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# Optimization Design of Customized Passenger Car Cockpit Layout based on Safety Ergonomic Principles

Xin Liu[a], Zheng Liu[a,*], and Hongzhong Huang[b]

[a]*Guangzhou University, Guangzhou, 510006, China*
[b]*University of Electronic Science and Technology of China, Chengdu, 611731, China*

**Abstract**

The optimization design problem of customized passenger car cockpits layout is increasingly complex and of growing interest in the Chinese car market. A new system is proposed to solve this problem based on ergonomic principles. Firstly, based on Kendall's *W*, groups and optimization sequences of facilities are determined using a combination of Delphi and the analytic hierarchy process. Secondly, the degree of crowdedness in the cockpit layout can be controlled by users' preference. Thirdly, a particle swarm optimization (PSO) algorithm is adapted to three-dimensional car cockpit layout optimization, and the resulting inertia-adaptive PSO is compared with some typical algorithms to show superiority. Finally, the results are reasonably analyzed in ergonomic simulation software. Thus, the proposed platform is demonstrated to be feasible and effective.

*Keywords*: optimization design; ergonomic; Delphi-AHP; PSO

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## 1. Introduction

Customized services are increasingly popular and are becoming the general trend of passenger car cockpit design in China. The conception of the passenger cars considered in this article is based on the definition of GB/T3730.1-2001. As the science and technology incorporated in passenger cars increase, new functions need to be integrated into the cockpit based on customer demands. This may require the cockpit interior to be reshaped, which refers to the safety ergonomic problems. At present, the layout of a passenger car cockpit mainly depends on the experience of experts and designers. After any modification, an evaluation method is used, but this cannot solve the problem of passenger vehicle designing and development quickly. The cockpit layout optimization problem has received increasing attention. However, only the safety ergonomic theory was applied in the cockpit layout optimization [1-5], thus neglecting drivers' affective factors. Additionally, most research subjects are non-standard cockpits, such as those of aircraft and submersibles. There is no effective method for solving the problem of passenger car cockpit layout optimization. Thus, an optimization design platform for the customized passenger car cockpit layouts based on safety ergonomic principles is needed. Analytic hierarchy process (AHP) as an evaluation measure has been used in cockpits effectively. In addition, Delphi and AHP have been incorporated in various frameworks to conduct process evaluations [6], with Delphi applied to find the subjectively hierarchical relationships of AHP [7]. In 2009, Delphi and AHP were used in an exploratory study to rank critical success factors contributing to effective quality engineering tools and techniques [8].

There are a number of studies related to the design and optimization of different cabin or cockpit layouts using computational intelligence. In 2001, a genetic algorithm (GA) using human–computer interaction was used to solve the problem of constrained layout optimization [5]. In 2013, a GA was successfully applied to cockpit layout optimization in civil aviation [9]. The same year, a GA and an ant colony algorithm were used to optimize the cockpit layout of a manned submersible [1-2]. However, PSO is easier and more efficient than the evolutionary algorithms mentioned above. PSO is a population-based stochastic optimization technique that was developed by [10]. In 2007, PSO was used to solve the multiple-level warehouse layout design problem [11]. In 2011, Kulturel-Konak successfully used PSO to solve the

* Corresponding author.
*E-mail address*: liu_best@yeah.net

engineering problem for the layout of unequal area facilities with a flexible bay structure, which is a very common layout in manufacturing and retail facilities [12]. In 2012, PSO was applied to optimize the layout of a vertical channel in a ship's hull [7]. Thus, PSO is known to be effective in solving complex engineering layout problems. Although the PSO algorithm has been successfully applied to different industrial areas and different engineering problems, relatively few applications have considered the layout design of cabins or cockpits. The optimization of a cockpit layout considers how facilities can be arranged more appropriately within a limited space. The cockpit layout optimization problem can be divided into two-dimensional and three-dimensional layout optimization problems [13]. In 2003, PSO was first used to solve the two-dimensional layout optimization of round facilities in a satellite cabin [14]. The following year, PSO was applied to solve the two-dimensional layout optimization problem of cube-like facilities in a rotation module [15]. However, PSO has been rarely used to solve three-dimensional cockpit layout optimization problems [16], especially the problem of car cockpit layouts.

