of GCA, designers can infer the individual subject’s gray conjunction levels according to the current information. The results of these levels represent the relative conjunction scales among subjects. This study is trying to use the conjunction levels to compensate insufficiencies of children’s subjective aptitude of comfort.

Therefore, this study attempts to apply the GCA to infer children’s mechanical comforts to car seats in accordance with the results, which are acquired from the ergonomic experiment of interface pressures.

2. Method

This study can be archived through two major stages. The first stage is an experiment of physiological measurements. The second stage is the construction of ICE model by applying the gray conjunction method.

2.1. Experiment of physiological measurement

2.1.1. Control of experimental variables

(1) Subjects

The experiment pinpoints foldable child car seat, subjects are the children aged from one-year old to four-year old and weighted under 20 kilograms, with average weights 16.72 kilograms. There are twenty-one subjects, including ten boys and eleven girls, consented by their parents to participate in the experiment.

(2) Independent variables

The independent variables are the angles of back-resting support and material textures of soft mat. Cross experiment of these variables are also performed.
The choice of back-resting angles is in accordance with the standard specifications of restrain safety devices for automobiles. (China National Standard; CNS 11497) The maximal leaning angle cannot exceed 60 degrees. Three levels, which are 20-degree, 40-degree and 60-degree, are used in this study. Three different textures of local-made seat mats with different density were used in the study. Types of these textures are KR, KQ and HD. A contrast texture without any soft mat are also added as a comparison. Thus, a total of four levels of experimental variables were adopted. According to the standard inspecting method, ( CNS 4452 ) the values of hardness of three seat textures were 116.46 N, 100.78 N, 135.38 N for texture type KR, KQ and HD, respectively.

(3) Dependent variables

There are thirteen pressure values measured as dependent variables, which include Back Contact Pressure( BCP), Back Peak Pressure( BPP), Back Contact Area( BCA), Right Scapula Pressure(RSP), Left Scapula Pressure(LSP), Lumbar Vertebra Pressure(LVP), Cushion Contact Pressure(CCP), Cushion Peak Pressure(CPP), Cushion Contact Area( CCA), Right Ischium Pressure(RIP), Left Ischium Pressure(LIP), Right Thigh Pressure(RTP) and Left Thigh Pressure(LTP). In the study of GCA, only six pressure values are used as dependent variables, which are BCP, BPP, BCA, CCP, CPP and CCA.

2.1.2. Experimental facilities

Major facilities adopted in the experiment are depicted as follows:

(1) Stature and weight equipment :

Before the experiment, the subjects’ stature and weight are measured to ensure complying with the standard.

(2) Tekscan Seating Sensor system and Tekscan Seating System V3,70 :

Tekscan Seating Sensor system includes pressure sensors and converters. ( figure1,(a)) It is made of plastic soft material with areas of 480x495 square millimeters, and can provide precision measuring areas of 5 square millimeters with four sensors in one square centimeter. Through the analysis of Tekscan Seating System, a computer software package, pressure distribution charts can be acquired for the reference of designers.

(3) Twin axial material tester (858 Mini Bionix) :

It is a hardness testing machine of soft mat materials.( figure1,(b)) From the indention load of testing material, the value of hardness, with a unit of Newton ( N ) , for the soft mat can be got.

(4) Child car safety seat :

A local made typical car seat with two-step, 20 degrees and 40 degrees, back-rest support adjustable angles is adopted in this experiment.

(5) High-raised platform with adjustable angles(figure1,(c)) :

This is a changeable mechanism specifically designed for increasing adjustable angles of child car seat.

