Ergonomics Optimization of Heavy Commercial Vehicle

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Abstract. Optimize the cab seat height of the heavy commercial vehicle and the maneuverability of the shift lever. Method: The mathematical model of human sitting posture and upper limb operation were established. The Chinese human body size was corrected by the combination of height growth rate and height linear ratio. Under the constraint of sitting posture, the H-point fitline model of the 5th, 50th and 95th percentile male drivers in China was obtained, and the optimal H-point range and SgRP point height were determined. The problem of high seat height has been optimized. At the same time, a operating lever layout position model is established; The actual measurement was made in the Class A vehicle, and the shift lever arrangement position was redefined. Conclusion: The height adaptability of the seat is improved; the operating comfort of the shift lever is improved; the visible area of the instrument panel becomes larger, and the 10th percentile male driver in China has a larger blind spot.

1. Introduction
Cab comfort is critical to the driver. Low comfort level can easily lead to driver fatigue, affect safe driving, and cause driving diseases. With the frequent occurrence of driving occupational diseases, users pay more attention to the comfort of the cab. At present, comfort problems related to seats and gear levers in heavy commercial vehicles are becoming more and more serious, and these problems are also problems in the current industry. It is increasingly important to explore ways to solve such problems. In the 30 years after the promulgation in 1989, the domestic human body size has not been updated, which severely restricted the layout design of the cab for heavy vehicles. The size of the lower limbs in my country is shorter than that of Americans, so the sitting height is lower than that of Americans. Therefore, for Chinese drivers, the design level of Class B cars designed according to SAE standards is low. Lanbao [1], Wang Ji [2], Wang Yijia et al. [3] all choose the heavy-duty vehicle cab as the carrier to correct the human body size of GB10000-1988, optimize the comfort range, and improve seat comfort. Americans sit behind the Chinese while driving. As a
result, according to the SAE standard design, the location of the shift rod is low for Chinese comfort. Liu Mingzhou et al. [4] proposed a fuzzy neural network based vehicle gearbox steering comfort evaluation method. Yang Fei et al. [5] arranged and designed driver's seat and various control devices of the tractor cab. Yang Fei et al. [6] use the RULA method to find the best distribution of manipulating parts. Matthew B. Parkinson. et al. [7] take the heavy-duty cab as the research object to determine the adjustment range of the seat arrangement that satisfies the user's differences. This article mainly optimizes the following comfort issues for a heavy commercial vehicle: 1. Sitting comfort aspect: The driver's seat is too high, the driver sits on the seat and slides down, unable to adjust to a comfortable angle. 2. Operational comfort: The shift lever is arranged behind the position and layout parameters are as follows: The vertical height of the SgRP point is 491mm. The X-direction distance of the shift lever from the SgRP point is 211mm; the Y-direction distance of the shift lever from the SgRP point is 400mm; the Z-direction distance of the shift lever from the SgRP point is 91mm.

2. Human operation model establishment
Driving behavior is a dynamic process. In order to simplify the research, the interior layout of the cab is often studied statically. The matching between the interior layout of the cab and the human body determines the comfort level of driving. Simplify the driver's sitting posture model into a two-dimensional rod-like structure and establish a plane rectangular coordinate system, as shown in Figure 1. The driver's sitting comfort model is established under the constraints of sitting body characteristics, as in equations (1) and (2). Using the same principle, the H point is used as the coordinate origin of the mathematical model, and the mathematical model of the upper limb manipulation device is established, as in equations (3), (4), (5) and (6).
Figure 1. Driver’s seated two-dimensional rod model