The remainder of this paper is organized as follows. In Section 2, our method for an optimal design platform is introduced. We first describe the workflow for establishing the platform, and then describe how to determine the optimization sequence and importance of facilities in Chinese passenger cars using Delphi-AHP. Next, we explain how to optimize the layout using an inertia-adaptive particle swarm optimization (PSO) algorithm based on ergonomic theory and the degree of crowdedness desired by the user. Section 3 describes the implementation of the algorithm and presents some examples. These simulations demonstrate the feasibility and effectiveness of the proposed technique.

## 2. Optimal Design Platform

The facilities optimization depends on the Delphi-AHP analyses, and the optimal plan depends on the modified PSO analyses. The workflow of the optimal design platform is shown in Figure 1.

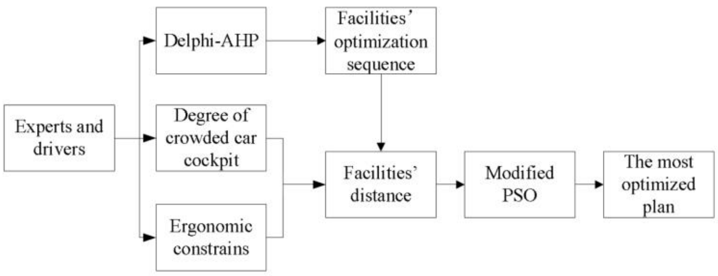



Figure 1. Workflow of the proposed optimal design platform

### *2.1. Using Delphi-AHP to Determine Rankings and Weights for Car Cockpit Facilities*

#### *2.1.1. Determination of Mean Rankings*

It is important to determine the list of experts involved in the Delphi process. The experts should have considerable knowledge about the major operational experiences. According to the research needs, around 10-18 specialists should be consulted. Facilities in passenger cars are classified by the experts and customers. Then, the facilities groups are ordered by importance, with the choices made by experts dominated by those of the customers to some extent. The consultation platform is established over the internet. Based on the principles of being scientific, comprehensive, systematic, significant, and feasible, the customers and specialists' complete questionnaires on the internet, and then statistical processing is carried on repeatedly until a consensus is reached. It is assumed that the $h^{\text{th}}$ criterion level has $k$ optimization indexes $B_1^h$, $B_2^h$, $\cdots$, $B_k^h$. The optimization index system of the $h^{\text{th}}$ criterion level is $\boldsymbol{B}^h = \{B_1^h, B_2^h, \cdots, B_k^h\}$, and the next level of $B_j^h$ can be subdivided into $\boldsymbol{B}_j^{h+1} = \{B_{j1}^{h+1}, B_{j2}^{h+1}, \cdots, B_{jn}^{h+1}\}$, where $j = 1, 2, \cdots, k$ and $h, k, n \in \mathrm{N}_+$.

Because the data analysis is related to the diversity, as suggested by [17], the consensus among the rankings was measured using Kendall's *W*.

According to the *P* experts' rankings, the facilities are ranked 1, 2, $\cdots$, $k$ in order of importance, from low to high. In addition, $B_1^h$, $B_2^h$, $\cdots$, $B_k^h$ are the ranking numbers in the $h^{\text{th}}$ hierarchy. The hypotheses for testing are then:

- $H_0$: *p* rankings are inconsistent
- $H_1$: *p* rankings are consistent

The formula for Kendall's $W$ is:

$$W = \frac{12\sum_{j=1}^{k} R_j^{\,2} - 3p^2k(k+1)^2}{p^2k(k^2-1)} \quad (1)$$

Where $p$ is the number of experts, $k$ is the number of facilities, and $R_j$ is the sum of the rank order numbers from facility $j$. If two or more items are assigned the same rank order by the experts, Kendall's $W$ is given by:

$$W_c = \frac{12\sum_{j=1}^{k} R_j^{\,2} - 3p^2k(k+1)^2}{p^2k(k^2-1) - p\sum(t^3 - t)} \quad (2)$$

Where $t$ is the number of items with the same rank order. The chi-squared value is then calculated as:

$$\chi^2 = p(k-1)W \quad (3)$$

According to the number of degrees of freedom, $v = k-1$, and the chi-squared test should be conducted to confirm whether the ranking is consistent. If $\chi^2_{0.05,k-1} < \chi^2$, $P < 0.5$, and $H_0$ can be rejected; thus, $H_1$ is accepted, which means that the level of consensus among the experts is high.