(6) Digital video camera and digital camera :

It is used to take moving pictures of subject’s seating activities and record their postures.
2.1.3. Experimental procedures

The experimental procedures are proceeded with the following steps:

1. Explain the measuring process to all subjects’ parents and ask their assistances to the subjects in the experiment.

2. Proceed the surveys of subject’s basic data including age, gender, stature and weight.

3. Set up and calibrate the Tekscan Seating System, include the following:
   a. Set up unit as \( \text{kg/cm}^2 \)
   b. Set up recording parameters, such as recording one frame per 0.04 second, and total records are 25 frames.
   c. Calibrate the weight with the weight of one experimenter as a standard

4. Place the Tekscan Seating Sensor on the safety seat.

5. The subject sits on the child car seat peacefully and cannot move his or her body at random.

6. Record the pressure values with the Tekscan Seating System

7. Record the motion pictures with the digital video camera and digital camera

8. Change the angle of back-resting support and/or replace another seat mat, and then repeat the successive steps of (4), (5) and (6)

9. Finish this subject’s measurements and replace another subject

10. Accomplish the experiment

2.1.4. Building process of ICE model

The construction of the ICE model is based on the GCA of gray systemic theory. The model applies the GCA to analyze the pressure parameters of child car seats, and to make the relative evaluation of user’s comfort to each car seat. The program languages used to construct the new ICE model can be Visual Basic or C++. In this case, we adopted the Visual Basic since it is commonly used in many schools. The building process is described as follows:

1. Build the relation table between seat variables and seat pressure parameters

2. Proceed the gray conjunction analysis

From the relations between seat variables and seat pressure parameters (table 1), the reference series are defined. In other words, depending upon the expected value of each seat pressure parameter, a reference series \( X_0 \) is chosen from these series. The definition of the expected value of each seat pressure parameter is depicted as follows:
Table 1 Relationships between seat’s variables and seat’s parameters

<table>
<thead>
<tr>
<th>Seat No.</th>
<th>Seat Angle</th>
<th>Soft Mat</th>
<th>BCP</th>
<th>BPP</th>
<th>BCA</th>
<th>CCP</th>
<th>CPP</th>
<th>CCA</th>
</tr>
</thead>
<tbody>
<tr>
<td>No, 1</td>
<td>20°</td>
<td>non</td>
<td>0.13861</td>
<td>0.1569</td>
<td>0.04410</td>
<td>9</td>
<td>0.4689</td>
<td>0.26795</td>
</tr>
<tr>
<td>No, 2</td>
<td>20°</td>
<td>KR</td>
<td>0.14746</td>
<td>0.0932</td>
<td>0.06333</td>
<td>2</td>
<td>0.1896</td>
<td>0.32043</td>
</tr>
<tr>
<td>No, 3</td>
<td>20°</td>
<td>KQ</td>
<td>0.15094</td>
<td>0.1172</td>
<td>0.05771</td>
<td>7</td>
<td>0.2247</td>
<td>0.30624</td>
</tr>
<tr>
<td>No, 4</td>
<td>20°</td>
<td>HD</td>
<td>0.18857</td>
<td>0.0961</td>
<td>0.05071</td>
<td>2</td>
<td>0.2066</td>
<td>0.29919</td>
</tr>
<tr>
<td>No, 5</td>
<td>30°</td>
<td>Non</td>
<td>0.27709</td>
<td>0.1695</td>
<td>0.08519</td>
<td>9</td>
<td>0.3586</td>
<td>0.27648</td>
</tr>
<tr>
<td>No, 6</td>
<td>30°</td>
<td>KR</td>
<td>0.32473</td>
<td>0.1161</td>
<td>0.11867</td>
<td>5</td>
<td>0.163</td>
<td>0.30686</td>
</tr>
<tr>
<td>No, 7</td>
<td>30°</td>
<td>KQ</td>
<td>0.31535</td>
<td>0.1168</td>
<td>0.12314</td>
<td>8</td>
<td>0.1687</td>
<td>0.30667</td>
</tr>
<tr>
<td>No, 8</td>
<td>30°</td>
<td>HD</td>
<td>0.23438</td>
<td>0.1071</td>
<td>0.09924</td>
<td>6</td>
<td>0.1709</td>
<td>0.29486</td>
</tr>
<tr>
<td>No, 9</td>
<td>40°</td>
<td>Non</td>
<td>0.29875</td>
<td>0.1917</td>
<td>0.09543</td>
<td>7</td>
<td>0.2927</td>
<td>0.25591</td>
</tr>
<tr>
<td>No, 10</td>
<td>40°</td>
<td>KR</td>
<td>0.33883</td>
<td>0.1057</td>
<td>0.13448</td>
<td>4</td>
<td>0.1495</td>
<td>0.28310</td>
</tr>
<tr>
<td>No, 11</td>
<td>40°</td>
<td>KQ</td>
<td>0.27513</td>
<td>0.1443</td>
<td>0.14119</td>
<td>9</td>
<td>0.2248</td>
<td>0.28405</td>
</tr>
<tr>
<td>No, 12</td>
<td>40°</td>
<td>HD</td>
<td>0.31536</td>
<td>0.1342</td>
<td>0.11543</td>
<td>7</td>
<td>0.2141</td>
<td>0.27724</td>
</tr>
</tbody>
</table>