Description of the symbols in Figures 1, 2 and 3: \( L_1 \) - the length of the neck joint point to the \( H \) point; \( L_2 \) - the length of the shoulder joint to the \( H \) point; \( L_3 \) - the length of the knee joint point to the \( H \) point; \( L_4 \) - the length of the ankle joint point to the \( H \) point; \( L_5 \) - the length of the elbow joint point to the \( H \) point; \( L_6 \) - the length of the elbow joint to the wrist point; \( L_7 \) - the length from the center of the hand to the point of the wrist; \( L_8 \) - the vertical distance from the ankle joint to the sole plane; \( L_9 \) - the distance from the \( AHP \) point to the foot in the definition of \( L_8 \); \( L_{10} \) - the length of the ankle joint to the defect; \( \alpha_1 \) - the angle between the center line of the trunk and the vertical line; \( \alpha_2 \) - the angle between the center line of the trunk and the center line of the thigh; \( \alpha_3 \) - the angle between the center line of the thigh and the center line of the calf; \( \alpha_4 \) - the angle between the center line of the calf and the plane of the sole; \( \alpha_5 \) - the angle between the center line of the trunk and the center line of the upper arm; \( \alpha_6 \) - the angle between the center line of the upper arm and the center line of the forearm; \( \alpha_7 \) - the angle between the center line of the forearm and the center line of the hand; \( \alpha_8 \) - the angle between the plane of the sole and the horizontal plane; \( \alpha_9 \) - The angle between the center line of the thigh and the horizontal line; \( l_1 \) - has the same meaning as \( L_1 \); \( l_2 \) - the length of the upper arm; \( l_3 \) - the length of the forearm + length of 1/2 hand; \( l_4 \) - half shoulder width of the human body; \( \theta_2 \) - driver’s backward tilt angle; \( \theta_3 \) - the upper arm lift angle of the driver; \( \theta_4 \) - the angle between the driver’s forearm and the upper arm extension line; \( \theta_5 \) - body twist angle; \( \theta_6 \) - the angle of extension of the right arm.

![Figure 1](image1.png)

Figure 2. Human upper limb line model

Figure 3. Top view of the human body point line model

Set heel point coordinates \((X_{AHP}, Z_{AHP})\), the coordinates of the seat \( H \) point are \((X_H, Z_H)\). From the geometric relationship:

\[
X_H = X_{AHP} + L_{10} \cos (\pi - \alpha_8 - \alpha) + L_4 \cos (\pi - \alpha_8 - \alpha_4) + L_5 \cos (\alpha_9) \\
Z_H = Z_{AHP} + L_{10} \sin (\pi - \alpha_8 - \alpha) + L_4 \sin (\pi - \alpha_8 - \alpha_4) - L_5 \sin (\alpha_9)
\]

Let the three-dimensional coordinates of the target point be \((x, y, z)\). Simplify the problem study, assuming that the driver completes the operation in the order of raising the arm, then stretching the arm and turning. According to the geometric relationship, the coordinate expression of the target point before turning around on the \( X \) axis is obtained:
\[ x_i = l_1 \sin \left( \theta_2 \right) + l_2 \sin \left( \pi - \theta_2 - \theta_3 \right) \]

(3)

At the same time, the calculation formula of the coordinates of the target point after the driver turns around is obtained:

\[ x = x_i \cos \left( \theta_3 \right) + l_4 \sin \left( \theta_4 \right) - l_1 \sin \left( \theta_1 \right) \]

(4)

\[ y = x_i \sin \left( \theta_3 \right) + l_4 \cos \left( \theta_4 \right) \]

(5)

\[ z = l_2 \cos \left( \theta_2 \right) + l_1 \cos \left( \pi - \theta_2 - \theta_3 \right) \]

(6)

3. Human body size

Human body size as the basic information of human-machine system or product design is the basic technical basis for a country's production [8]. After the release of the GB10000-1988 adult human body size standard, there has been no standardized adult human body size data released in the past 30 years, which has brought great challenges to the design of automobiles, especially the development of the B-type vehicle cab. Therefore, GB10000-1988 adult body size cannot be applied at this stage. Some enterprises and research institutes have conducted some surveys on the adult human body size at this stage. For example, Southwest Jiaotong University conducted an investigation on the height of 303 bus drivers in a bus company in Chengdu in 2015 [9]. The data is shown in Table 1.

Table 1. Chengdu bus driver height statistics in 2015.

| Project               | P5(mm) | P50(mm) | P95(mm) |
|-----------------------|--------|---------|---------|
| Driver height         | 1583   | 1701    | 1795    |

The growth rate of males in the southwest region in 2015 was compared with that in 1988, as shown in Table 2.