### *2.1.2. Weights Calculated by Delphi-AHP*

AHP can be improved by applying the Delphi process. As the matrix-based Delphi ranking is consistent, many steps of the associated consistency tests are unnecessary. The judgment matrix for the lowest criterion level can be written as:

$$\begin{pmatrix} 1 & B_1^h/B_2^h & \cdots & B_1^h/B_k^h \\ B_2^h/B_1^h & 1 & \cdots & B_2^h/B_k^h \\ \vdots & \vdots & \ddots & \vdots \\ B_k^h/B_1^h & B_k^h/B_2^h & \cdots & 1 \end{pmatrix} = \left( B_m^h/B_n^h \right)_{k\times k}, \quad m,\ n\ =\ 1,\ 2,\ \cdots,\ k;\ B_k^{\ h}\ =\ 1,\ 2,\ \cdots,\ k \quad (4)$$

Because $\boldsymbol{B}^h$ is a consistent matrix, the rank of $\boldsymbol{B}^h$ is 1. The unique nonzero characteristic value of $\boldsymbol{B}^h$ is $k$, and the normalized eigenvector of $\boldsymbol{B}^h$ can be used as the weight vector according to:

$$\boldsymbol{B}^h w = k\boldsymbol{w},\ \boldsymbol{w} = (w_1, w_2,\ \cdots,\ w_k) \quad (5)$$

After normalizing $\boldsymbol{w}$, the relative importance of the criteria at the lowest criterion level is given by [18]:

$$w_j^{\,h} = w_j \Big/ \sum_{j=1}^{k} w_j \quad (6)$$

## *2.2. Layout Optimization Problem Solved by Inertia-Adaptive PSO*

### *2.2.1. Theory of Inertia-Adaptive PSO*

In PSO, each single solution is a particle in the search space. All particles have fitness values that are evaluated by a fitness function and velocities that determine their direction within the search space. The particles move through the problem space by following the current optimum particles [19]. PSO is modified by the inertia-adaptive factor to improve the global search ability and prevent becoming trapped around local optima. The inertia-adaptive factor is given by:

$$w=\begin{cases} w_{\min}-\dfrac{(w_{\max}-w_{\min})\times(f-f_{\min})}{f_{avg}-f_{\min}}, & f\le f_{avg} \\ w_{\max}, & f>f_{avg} \end{cases} \tag{7}$$

Where $w_{\max}$ and $w_{\min}$ are the maximum and minimum values of $w$, respectively, and $f$ is the objective function of the current particle position. $f_{avg}$ and $f_{\min}$ are the average and minimum values of the current particle position, respectively, so the inertial factor adjusts itself adaptively according to the particle trajectory. When the values of the current particle positions are uniform, the value of $w$ increases; otherwise, when the values of the current particle positions are dispersed, the value of $w$ decreases. In this way, the inertia-adaptive factor encourages the particles to come together and exploit a potential optimum point.

### *2.2.2. Establishment of the Objective Function*

Based on ergonomic theory, the positional relationships among facilities in passenger car interiors require several targets to be optimized, i.e., ergonomic layout optimization is a multi-objective optimization problem. The approach of linear scalarization, which can convert multi-objective optimization problems into single-objective optimization problems, can be written as:

$$\begin{cases} \min\eta=\min\sum_{i=1}^{n} w_i f_i(\varphi) \\ \text{s.t.}\quad \varphi\in D \end{cases} \tag{8}$$

Where $w_i$ is the weight of the objective ($0<w_i<1$, $\sum_{i=1}^{n} w_i=1$) and *D* is the feasible solution set.

### *2.2.3. Ergonomic Constraints of Facilities Layout Optimization*

According to the standard of the Society of Automotive Engineers, drivers of different statures can adjust the driving seat to the desired position in the car. Hence, the distribution of drivers' eye positions will form an ellipse when they are seated in a relaxed manner. To achieve a definite optimization scheme, the eye position is simplified to be at the axis of the ellipse, which means the driver has the seat fixed at the middle of its adjustable range. In addition, the origin of the coordinates in the proposed framework is the point midway between the driver's eyes.

**Visual field constraints of human eyes:** The angle of view is formed by two light rays running from the two end points of the facility to the eyeball. The size of this field of view is determined by the distance from the eyeball to the facility and the distance between the two end points of the facility. The angle of view can be calculated as follows:

$$\alpha=\arctan\frac{\sqrt{(x_i^2+y_i^2+z_i^2)(x_k^2+y_k^2+z_k^2)-(x_i x_k+y_i y_k+z_i z_k)^2}}{x_i x_k+y_i y_k+z_i z_k} \tag{9}$$

Where $\alpha$ represents the angle of view from facility *i* to facility *j*. $(x_i, y_i, z_i)$ are the areal coordinates of facility *i*, and $(x_k, y_k, z_k)$ are the areal coordinates of facility *k*. The maximum horizontal view angle of the human eye is 156°, and the maximum horizontal view angle of both eyes together is 188°. In this case, the angle of the overlapping space is 124°, and the comfortable view angle of one eye is 60° [20].