- Back Contact Pressure (BCP): As the surface pressure of skin is too large, it may cause the circulating damage of blood capillary and lead to the organ anoxaemia and cell necrosis (Dennis, 1988). Therefore, the value of BCP should be an expected small value [9].

- Back Peak Pressure (BPP): As the pressure distribution reaches a balance, it should avoid concentrating pressure on the same area to form a sharp pressure. A good designed seat should be able to relieve the pressure of ischial tuberosity and to avoid generating partial anemia, uncomfortable and painful feelings (Dennis, 1988). Therefore, the value of BPP should be an expected small value.

- Back Contact Area (BCA): According to the Herz contact theory, it will produce the least surface interface pressure while two plastic objects contact with each other and the geometric shapes completely match themselves. It can also infer while the effective contact area is larger, the interface pressure is
smaller. Mehta and Tewari (2000) also indicated that a good distribution of soft seat mats should match the surface area of skin. Therefore, the value of BCA should be an expected large value[10].

**Cushion Contact Pressure (CCP):** Same theory as the above, the value of CCP should be an expected small value.

**Cushion Peak Pressure (CPP):** Same theory as the above, the value of CPP should be an expected small value.

**Cushion Contact Area (CCA):** Same theory as the above, the value of CCA should be an expected large value.

Therefore, according to the definition of individual pressure parameter for each series, the reference series can be obtained as the following:

\[ X_0 = (0.13861, 0.0932, 0.14119, 0.072699, 0.1495, 0.32043) \]  

Through the calculation of gray conjunction, the intensity of gray conjunction for each seat can be acquired. Higher intensity of gray conjunction represents closer to the expected value. Hence, we can infer that the higher intensity of gray conjunction possesses the better ergonomic comfort.

### 2.2. Construction of ICE model

The purpose of this new ICE model is tried to evaluate the user’s comfort of child car seats. In other words, depending upon the experiment of seating pressure measurements, pressure data are used as the inputs of this ICE model. Additionally, by applying GCA to proceed the evaluation of comfort, the relative comfort of individual safety seats can be calculated afterward.

According to this evaluation system, product designer or related design develop personnel can proceed product design and development as well as product assessment and comparisons. It can provide an objectively scientific comfort-evaluating method to eliminate subjectively personal errors in the design process. In addition, it can effectively offer the design criteria of child’s comfort for safety car seats.

Main frameworks of this evaluation system can be divided into three parts, which are described in detail as follows: (figure 2)

**Data transformation of car seat pressure distribution:**

Due to the information obtained from the pressure experimental results is ASCII pure characters’ data, thus easily readable pressure distribution charts, including colour pressure distribution chart and 3D pressure distribution chart, which are transformed from these data, is needed. These charts can be easily perceived by the users to analyze interface pressure information.

**Parameter calculation of car seat pressure:**

Related parameter calculations to the ASCII pure characters’ data are proceeded to. Calculations include: Back Contact Pressure (BCP), Back Peak Pressure (BPP), Back Contact Area (BCA), Cushion Contact Pressure (CCP), Cushion Peak Pressure (CPP) and Cushion Contact Area (CCA). Users can proceed to discussion, and these pressure parameters are important indexes of comfort evaluations as well.

**Comfort evaluation and analysis of child car seat:**
By using each seat pressure parameter as the conjunction series of gray conjunction analysis, and proceeding the calculation of gray conjunction analysis, the users can evaluate the relative comfort levels of car seats. After understanding the comfort levels of child car seats from the evaluation results, the users can make final decisions to choose better designs.