Table 2. Growth rate of male human body in Southwest China.

| Percentile | 1988 (mm) | 2015 (mm) | growth rate |
|------------|-----------|-----------|-------------|
| P5         | 1554      | 1583      | 0.0187      |
| P50        | 1647      | 1701      | 0.0328      |
| P95        | 1740      | 1795      | 0.0316      |

\[
\rho = \frac{H_2 - H_1}{H_1} \]

(7)

Where: \( H_1 \) - male height in southwestern region in 1988; \( H_2 \) - male height in southwestern region in 2015; \( \rho \) - height growth rate.

The size growth rate of males in the southwest region is approximated as the growth rate of adult human body size in the whole country. Before and after the revision, the comparison of the human body height and height of the Chinese adult males is shown in Table 3.
Table 3. Chinese adult male height dimensions.

| Percentile | Male height 1988(mm) | Male height 2015(mm) |
|------------|------------------------|----------------------|
| P5         | 1583                   | 1613                 |
| P50        | 1678                   | 1733                 |
| P95        | 1775                   | 1831                 |

There is an approximate linear relationship between the static size and height of various parts of the human body with normal posture [7]. From the equation (8), the main body size of the common male percentile in 2015 is obtained, as shown in Table 4.

Table 4. Main dimensions of male human body in 2015.

| Project                  | Male (18-60 years old) percentile (mm) |
|--------------------------|----------------------------------------|
|                          | Male height | P5       | P50     | P95     |
|                          |             | 1613     | 1733    | 1831    |
| Forearm length           | 220         | 245     | 266     |
| Sitting height           | 763         | 824     | 874     |
| Sitting shoulder height  | 568         | 618     | 661     |
| Sitting elbow height     | 232         | 272     | 307     |
| Calf length plus foot height | 390   | 427     | 462     |
| Sitting deep             | 429         | 472     | 510     |

\[
\frac{y_1}{y_2} = \frac{kH_1}{kH_2} = \frac{H_1}{H_2}
\] (8)

Where: \(y_1\) - static size of adult male parts in 1988; \(y_2\) - static size of adult male parts in 2015; \(k\) - proportion coefficient.

Considering the correlation of human joint motion, comfort analysis and dynamic human body size are used when creating digital human body models [10]. The dynamic body size was obtained from the human body measurement dimensions, and the results are shown in Table 5.

Table 5. Male dynamic body size.

| Name                      | P5 (mm) | P50 (mm) | P95 (mm) |
|---------------------------|---------|----------|----------|
| Forearm connection L6     | 220     | 245      | 266      |
| Upper arm connection L5   | 336     | 346      | 354      |
| Hand connected L7         | 85      | 92       | 98       |
| Thigh connection L3        | 343     | 378      | 408      |
| Calf connection L4         | 312     | 342      | 370      |
| Spinal connection L2       | 568     | 618      | 661      |

4. Driver comfort angle range
In the comfortable driving position, the joint angles of the human body will be within the corresponding comfort angle. The components should be placed in the comfort zone of each joint.
when the cab is placed. Many scholars have studied the comfort range of each joint and summarized the range of comfortable joint angles in the sagittal plane as shown in Table 6 [11].

**Table 6.** Class B car driver sitting comfort joint angle.

| Name | Minimum angle (°) | Maximum angle (°) |
|------|-------------------|-------------------|
| a1   | 3                 | 20                |
| a2   | 90                | 115               |
| a3   | 95                | 135               |
| a4   | 72                | 99                |
| a5   | 0                 | 50                |
| a6   | 80                | 130               |
| a7   | 170               | 190               |
| a8   | 46                | 76                |
| a9   | 2                 | 12                |

4.1. Lower Limb Comfort Joint Angle Range

From the two-dimensional rod-shaped human body model of Figure 1, the human lower limb joint angle satisfies the geometric relationship:

$$\alpha_4 + \alpha_8 = \alpha_3 + \alpha_9$$

The comfortable sitting position is determined by equation (9), and the following angles usually occur: one angle, two angles or three angles are known. Among them, \(\alpha_3\) is a typical hinge joint, which is easy to cause fatigue from the perspective of human factors engineering. The \(\alpha_3\) is constantly changing during driving to relieve fatigue. Therefore, \(\alpha_3\) should take the range value and cannot take the value.