**Reachable workspace constraint:** Customer groups with different size standards are now analyzed comprehensively. The model for what facilities are reachable by the driver's hands is given by Equation (10) and Equation (11). Customer stature data can be measured using a 3D scanning device.

$$\begin{cases} (x+S/2-T)^2+(y+E)^2+(z+L)^2 \le r^2 \\ (x-S/2+T)^2+(y+E)^2+(z+L)^2 \le r^2 \\ y \ge -E \end{cases} \tag{10}$$

$$\begin{cases} (x-S/2+T)^2/R_1^2+(y+E)^2/R_2^2+(z+L)^2/R_3^2 \le 1 \\ (x+S/2-T)^2/R_1^2+(y+E)^2/R_2^2+(z+L)^2/R_3^2 \le 1 \\ y \ge -E \end{cases} \tag{11}$$

In Equation (10) and Equation (11), the origin of the coordinate scheme is the center of the driver's eyes. $S$ denotes the shoulder width, $E$ is the horizontal distance from the eye to the shoulder along the y-axis direction, $L$ is the vertical distance from the eye to the shoulder, and $T$ is the distance from the outside of the shoulder to the *articulatio humeri*. $r$ is the radius of a circle formed by the human arm's normal attainable region. $R_1$, $R_2$, and $R_3$ are the axis lengths of the ellipsoid formed by the human arm's maximum attainable region in the $x$-axis, $y$-axis, and $z$-axis directions, respectively.

**Non-interference boundary constraints of the facilities:** The distance between two central points on two different facilities respectively should be greater than or equal to half of the sum of the lengths, widths, and heights of the two facilities, so the two facilities will not overlap with each other.

$$\begin{cases} \left|x_i-x_j\right| \ge (a_i+a_j)/2 \\ \left|y_i-y_j\right| \ge (b_i+b_j)/2 \\ \left|z_i-z_j\right| \ge (c_i+c_j)/2 \end{cases} \tag{12}$$

In Equation (12), $(x_i, y_i, z_i)$ are the areal coordinates of facility $i$, and $a_i$, $b_i$, and $c_i$ are the length, width, and height of facility $i$, respectively. Similarly, $(x_j, y_j, z_j)$ are the areal coordinates of facility $j$, and $a_j$, $b_j$, and $c_j$ are the length, width, and height of facility $j$, respectively.

*2.2.4. Degree of Crowdedness of Car Cockpit as Determined by User*

The semantic differential (SD) method can be used to extract user-centered emotional opinions [21]. To measure user attitudes to the degree of crowdedness in car cockpits [17], the semantic differential scale shown in Figure 2 was used to record the opinions of users. The relationship between the crowdedness in the car and the recorded figures can then be analyzed using least-squares multiple regression.


Figure 2. Semantic differential scale

## 3. Implementation and Examples

Nine experts with considerable experience and knowledge of theoretical principles were invited to join the consultation. A female customer completed the consultation platform before the experts, so that the customer results could be used as a reference. Among the nine experts, there were four passenger car designers, three common passenger car drivers, and two car mechanics. One expert was less than 30 years old, three were aged 30-40, two were aged 40-50, and three were older than 50. In addition, three experts had 5-10 years driving experience, three had 10–15 years of driving experience, and three had more than 15 years of driving experience.

Using the items in Table 1, the customer and nine experts ordered the items of criteria level $B^1$ in order of importance, from 1 (least important) to $k$ (most important). According to these rankings, the Kendall's $W = 0.797$, giving $\chi^2_{0.05,7} = 14.067$ and $\chi^2_{0.05,7} < \chi^2 = 55.758$. Thus, the ranking values were consistent. This result was achieved by the second round, because the values in the first round were inconsistent. In addition, the items in different criteria levels should be rearranged until the ranking values are consistent. Hence, the approximate optimization sequence in criteria level $B^1$ was found to be $B_1^1$, $B_2^1$, $B_6^1$, $B_3^1$, $B_5^1$, $B_4^1$, $B_8^1$, $B_7^1$. Owing to the variety of facilities, the sequences can be adjusted somewhat during the process of optimization. Based on Delphi-AHP, the sequences and weights of all items can then be calculated.

