Research of Ergonomic Comprehensive Evaluation For Suit Production Operation Based On Hybrid Method With IAHP And Gray Entropy

Laihong Du (✉ dlh06@xaufe.edu.cn)

Xi'an Technological University School of Materials Science and Chemical Engineering

<https://orcid.org/0000-0002-0057-4632>

Hua Chen

Xi'an Technological University School of Materials Science and Chemical Engineering

Yadong Fang

Xi'an University of Finance and Economics

Research

Keywords: Ergonomic evaluation, IAHP, gray entropy, suit production, evaluation index system

Posted Date: June 15th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-591531/v1>

License: This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Research of Ergonomic Comprehensive Evaluation for Suit Production Operation based on Hybrid Method with IAHP and Gray Entropy

**Laihong Du^{1, 2}, Hua Chen¹, Yadong Fang¹*

¹School of Mechanical and Electrical Engineer, Xi'an Technological University, Xi'an, 710021, China, dlh06@xaupe.edu.cn; chenhua126@163.com;

²School of Management, Xi'an University of Finance and Economics, Xi'an, 710010, China, fangyadong@xatu.edu.cn

Abstract. To solve the problem of ergonomic evaluation of suit production system, a Hybrid method with IAHP and gray entropy theory is proposed. Firstly, literature review about ergonomics evaluation tools and technology is introduced. Furthermore, the ergonomic evaluation index system of suit operation is established according to production practice. Besides, comprehensive evaluation model process with gray entropy and IAHP is introduced. Finally, detailed evaluation process of suit sewing, ironing and clipping operation is introduced by an example, and the results show that the evaluation method in the paper is helpful to verify the feasibility and effectiveness of the operation system improvement demonstration.

Keywords: Ergonomic evaluation; IAHP; gray entropy; suit production; evaluation index system

1 Introduction

It has been estimated that more than a quarter of all injuries related to industrial work are directly associated with Manual Materials Handling (MMH) activities [1]. Suit production is a kind of typical industry of intensive labor, complicate procedure, more variety and minor batch. Unreasonable procession and operation method, is recognized as a major cause of injury in general and an important contributor to the etiology of low-back pain (LBP) in particular [2]. Ergonomics, as an interdisciplinary, researches system relationship among human, machine and environment, which achieves the goal of optimizing man-machine performance by identifying and reducing the risk factors in the work at the early stage[3]. There are observation method, experimental method and computer simulation method in ergonomics study. The observation method mainly analyzes ergonomics problem by means of questionnaire and video tracking in statistics, and its main disadvantages are long period, difficult to quantify and poor adaptability. The experimental method is mainly used surface electromyography (sEMG) to test and evaluate the labour load by applying electrode slices or wearable devices to the lumbar spine of the back. Although the method can accurately obtain the force or torque of human muscles and bones, its procedure is tedious, which causes discomfort of worker body [4]. Computer simulation method realizes rapid, accurate and low-cost ergonomics evaluation in virtual environment by computer aid tools integrated digital human models(DHM), and it can be tested repeatedly[5].

1.1 Related work

Presently, many commercial tools are applied in proactive evaluation of ergonomics issues, such as Dassault Systèmes' SAFEWORK, Siemens's JACK and NEXGEN's HumanCAD. Throughout the globe, diverse industrial sectors are harnessing benefits of DHMS software applications. Some of them include automobile, aviation and aerospace, defense research, healthcare, general industrial applications, clothing and textile, service and animation, agricultural division, product design and so forth [6]. Patel Thaneswer constructs customizable DHM in DELMIA software, and finish virtual simulation and evaluation of thresher product [7]. Yin H utilizes JACK software to construct DHM, and evaluate body accessibility, visibility and comfortable [8]. Jie Zhang takes the man-machine efficiency requirements of the accessibility and comfort into account to propose an evaluation method for the layout of the cockpit manipulating equipment in the virtual reality environment [9]. Qingsong Yi establishes the customized digital human model corresponding to participants with the Jack software, and quantitatively evaluates the comfort of the joint [10].