When one of the lower limbs \(\alpha_4, \alpha_3, \alpha_9\) is known, the \(H\)-point comfort range constitutes a comfort zone. When the two corners of the lower limbs \(\alpha_4, \alpha_9\) are known, the comfort point of the \(H\)-point satisfies a linear relationship. In order to compare with the \(H\)-point fitline recommended by SAE. In this paper, only the linearity relationship of \(H\)-point comfort range is studied. The results are shown in Table 7.

**Table 7.** Human lower limb angle comfort range.

| Name | Situation one: \(\alpha_5-\alpha_9\) | Situation two: \(\alpha_5-\alpha_9\) | Situation three: \(\alpha_4-\alpha_9\) | Situation four: \(\alpha_4+\alpha_8\) | Situation five: \(\alpha_4+\alpha_8\) |
|------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|
| \(\alpha_3\) | [34°,36°]                       | (36°,63°]                        | [60°,89°]                        | [118°,137°]                      | (137°,145°]                      |
| \(\alpha_4\) | [106°,135°]                     | (108,135°]                       | [106°,135°]                     | [106°,135°]                     | (125°,135°]                     |
| \(\alpha_5\) | [72°,99°]                       | [72°,99°]                        | -                               | -                               | -                               |
| \(\alpha_8\) | -                               | -                               | [46°,75°]                       | -                               | -                               |
| \(\alpha_9\) | -                               | -                               | -                               | [2°,12°]                        | (2°,12°]                        |

1) When \(\alpha_5\) and \(\alpha_9\) are known, the equation (9) can be expressed as a straight line \(\alpha_5 - \alpha_9 = \alpha_8 - \alpha_4\).

When \(\alpha_5 - \alpha_9 \in [\alpha_{\min}, \alpha_{\max}], \alpha_{\max} - \alpha_{\min}\) , i.e. \(\alpha_5 - \alpha_9 \in [34°, 36°]\) , obtain \(\alpha_8 \in [106°, 135°]\) , \(\alpha_4 \in [72°, 99°]\).
When \( a_x - a_y \in [a_{\text{max}} - a_{\text{min}}, a_{\text{max}} - a_{\text{max}}] \), \( \alpha \), obtain \( a_x \in [108^\circ, 135^\circ] \), \( \alpha \in [72^\circ, 99^\circ] \).

2) When \( \alpha \) and \( \alpha \) are known, the equation (9) can be expressed as a straight line
\[
a_x - a_y = \frac{\alpha - \alpha}{\alpha - \alpha},
\]
\( \alpha \) and \( \alpha \) are
\[
a_x - a_y \in [60^\circ, 89^\circ],
\]
obtain \( a_x \in [106^\circ, 135^\circ] \), \( \alpha \in [46^\circ, 75^\circ] \).

3) When \( \alpha \) and \( \alpha \) are known, the equation (9) can be expressed as a straight line
\[
a_x + a_y = \frac{\alpha + \alpha}{\alpha + \alpha},
\]
\( \alpha \) and \( \alpha \) are
\[
a_x + a_y \in [118^\circ, 137^\circ],
\]
obtain \( a_x \in [106^\circ, 135^\circ] \), \( \alpha \in [2^\circ, 12^\circ] \).

4.2. Upper Limb Joint Angle Range Determination

In order to optimize the maneuverability of a heavy commercial vehicle, the angle of the right arm joint when the driver manipulates the shift lever of the class A is measured.

Measurement requirements: The fixed seat back angle is \( \theta_1 = 11^\circ \).

Measurement target: 10 healthy male drivers with an age limit of 24 to 50 years old, with an average driving age of more than 5 years. The height limit is 165cm~182cm and there is no upper limb and trunk sprain in 3 months. Take the right arm as the measurement object.

Measurement items: Operate the shift lever to the limit position and raise the angle \( \theta_2 \) from the upper right arm. The angle between the right forearm and the upper arm extension line \( \theta_3 \). The body twist angle \( \theta_4 \) and the right arm stretch angle \( \theta_5 \).