Because the customer was sensitive about the degree of crowdedness in the cockpit, more surveys were conducted. A total of 203 questionnaires were sent and collected, with data from 119 considered to be usable. Based on least-squares multiple regression, the relationship between the degree of crowdedness in car cockpits and the customer satisfaction was found to be:

Table 1. Least-squares multiple regression results

| Dependent Variable | $S$ | $S^2$ | $S^3$ | Constant |
|---|---|---|---|---|
| Coefficient | 0.1474$^{***}$ | -0.0144$^{***}$ | -0.0036$^{*}$ | 1.6566$^{***}$ |
| t statistic | 9.51 | -3.14 | -2.18 | 52.87 |

$^{***}P \le 0.005$, $^{**}P \le 0.01$, $^{*}P \le 0.05$

$$A = -0.0036\hat{S}^3 - 0.0144\hat{S}^2 + 0.1474\hat{S} + 1.6566 \tag{13}$$

In Table 1 and Equation (13), the dependent variable $S$ is the semantic differential scale value given by the user, and the dependent variable $A$ is the ratio between the user's ideal distance and the minimum distance among the facilities in the car. The number of observations was 119, $F(3,115) = 92.26$, $Prob > F$ =0.0000, and $R^2 = 0.7065$. These statistics indicate that the results are ideal.

From an ergonomic perspective, there is a most suitable distance between two facilities or the car bulkhead, but not all facilities can be placed in their optimal positions. Thus, the facilities must be arranged to form the most satisfactory integral layout. The objective function $f(x)$ was constructed based on this idea. Using the minimum Euclidean distance, Equation (9) was computed to determine the viewing angles formed among different related facilities. Therefore, as an objective function, we seek to minimize:

$$\begin{aligned} \min f(x) = & \sum_{i=1,j=1}^{n} w_{1ij} \left( \frac{|x_i - x_j|}{Ao_{ij}^{1}} - 1 \right)^2 + \sum_{i=1,j=1}^{n} w_{2ij} \left( \frac{|y_i - y_j|}{Ao_{ij}^{2}} - 1 \right)^2 + \sum_{i=1,j=1}^{n} w_{3ij} \left( \frac{|z_i - z_j|}{Ao_{ij}^{3}} - 1 \right)^2 \\ & + w_4 \arctan \frac{\sqrt{(x_i^2 + y_i^2 + z_i^2)(x_k^2 + y_k^2 + z_k^2) - (x_i x_k + y_i y_k + z_i z_k)^2}}{x_i x_k + y_i y_k + z_i z_k} \end{aligned} \tag{14}$$

The constraints for Equation (14) are given by Equation (11) and Equation (12). In Equation (14), $(x_i, y_i, z_i)$ are the coordinates of a point on facility $i$, and similarly for subscripts $j$ and $k$. The selected points on those facilities are determined by the optimization objective. Facility $j$ is normally close to facility $i$, notwithstanding the non-interference boundaries, or they are related with each other in terms of the driving process. They may be in the same group, but the optimization sequence of facility $j$ is behind that of facility $i$. $o_{ij}$ is the optimal distance between the points on facility $i$ and those on facility $j$ according to the theory of ergonomics. Based on driving requirements, facility $i$ and facility $j$ should have an appropriate viewing angle. $A$ is the ratio between the user's ideal distance and the minimum distance among the facilities in the car.