![Figure 2 Basic systemic framework of ICE model](image)

### 3. Results and Discussions

Results of the experiment and the gray conjunction evaluation can be summed up and discussed as the following:

1. From the Results of total gray conjunction evaluation, while arranging KR soft and HD soft mat into pairs and adjusting the angle of back-resting support at 30 degrees, the child’s comfort is the optimal.

2. As shown in figure 3, a larger angle of seats can share the pressure load of buttocks, but if not adding soft mat, on the contrary, it will increase the peak value of back pressure and lead to lower child’s comforts. Thus, while desiring to increase angles of seat, the choice of soft mats should be emphasized in order to spread the peak values of pressures.

3. In the aspects of soft mat textures, there is an obvious difference between no soft mat and other three soft mats. In other words, the total values and peak value of back and buttock pressures, as well as the utility value of contact area for seat without soft mat are less than those of other three soft mats. While proceeding with the total evaluations by applying GCA, the gray conjunction intensities of the three soft mats are obviously higher than those of no soft mat. Thus, adding these three soft mats will obviously enhance the child’s comfort.

4. In the aspects of comparisons of three soft mats, for the softest one, KQ with hardness 100.78 N, although the utility values of back and seat contact areas are higher, the total values and peak value of pressures are less than KR and HD soft mats, with hardness 116.46 N and 135.38 N, respectively. While proceeding the total evaluations in gray conjunction analysis, the KQ soft mat is not better than KR mat. The reason maybe is the same as the study of Sprigle and Chung (1990) who indicated that softer mats may cause becoming deformed.
too much and cannot spread contact pressures effectively. Thus, the child’s comfort will be lower due to larger contact pressures and higher peak value of pressures [11].

(5) Results of the relations among pressure parameters show that the percentage of the peak value of seat’s back pressure occurred in the scapulas or the lumbar vertebra is 81%, and 60% in the ischium tubercles or the thighs. Although the relations of experimental parameters and the occurred areas are not very sure. Results shown in figure 4, also indicate that the most frequently occurred areas of the peak value for seat’s back pressure are on the scapulas or the lumbar vertebra while for seat’s pressure are on the ischium tubercles or the thighs. Therefore, in the design of child car seat, designers should design a chair, which fits child’s anthropometrical profiles to avoid producing peak values of back-supporting and buttock-supporting pressure.

(6) From the pressure distribution chart (figure 5), while increasing the angle, the legs will produce new pressure regions. Thus, as designing the car seat, designers should aim at the legs to proceed seat profile designs or soft mat designs to scatter the pressure values of these areas, so that to avoid producing new uncomfortable areas for the children.

(7) From the results of GCA to total seats (table 2), the total comfort evaluations of seat no. 6 (with angle of 30 degrees and KR soft mat), seat no. 2 (with angle of 20 degrees and KR soft mat) and seat no. 10 (with angle of 40 degrees and KR soft mat) are optimal. That shows the KR soft mat with any angle is generally better than the other two sets of soft mat. Thus, the KR soft mat is an optimal choice.

(8) To sum up the results of GCA, we will know that the final conclusion is generally the same as what we adopt the method of statistics. It also can prove that the effect of this evaluation method by applying GCA is correct. The reason of applying GCA in this study is that it is not restricted to the types of analysis data, such as not demanding a large number of subjects and the strict restriction of data distributions. Besides, in the application of the experimental analysis in human physiological measurements, the GCA can make the evaluation analysis more efficient and more accurate.

(9) Furthermore, depending on the building of this evaluation system, the users not only can obtain the seat’s evaluating results, but also can get other related information of seat pressures through the pressure distribution charts, such as the distribution situations of contact interface pressures, the pressure value for each location and so on. This system can assist the research developers or designers to proceed the product evaluation and seat design, and obtain the effective evaluation criteria and decision supports.