The measured sample data were counted and the results are shown in Table 8.

| Measurement item | Recent front position | Measurement item | Recent front position | Measurement item |
|------------------|-----------------------|------------------|-----------------------|------------------|
| \( \theta_2 \)    | [31º, 63º]            | \( \theta_3 \)   | [13º, 45º]            | [35º, 60º]       | [8º, 42º]       |
| \( \theta_4 \)    | [0º, 41º]             | \( \theta_5 \)   | [20º, 75º]            | [0º, 32º]        | [23º, 56º]      |
| \( \theta_2 \)    | [5º, 18º]             | \( \theta_5 \)   | [6º, 30º]             | [6º, 25º]        | [7º, 37º]       | [7º, 38º]       |

Considering that the shift lever reaches each limit position, the movement angles of the joints of the right arm of each percentile are in different ranges. Therefore, each location must be analyzed separately.

5. Cab man-machine comfort optimization

5.1. Comfort Problem Optimization

5.1.1. Sitting comfort optimization

The design of the B-class cab adopts 90:10 and 95:5 male to female ratios. Therefore, the paper mainly based on the size of the male body. Chen Jinghui et al [12] verified that the vertical height of
the seat $H$ point is greater than 405mm, and the value of $\alpha_1$ and $\alpha_4$ is not much different. The overall comfort of the $\alpha_8=35^\circ$ model is higher than that of the $\alpha_8=45^\circ$ model. In order to ensure the comfort of the multi-percentile driver in China, the angle of the pedal and the inclination of the seat cushion should be chosen to be too small, even beyond the comfort range.

**Table 9.** Sitting posture mathematical model constraints.

| Variable | $P_5$ | $P_{50}$ | $P_{95}$ |
|----------|-------|----------|----------|
| $L_3$    | 343mm | 378mm    | 408mm    |
| $L_4$    | 312mm | 342mm    | 370mm    |
| $L_{10}$ | 98mm  | 107mm    | 116mm    |
| $\alpha_3$ | [106°,135°] | [106°,135°] | [106°,135°] |
| $\alpha_4$ | [72°,99°] | [72°,99°] | [72°,99°] |
| $\alpha_8$ | 35° | 35° | 35° |
| $\alpha_9$ | 2° | 2° | 2° |
| $\alpha_5$ | 53° | 53° | 53° |

Using Matlab to simulate the equation (1), the optimal $H$-point range distribution for drivers with different percentiles in China is obtained, as shown in Figure 4. The best $H$-point range: horizontal distance 431~661mm, vertical distance 310~456mm.

**Figure 4.** Best $H$-point position in a comfortable sitting position

Fitting 95,50 and 5th percentile models of $H$-point for adult males:

$$X_{H95} = -447 + 6.47Z_H - 0.0102Z_H^2, \ Z_H \in [368, 384]$$

$$X_{H50} = -411 + 6.47Z_H - 0.011Z_H^2, \ Z_H \in [368, 384]$$

$$X_{H5} = -380 + 6.75Z_H - 0.0121Z_H^2, \ Z_H \in [368, 384]$$

As can be seen from Figure 4, the seat height cannot meet the seat comfort of the 95th percentile and below in China, and the fitness for Chinese male drivers is less than 5%.

This paper the $\alpha_4$ is not fixed to 87°, and the fitting line satisfies the quadratic function relation. The vertical range of human $H$-point in the 5th, 50th and 95th percentiles is common [368 mm,384mm]. Therefore, there is a certain difference between the determination and SAE of SgRP.
points. In this paper, the median value of the vertical range of $H$-point is chosen as the vertical coordinate of the point, so as to the coordinates of the SgRP point that meets the comfort level of Chinese adult men are determined as (645,376). The height of the comfortable SgRP point is lower than the minimum height of the existing vehicle SgRP point 461 mm, considering that the existing vehicle combination instrument is not adjusted, the optimized height of the SgRP point can not be reduced directly to the comfortable SgRP point. The existing models are based on the SAE standard. In order to determine the SgRP point optimization height of the existing models. The three $H$-point of SAE standard[13]are combined with the 95th ,50th and 5th percentile $H$-point in China, because the height of the H points can not be lower than 368 mm, only the 95th percentile adult male and the 5th percentile population in the United States have an intersection point to meet the requirements. 

$$
\begin{align*}
X_5 &= 762.17 - 0.485Z \\
X_{495} &= -447 + 6.74Z_H - 0.0102Z_H^2
\end{align*}
$$