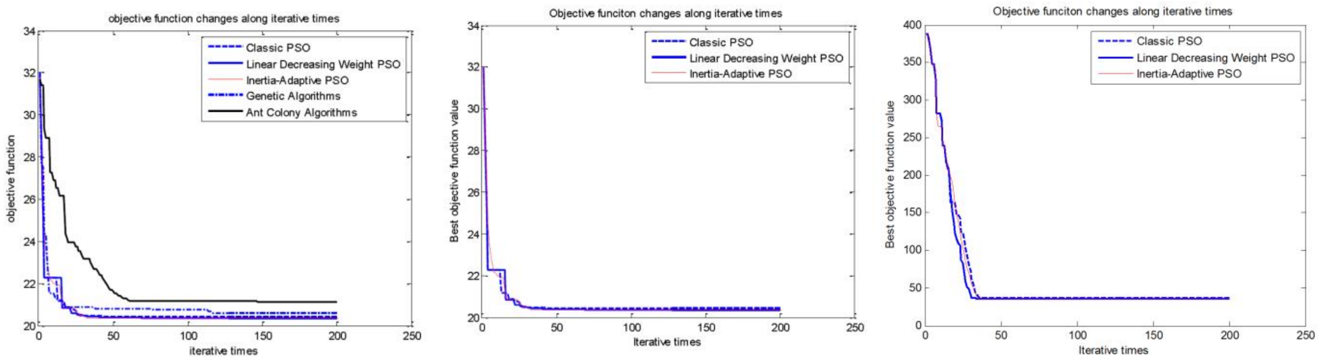
When $S = 2, A = 1.865$, the optimal values of the handbrake's central point can be found using the optimal design platform. For example, the coordinates of the multi-function steering wheel, gearstick, chair, and storage box are known. The coordinates of the multi-function steering wheel's central point are $k = (0\text{mm}, 362.2\text{mm}, \text{-}289.8\text{mm})$. The coordinates of the gearstick when pushed backward to its end point are $j_1 = (391.2\text{mm}, 236.5\text{mm}, \text{-}565.1\text{mm})$, and those of the chair's central point are $j_2 = (0\text{mm}, 65.2\text{mm}, \text{-}753.4\text{mm})$. The central point of the storage box is located at $j_3 = (391.2\text{mm}, \text{-}101.4\text{mm}, \text{-}586.8\text{mm})$. Based on the facilities ranked by the customer and nine experts in order of importance by Delphi-AHP, the mean rankings and weights can be obtained (see Table 2). The Kendall's $W$ = 0.834 and

$\chi^2_{0.05,9} = 16.919 < \chi^2 = 67.573$, which means that the ranking values are consistent.

Table 2. Mean rankings and weights from the customer and nine experts

| | $w_{111}$ | $w_{112}$ | $w_{113}$ | $w_{211}$ | $w_{212}$ | $w_{213}$ | $w_{311}$ | $w_{312}$ | $w_{313}$ | $w_4$ |
|---|---|---|---|---|---|---|---|---|---|---|
| Mean ranking | 6.56 | 6.61 | 5.72 | 8.22 | 8.17 | 9.17 | 2.28 | 2.33 | 1.44 | 4.50 |
| Weight | 0.11928 | 0.12019 | 0.103981 | 0.149459 | 0.148549 | 0.166719 | 0.041452 | 0.042362 | 0.026188 | 0.081819 |

To demonstrate the superiority of the proposed inertia-adaptive PSO, we compared the optimization results with those given by the classic PSO, linear decreasing weight PSO, GA, and ant colony optimization. The parameter values for each algorithm were as follows: in classic PSO, the learning factors were set to 2, the weight values were set to 1.1, and the number of particles was 50. In linear decreasing weight PSO, the learning factors were set to 2, the maximum weight was 1.1, and the number of particles was set to 50. The GA had a size of 50, crossover probability of 1.1, and a mutation probability of 0.7. In the ant colony optimization algorithm, the size was set to 50. In the proposed inertia-adaptive PSO, the learning factors were set to 2 and the number of particles was 50. The inertia weights have been recommended from 1.4 to 0 and have good performance [6]; thus, the maximum weight was set to 1.1 and the minimum weight was set to 0.7 to ensure satisfactory solutions. The results are presented in Table 3 and Figure 3(a). The minimum values given by the ant colony optimization algorithm are always unsatisfactory and become stuck around local optima; the GA always has lower efficiency than the other algorithms, because it requires more steps for the crossover and mutation operations. In Figure 3(b), not only is the efficiency of inertia-adaptive PSO slightly higher than that of classic PSO and linear decreasing weight PSO, but the minimum value found by the proposed approach is slightly smaller than those given by the classic and linear decreasing weight PSO methods. In Figure 3(c), the minimum value found by inertia-adaptive PSO is again slightly smaller than that found by the classic and linear decreasing weight approaches. Thus, the inertia-adaptive PSO is the best method for solving this problem.