Suit production belongs to labor intensive industries, and work-related musculoskeletal disorders occur frequently in suit production lines. However, there are few researches on man-machine ergonomics of garment production system, especially the multi-objective ergonomics evaluation and improvement. In the present evaluation method, there are

Corresponding Author: * Laihong Du
E-mail: dlh06@xaupe.edu.cn

widely used methods, such as technique for order preference by similarity to ideal solution (Topsis)[11], AHP[12], fuzzy comprehensive assessment method(FCAM)[13], gray correlation analysis(GCA)[14], entropy method(EM)[15] and so forth. The methods features are introduced as Table 1. The ergonomics evaluation index system belongs to hierarchy decision structure, and indexes information are fuzzy, uncertain and incomplete. According to above analysis, the paper applies gray correlation analysis method to solve problem of ergonomics assessment for three typical suit operations, and index weights are determined in terms of interval analytic hierarchy process (IAHP) and entropy method.

Table 1. Comparative analysis of comprehensive evaluation method

Method	Description of method	Feature analysis
Topsis	Relative approach degree of the ideal solution is utilized as evaluation criteria	It's not easy to solve ideal solution, and the method subjectivity is strong
AHP	Multi-criteria decision making is realized based on qualitative and quantitative analysis by determining scale of indexes importance	Point judgment matrix may be inaccurate due to decider grasp incomplete information
FCAM	Each evaluation index is evaluated and sequenced on the basis of fuzzy mathematics and maximum membership degree principle	Matrix is decided by membership degree. it is difficult to determine the membership function reasonably and effectively
GCA	It's a multiple statistical method, and describes relationship of evaluation indicators by correlation analysis	The method has features of clear concept, simple calculation. However, it has certain subjectivity due to equal rights treatment
EM	Entropy weight of index is determined by information entropy	The method is not suitable for subjective evaluation

1.2 Fatigue analysis of suit production operations

The production process of suits mainly includes discharge, blank clipping, piece bonding, sewing, ironing, finishing, packaging, and storage. The flowchart is shown as Fig. 1, and its working survey result is shown in the following Table 2. Sewing workers maintain the sitting forward leaning posture for a long time, and it may cause hypopsia and lumbar damage for long hours of focusing on one place and repeated sideways or bending. Ironing workers hold tools for a long time, which often leads to right limb pain. Clipping workers stand for a long time, and the movement range in the operation process is larger.

Fig. 1. Production process of suit

Table 2. Working time information

Project	Time	Total
Working time	8:00-12:20/13:10-19:20	630 minutes/day
Dining time	12:20-13:10	50 minutes
Shift	1	1 shift/day
Working day	26	26 Day/month

2 Methods

2.1 Ergonomics evaluation models

The ergonomic evaluation system for the production of suits must meet the principles of systemic, scientific, importance, and dynamic requirements. Applying the principles of ergonomics, management and statistics, the evaluation index system is constructed from three aspects of working conditions, working characteristics and working environment, as shown in Fig.2.

Fig. 2. Construction of ergonomic evaluation system

(1) Working conditions (U_1)

When operating objects, tools, and facility layout are unreasonable, the operation space may be unreachable, and operators are forced to finish the work with improper postures such as body excessive forward extension, twisting, and bending. The increase in work load easily causes work fatigue. Therefore, labor posture (U_{11}), instruments design (U_{12}), operation space (U_{13}), and bench height (U_{14}) are the main assessment factors.

(2) Working characteristics (U_2)

Suit production belongs to labor-intensive enterprises, and their working characteristics directly affect the fatigue of assembly line workers. The greater the labor intensity and the longer the duration, the easier the workers are fatigued. Thus working duration(U_{21}), working difficulty(U_{22}) and working intensity(U_{23}) are regarded as key factors. According to *China Classification of Manual Labor Intensity* (GB3869-1997) and operation time determination criteria, its grade division is shown as Table 3. The physical labor intensity is calculated according to Eq. (1). Where, I is physical labor intensity index, T is the labor time rate, M is the average capacity metabolism rate for 8 hours of workdays, S is the gender coefficient, and W is the coefficient of physical labor mode.

$$I=T.M.S.W.10 \quad (1)$$

Table 3. Grade division of duration and labor intensity index

Evaluation level	Very poor	Poor	Fair	Good	Excellent
Duration(U_{21})	[360, 300)	[120, 300)	[60, 120)	[30,60)	[0,30)
Labor intensity index (U_{22})	[25, 30)	[20, 25)	[15, 20)	[10,15)	[0,10)

(3) Working environment (U_3)

Poor working environment may lead to worker fatigue. For example, It will cause visual fatigue for worker by too strong or weak light, and appropriate temperature and humidity will also cause operator fatigue. The working environment includes light intensity (U_{31}), noise interference (U_{32}), and indoor temperature and humidity (U_{33}).