To summarize the above results, we know that the choice of soft mats will affect the pressure parameters. Choosing an adequate soft mat can effectively reduce peak value of pressures and increase child’s comfort. In addition, different angles of back-resting support can also affect pressure parameters. While increasing the angles of seats, designers should make use of soft mat design to reduce the peak value of pressures and simultaneously utilize profile chair or mat design to avoid producing new pressure loads. Results of this study by applying GCA are consistent with results of experimental statistics. Hence, the effect of this ICE model by applying GCA is right. This ICE model can also applied to different chair parameters, such as evaluating the relations between different chair’s contours and child’s comforts, the pressure affections of adding different accessories of chairs, and so on. Therefore, the construction of the evaluation system will be helpful to the design decisions and comfort considerations of child car seats.
Figure 3 Gray conjunction intensities of each soft mat under three different angles

Figure 4 The areas of peak values of back-support pressure (left) and peak values of buttock-support pressure (right)

Figure 5 Buttock-support pressure distribution charts for subject 1, 2 and 3, while inclining back-support with an angle of 40 degrees
<table>
<thead>
<tr>
<th>Soft mat</th>
<th>Seat angle</th>
<th>KR (116.46 N)</th>
<th>KQ (100.78 N)</th>
<th>HD (135.38 N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>non</td>
<td>20°</td>
<td>Seat no. 1</td>
<td>Seat no. 2</td>
<td>Seat no. 3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.7023</td>
<td>0.8375</td>
<td>0.8104</td>
</tr>
<tr>
<td></td>
<td>30°</td>
<td>Seat no. 5</td>
<td>Seat no. 6</td>
<td>Seat no. 7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.6499</td>
<td>0.8432</td>
<td>0.8158</td>
</tr>
<tr>
<td></td>
<td>40°</td>
<td>Seat no. 9</td>
<td>Seat no. 10</td>
<td>Seat no. 11</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.6526</td>
<td>0.8289</td>
<td>0.8259</td>
</tr>
</tbody>
</table>

### 4. Conclusions

The exploring scope of this study lies in the effects of interactions to user’s comforts between two types of variables, which include the angles of car seats and the material textures of soft mats. Nevertheless, while considering the child’s comforts of car safety seats, the evaluation principles will be more complicated, for instances, long-term load time, scattering effects of soft mat and shaking effects are all important indexes to affect the comforts. Besides, the choices of seat’s variables are not only angles and mats. Different seat’s contour designs or different safe belt designs will also affect the comforts. Final results show that the new ICE model is very effective for the car seat designers to solve the complex problems of ergonomic comfort. However, applying GCA to the ICE model for designing child car seats is still in the stage of starting point. The followings are several suggestions for the reference of future researchers[12-14]:

1. According to the study of Dennis (1988), the hardness of soft mat will affect sitting postures, and over soft mats will generate extra loads on the muscles of shoulder and abdomen. Thus, while considering the comfort, if adding the considering of forces applying on the shoulder and abdomen at the same time, we can obtain more comprehensive information of evaluations.

2. In the process of experiments, we found that the increasing angles will affect child’s sitting posture. For examples, too large angle of inclination will cause possible unreasonable motions for child’s neck and generate child’s unstable sense and neck loads. Therefore, when the child is sitting in the car seat, if we can measure the related positions of child’s body segments, maybe we can acquire the relationship between the sitting posture and comfort.

3. Due to the child’s subjective measurements are hard to acquire, the application of GCA to infer the comfort can compensate for the lack of subjective measurements. However, what is called comfortable sensation is the experienced physiological and psychological feeling. Although basing on the physiological measurements is still necessary, the child’s psychological feeling is likely to affect the entire comforts. Therefore, in order to describe the child’s comfort levels, more comprehensive physiological measurements and variable controls will likely be needed, for examples, long-term loads of pressure, electromyography of child’s muscles, child’s postures as well as the environmental temperature and humidity changes, to gain more realistic comfort measurements.
Current designs of angle-adjustable child car seats are mostly motion-linked type, which means the back support and buttock support are connected together. In other words, while adjusting the angles, a single angle adjusting of back support with fixed angle of buttock support is impossible. The motion-linked type of car seat will compress child’s abdomen and hinder the back muscular development. The current study of ICE model is only focused on the type of motion-linked car seats. Other types of isolated angle-adjustable car seats by using this new ICE model will be worthy of further studies.

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