(a) (b) (c)

Figure 3. (a) Handbrake values; (b) Handbrake values given by PSO; (c) Air conditioner control panel values given by PSO

Table 3. Optimal solutions and minimum values of objective function optimized by five different algorithms for the handbrake

| | Optimal solution on *x* | Optimal solution on *y* | Optimal solution on *z* | Minimum values |
|---|---|---|---|---|
| Classic PSO | 280.058mm | 101.9689mm | -489.0659mm | 20.4334 |
| Linear Decreasing Weight PSO | 275.5309mm | 105.7848mm | -489.8272mm | 20.3536 |
| *Inertia-Adaptive PSO* | 278.2273mm | 101.0705mm | -490.3623mm | 20.3518 |
| Genetic Algorithm | 291.2711mm | 118.0944mm | -481.5274mm | 20.5983 |
| Ant Colony Optimization Algorithm | 228.5719mm | 89.52847mm | -505.6151mm | 21.1401 |

Taking another example of the air conditioner panel, the coordinates of the point on the multi-function steering wheel fixed with the bulkhead are (0mm, 508.6mm, -239.8mm), the endpoint of the gearstick when pushed forward to its furthest extent is (391.2mm, 340mm, -565.1mm), the point on the center of the multimedia display and control panel is (316.0mm, 473.1mm, -269.6mm), and the point on the bottom center of the windscreen is (403.6mm, 887.1mm, -221.8mm). In this case, the coordinates of the air conditioner control panel center can be obtained as (315.1926mm, 395.3068mm, -189.2221mm).

As shown in Figure 4, the optimized positions of the 20 most important facilities are shown. According to the physical truth, optimized positions of facilities are needed to be adjusted properly. The optimized layout scheme is analyzed by the simulation software JACK as Figure 5. All of the facilities are in the proper visual fields and reach zones.

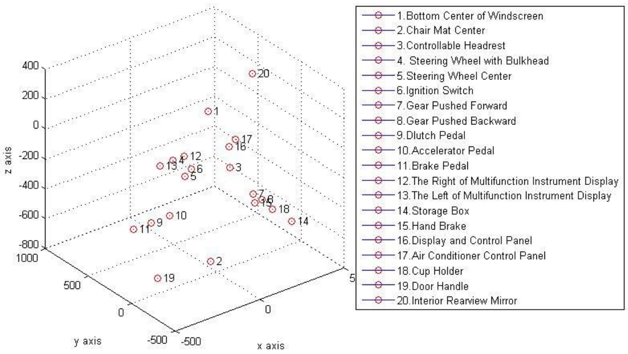



Figure 4. Optimized positions of the 20 most important facilities

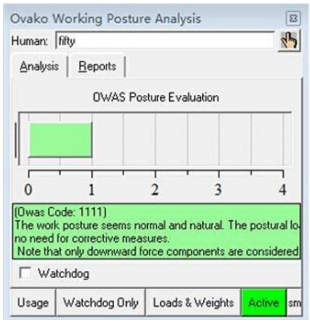



Figure 5. Analysis of visual fields, reach zones, and comfort assessment using JACK

## 4. Conclusions

This paper has described an optimal design platform for the layout of a car's cockpit. Using the optimal design platform, the limited workspace can be used efficiently and drivers can drive more safely, feel comfortable for a longer time, and reduce their effort. Additionally, the optimal design platform reduces the probability of drivers becoming fatigued, which reduces the likelihood of poor driving and incorrect operations.

To analyze the space layout problem for passenger vehicle cockpits, a combined AHP-Delphi process has been proposed. As the optimization process is difficult because of the many facilities to be arranged, the conventional AHP was adapted and improved using Delphi.

To prevent candidate solutions from becoming trapped around local optima in the optimization process, the inertia-adaptive PSO algorithm, which has fewer parameters and a higher degree of accuracy than conventional PSO, was applied to optimize the ergonomic layout of a car's cockpit in three dimensions. The modified layout was then compared with those given by several other optimization algorithms. The results demonstrate that the proposed approach provides a reasonable layout. The inertia-adaptive PSO algorithm combined with Delphi-AHP can solve the optimization design problem of customizing the safety ergonomic layout of passenger car cockpits in three-dimensional space effectively and efficiently.

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### References

1. W. Fan, S. Yu, W. Wang, B. Qi, and L. Zong, "Ant Colony Algorithm for Human-Machine Layout Optimization," *Mechanical Science and Technology for Aerospace Engineering*, Vol. 32, No.7, pp. 955-962, 2013
2. H. H. Han, D. F. Han, F. Liu, and X. B. Wang, "Research on 3D Layout Optimization of HOV Cabin," *Ship Engineering*, Vol. 35, No. 1, pp. 76-80, 2013
3. X. Liu, "The Ergonomic Cockpit Interior Design and Evaluation Methods Driven by Hybrid Kansei Engineering," Northwestern Polytechnical University, 2016
4. S. Niu and Y. Sun, "The Construction of the Ergonomics Criteria Framework in Civil Aircraft Cockpit Design," *Aircraft Design*, No. 34, No.1, pp. 73-76, 2014
5. Z. Q. Qian, H. F. Teng, and Z. G. Sun, "Human-Computer Interactive Genetic Algorithm and its Application to Constrained