2.2 Algorithmic framework

The algorithmic framework is presented in this section. The framework subsumes objective weight determination method with entropy theory, subjective weight determination method with IAHP and comprehensive evaluation based on gray correlation theory.

Algorithm 1 Evaluation index objective weight determination method with entropy theory

(1) Data standardization processing

The evaluation matrix is composed of m evaluation criteria and n evaluation indexes, and it is $X=(x_{ij})_{m \times n}$, $i=1,2,\dots,m$, $j=1,2,\dots,n$. In order to eliminate the influence of different dimensions on the evaluation results, the indexes need to be standardized:

$$\begin{aligned} \text{Positive indexes } x'_{ij} &= \frac{x_{ij} - \min x_{nj}}{\max x_{nj} - \min x_{nj}} \\ \text{Negative indexes } x'_{ij} &= \frac{\max x_{nj} - x_{ij}}{\max x_{nj} - \min x_{nj}} \end{aligned} \quad (2)$$

The proportion of the value of the i th individual in the index j :

$$y_{ij} = x'_{ij} / \sum_{i=1}^m x'_{ij} \quad (3)$$

(2) Calculation of index entropy value and variation coefficient
The entropy value of j th index is:

$$e_j = -k \sum_{i=1}^m y_{ij} \ln y_{ij} \quad (4)$$

By the Lagrangian extremum method, only if $y_1=y_2=\dots=y_n$, the entropy got the extreme $e_{j\max}=l\ln m$.
Coefficient of variation is:

$$d_j = 1 - e_j \quad (5)$$

(3) Calculation of the weight of evaluation index
The weight of the j th index is:

$$W_j^{\text{entropy}} = d_j / \sum_i d_j \quad (6)$$

(4) Determine of the sample evaluation value

$$S_i = \sum_{j=1}^m W_j^{\text{entropy}} y_{ij} \quad (7)$$

Algorithm 2 Evaluation index subjective weight determination method with IAHP

(1) Interval judgment construction

According to 1~9 scale method, interval number judgment matrix R is constructed, and r_{ij} is the interval number of interval number judgment matrix R in row i and column j .

$$R = (r_{ij}^-, r_{ij}^+)_{n \times n} = [R^-, R^+] \quad (8)$$

(2) Parameters calculation and consistency check

The parameters k and m are calculated, and consistency test of the interval judgment matrix is conducted. When $k \leq 1$ and $m \geq 1$, the judgment matrix has good consistency. When $k > 1$ or $m < 1$, indicates that the inconsistency degree of the judgment matrix exceeds the allowable range, and the interval judgment matrix needs to be rebuilt until it passes the consistency test.

$$k = \sum_{j=1}^n \frac{1}{\sum_{i=1}^n r_{ij}^+} \quad (9)$$

$$m = \sum_{j=1}^n \frac{1}{\sum_{i=1}^n r_{ij}^-} \quad (10)$$

(3) Determine the weight of the interval judgment matrix

The eigenvector λ^- for R^- and λ^+ for R^+ are calculated, and then the interval weight vector W^I is determined by using Eq. (11). Where, $W_i^I = [k\lambda_i^-, m\lambda_i^+]$, $i=1,2,\dots,n$.

$$W^I = [k\lambda^-, m\lambda^+] = (W_1^I, W_2^I, \dots, W_n^I) \quad (11)$$

(4) Calculation of the probability degree P

In order to compare each index importance, the weight interval is transformed into a point value by sorting the probability degree P , and the probability degree P can be calculated by Eq. (12). Where, $L(W_i^I) = W_i^{I+} - W_i^{I-}$, $L(W_j^I) = W_j^{I+} - W_j^{I-}$.