The calculated $Z_H$ is 442 mm, so the optimization height of SgRP points can be determined in [368mm,442mm]. In this paper, the median value is 405 mm. Figure 4 shows that the 5th percentile adult male sitting comfort can not be satisfied, so this paper selects the 50th percentile (the largest number distribution) male size for follow-up study, and determines that the seat SgRP point coordinates are (612,405). At the same height, when the seat level is adjusted, the normal weight is SgRP point behind the obese and lean. From the regression function relationship between the body mass index and the $H$-point distance [14] on the sagittal plane, as shown in Table 10. The calculated $H$-point distance range of body size difference is 9–25 mm, and the optimized seat adjustment stroke is determined to be 175 mm.

| BMI            | Man $H_{point}$ (mm)       |
|----------------|---------------------------|
| Thinnish 13.5 ≤ BMI < 18.5 | 72.28 + 1.67 * BMI         |
| Normal 18.5 ≤ BMI < 25      | 64.12 + 2.11 * BMI         |
| Overweight 25 ≤ BMI < 30    | 71.94 + 1.79 * BMI         |
| Fat 30 ≤ BMI < 40           | 77.29 + 1.62 * BMI         |

The 25th percentile male static size is obtained from equation (11) and converted to dynamic size to meet the vertical height of the seat seat SgRP point. Prove that the optimized seat meets the seat comfort of the 25th to 95th percentile male driver, and the male driver's fitness is 70%.

$$x_{i,p} = u_i \pm \sigma_i K$$  

5.1.2. Operational comfort optimization

Definition: X-axis -the direction in which the vehicle is moving forward is the positive direction; Y-axis -the direction in which the vehicle is laterally to the right is the positive direction; Z-axis -The direction perpendicular to the ground is positive. The shift lever arrangement is based on the design scale of the IIB type, the 5th percentile body size is selected, and the formulas (2) and (3) are calculated by Matlab. The two-dimensional size results of YX plane and YZ plane are shown in
Figure 5. Shift lever layout two-dimensional size map

The comprehensive analysis shows that the range of the X direction is between 324 mm~401 mm, the Y direction is between 265mm~ 356mm, and the Z direction is between 79mm~ 138 mm. The center of shift rod is set at the midpoint of each direction of X, Y, Z, that is, the X distance between shift rod and SgRP point is 363 mm, and the Y distance between shift rod and SgRP point is 310 mm, and the Z distance between shift rod and point is 109mm.

5.2. Optimization Scheme Verification

The comfort angles in Table 6 are graded, and the driver comfort simulation is performed using CATIA software to verify the rationality of the optimization results. The seat is selected according to the adjustable design criteria, and the 95,50,5th percentile were selected as the simulation object.

The driver’s posture scores before and after optimization are shown in Table 11. Comparing driving posture scores before and after optimization, after the seat height is lowered, the lumbar comfort score increased significantly. The overall comfort after optimization is improved compared to the overall comfort before optimization.

Table 11. Driving posture scores before and after optimization

| Joint   | P5  |       | P50 |       | P95  |       |
|---------|-----|-------|-----|-------|------|-------|
|         | Before | After | Before | After | Before | After |
| lumbar  | 62   | 70    | 70   | 96    | 83    | 96    |
| thigh   | 60   | 72    | 80   | 90    | 88    | 94    |
| calf    | 64   | 76    | 70   | 94    | 72    | 90    |

The RULA module is used to evaluate the comfort of the upper limbs when the shift levers of the two schemes are used, and the advantages and disadvantages of the improved scheme are analyzed. According to the evaluation principle of the RULA method, the posture is graded [15], see Table 11.

Table 11. RULA method to assess posture grading

| Score | Rating | Degree of acceptance |
|-------|--------|----------------------|
| 1~2   | I      | acceptable           |
| 3~4   | II     | Still to be studied  |
The 50th percentile male driver in China was selected for RULA analysis before and after shift lever optimization. The results are shown in Figure 6 and Figure 7. In the original scheme, the arrangement position of the joystick is larger than the Y-direction distance of the SgRP point, and the driver's upper arm abduction angle is large. The joysticks of heavy commercial vehicles are used more frequently. The shifting action is a repetitive motion at a higher frequency, in which the comfort of the upper arm and the wrist is relatively low, so that the driver's total score in this position is 4 points, belonging to the second level. After the improvement, the arrangement position of the joystick is shorter than the original Y-direction distance of the driver SgRP point, and the driver's upper arm abduction angle is small. The driver's total score in this position is 2 points, which belongs to the first level. This arrangement range is comfortable.