Layout Optimization," *Chinese Journal of Computers*, No. 24, pp. 553-559, 2001
6. Y. Shi and R. C. Eberhart, "Parameter Selection in Particle Swarm Optimization," in *Proceedings of International Conference on Evolutionary Programming*, pp. 591-600, Springer, Berlin, Heidelberg, 1998
7. W. Q. Wang, S. Huang, Y. L. Hu, and Y. H. Hou, "Particle Swarm Optimization based Algorithm for Ship Vertical Passage Layout Optimization," *Advanced Materials Research*, Vol. 479-481, pp. 1885-1888, 2012
8. N. T. Putri and S. M. Yusof, "Critical Success Factors for Implementing Quality Engineering Tools and Techniques in Malaysia and Indonesia's Automotive Industries: An Exploratory Study," in *Proceedings of the International Multi-Conference of Engineers and Computer Scientists*, Vol. 2, pp. 18-20, 2009
9. S. Niu, "The Layout Optimization Study for Civil Aircraft Cockpit Ergonomics Design," Nanjing University of Aeronautics and Astronautic, 2013
10. J. Kennedy, "Particle Swarm Optimization," Encyclopedia of Machine Learning, Springer, Boston, MA, 2011
11. S. Önüt, U. R. Tuzkaya, and B. Doğaç, "A Particle Swarm Optimization Algorithm for the Multiple-Level Warehouse Layout Design Problem," *Computers & Industrial Engineering*, Vol. 54, No. 4, pp. 783-799, 2008
12. S. Kulturel-Konak and A. Konak, "A New Relaxed Flexible Bay Structure Representation and Particle Swarm Optimization for the Unequal Area Facility Layout Problem," *Engineering Optimization*, Vol. 43, No. 12, pp. 1263-1287, 2011
13. Y. Li, B. Zheng, and Z. Dai, "General Particle Swarm Optimization based on Simulated Annealing for Multi-Specification One-Dimensional Cutting Stock Problem," in *Proceedings of International Conference on Computational and Information Science*, Springer, Berlin, Heidelberg, 2006
14. F. Liu, M. Sun, N. Li, D. Sun, and T. Zou, "Particle Swarm Optimization and its Application of Constrained Layout Optimization," *Computer Engineering and Applications*, No. 12, pp. 71-93, 2004
15. M. Sun, F. Liu, D. Sun, N. Li, and T. Zou, "Layout Optimization of Cube Group in Rotation Module," *Computer Engineering and Applications*, Vol. 34, No. 40, pp. 92-94, 2004
16. W. Lee, K. Jung, J. Jeong, J. Park, J. Cho, H. Kim, et al., "An Anthropometric Analysis of Korean Male Helicopter Pilots for Helicopter Cockpit Design," *Ergonomics*, Vol. 56, No. 5, pp. 879-887, 2013
17. K. S. Shen, K. H. Chen, C. C. Liang, W. P. Pu, and M. Y. Ma, "Measuring the Functional and Usable Appeal of Crossover B‐Car Interiors," *Human Factors and Ergonomics in Manufacturing & Service Industries*, Vol. 25, No. 1, pp. 106-122, 2015
18. J. Cho and J. Lee, "Development of a New Technology Product Evaluation Model for Assessing Commercialization Opportunities using Delphi Method and Fuzzy AHP Approach," *Expert Systems with Applications*, Vol. 40, No. 13, pp. 5314-5330, 2013
19. M. N. Rahman and M. A. Matin, "Efficient Algorithm for Prolonging Network Lifetime of Wireless Sensor Networks," *Tsinghua Science & Technology*, Vol. 16, No. 6, pp. 561-568, 2011
20. X. Liu, S. H. Yu, T. C. Gong, Q. Zhang, M. L. Zhao, and W. Y. Zhang, "Ergonomics Layout Optimization of the Aircraft Cockpit based on Particle Swarm Optimization," *Advanced Materials Research*, Vol. 1044, pp. 1851-1854, 2014
21. F. Guo, W. L. Liu, Y. Cao, F. T. Liu, and M. L. Li, "Optimization Design of a Webpage based on Kansei Engineering," *Human Factors and Ergonomics in Manufacturing & Service Industries*, Vol. 26, No. 1, pp. 110-126, 2016