**Figure 6.** Pre-optimal RULA analysis

**Figure 7.** Optimized RULA analysis

In Figure 8, (a) and (b) are the visual field of the male driver's dashboard of the 95th and 5th percentiles before optimization, respectively. This arrangement is not suitable for Chinese drivers to view the contents of the dashboard.

In Figure 9 (a), (b) and (c) are the visible visual field of the 10th, 25th and 95th percentile male driver's dashboard and the front lower visual field tangent. After optimization, the dashboard has a good viewing area for comfortable viewing of the dashboard content. The layout of this scheme is larger for the 10th percentile male driver in China.

**Figure 8.** Simulation of the driver's lower field of vision before optimization
Figure 9. Optimized driver's lower field of view simulation

6. Conclusion
This paper simplifies the human body model into a two-rod structure, and establishes a human sitting posture model and a steering wheel model for the upper limbs, based on the revised Chinese human body size. Constrained by the driver's comfortable joint angle, carrying a high-heavy commercial vehicle seat high and optimization of the steering wheel top stomach problem. In terms of sitting comfort, the seat height is optimized from a fitness of less than 5% to a fitness of 70%. In terms of operational comfort: the final score of the shift lever is 2 points, which belongs to the first level, indicating that the arrangement results are reasonable and the operation comfort is satisfied. Vision: After optimization, the visible area of the instrument panel becomes larger, and the driver can comfortably view the contents of the instrument panel. However, the 10th percentile male driver in China has a large blind area in front.

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References
[1] Lan B 2009 Research on Ergonomics of Automobile Cab Based on Chinese Human Body Size Jilin University 26-9
[2] Wang J 2016 Optimal design of construction Machinery cab Based on Ergonomics Shijiazhuang Railway University 44-7
[3] Wang Y J, Wang Y R, Yu J L 2016 The comfort design and simulation research of cab based on Ergonomics Agricultural Mechanization Research 38 247-53
[4] Liu M Z, Starhong A, Hu J, Zhang M and Qian P L 2016 Evaluation Method for Handling Comfort of Vehicle Gear Shift Lever Based on Fuzzy Neural Network Chinese Mechanical Engineering 27 2402-7
[5] Yang F, Guang Z Y and Kang M 2017 Ergonomics optimization research of tractor cab based on RULA Journal of Chinese Agricultural Mechanization 38 88-93
[6] Yang F, Shi W C, Wan x 1 and Zhu s h 2013 Ergonomics evaluation method of tractor cab based on Pro/E Manikin Transactions of the Chinese Society of Agricultural Engineering 29 32-8
[7] Parkinson M B, Reed M P, Kokkolaras M and Papalambros P Y 2007 Optimizing truck cab layout for driver accommodation Journal of Mechanical Design 129 1110-7
[8] Ren J D 2010 Automobile Ergonomics (Beijing: Peking University Press) pp 21-2
[9] Dai N 2016 Reach on Man-machine Engineering of Bus Bridge Southwest Jiaotong University 27-42
[10] Xu L Y, Wu Y W and Zhou Z L 2016 Design of workplace for tractor operator based on anthropometry Transactions of the Chinese Society of Agricultural Engineering 32 124-9
[11] Cao G H 2010 Study on Ergonomic Design Method for Cab of Light Bus Wuhan University Of Technology 21-45
[12] Chen J H, Ren J D, Lu S B and Du X M 2013 A Research on the Evaluation of Driver’s Posture Comfort Automotive Engineering 35 548-52+64
[13] SAE J1517. Driver Selected Seat Position. SAE Handbook
[14] Parenteau C.S, Zhang P, Holcombe S, Kohoyda-Inglis C and Wang S.C 2013 Proc. Int. Conf. International Research Council on the Biomechanics of Injury (2013 IRCOBI) vol 13-81 (Gothenburg, Sweden) 687-97
[15] Zhang S X 2010 Key Parameters’ Design and Simulation of Forklift Cab Shandong University 65-6