$$P(W_i^I > W_j^I) = \max \left(0, 1 - \frac{\max(0, W_j^{I+} - W_i^{I-})}{L(W_i^I) + L(W_j^I)} \right) \quad (12)$$

(5) Construction of probability judgment matrix

The interval weight vector W^I and the probability judgment matrix among the interval numbers $P = [P_{ij}]_{n \times n}$ are constructed. via Eq. (13), the possible degree point value matrix is transformed into each index weight, and then the weight vector W^{IAHP} is formed. Where, $W^{IAHP} = (W_1^{IAHP}, W_2^{IAHP}, \dots, W_n^{IAHP})$.

$$W_i^{IAHP} = \frac{\sum_{j=1}^n P_{ij} + 0.5n - 1}{n(n+1)} \quad (13)$$

The comprehensive weight of evaluation index is determined according to Eq. (14).

$$W_i = \frac{W_i^{IAHP} W_i^{entropy}}{\sum_{i=1}^n W_i^{IAHP} W_i^{entropy}} \quad (14)$$

Algorithm 3 Comprehensive evaluation of ergonomics based on gray correlation theory

(1) Determination of the optimal index set

$$X^* = \{x_i^* | x_i^* = \max x_{ij} \text{ or } \min x_{ij}\} \quad (15)$$

Where, $i=1,2,\dots,m$; $j=1,2,\dots,n$; $\max x_{ij}$ and $\min x_{ij}$ are respectively the most and least satisfied value in different evaluation criteria of the same index.

(2) Calculation of the difference matrix

$$D = \{d_{ij} | d_{ij} = |x_{ij} - x_i^*|\} \quad (16)$$

Where, x_{ij} is raw value, x_i^* is optimal value.

(3) Calculation of gray correlation coefficient and weighted degree

The correlation coefficient of X_i to X_0 of the K th index is:

$$\xi_i(k) = \frac{\min_i \min_k |x_{0k} - x_{ik}| + \alpha \max_i \max_k |x_{0k} - x_{ik}|}{|x_{0k} - x_{ik}| + \alpha \max_i \max_k |x_{0k} - x_{ik}|} \quad (17)$$

Where, resolution coefficient $\alpha=0.5$.

The gray correlation weighted degree is:

$$r_i = W(k) \sum \xi_i(k) \quad (18)$$

Where, $W(k)$ is the weight of the k th index.
(4) Determine of multi-level gray correlation

$$L^{i+1} = W^i \cdot L^i \quad (19)$$

Where, W^i is current level evaluation factor weights, L^i is the previous evaluation results.

3 Results and discussion

3.1 Experimental preparation

In this experiment, the research object is a suit production operation, and it is evaluated according to assessment system shown as Fig.2. The evaluation results are divided into five grades: very poor(v1), poor(v2), fair(v3), good(v4) or excellent(v5), and the comment set is $V=\{v1, v2, v3, v4, v5\}$. According to the survey data, the daily average output of WZ garment factory is about 500 pieces, and the working time of workers is 630min per day, duration is 120-150min.

Labor time T =Net working time in workday/Total length of the workday=541/630=85.9%

Labor intensity index is acquired by Eq. (1).

$$I_{\text{Sewing}} = T_{\text{Sewing}} \cdot M_{\text{Sewing}} \cdot S_{\text{Sewing}} \cdot W_{\text{Sewing}} \cdot 10 = 0.859 \times 1.936 \times 1.3 \times 0.05 \times 10 = 1.08$$

$$I_{\text{Ironing}} = T_{\text{Ironing}} \cdot M_{\text{Ironing}} \cdot S_{\text{Ironing}} \cdot W_{\text{Ironing}} \cdot 10 = 0.859 \times 3.158 \times 1 \times 0.05 \times 10 = 1.36$$

$$I_{\text{Clipping}} = T_{\text{Clipping}} \cdot M_{\text{Clipping}} \cdot S_{\text{Clipping}} \cdot W_{\text{Clipping}} \cdot 10 = 0.859 \times 3.619 \times 1 \times 0.05 \times 10 = 1.55$$

For sewing, ironing and clipping operations, quantitative index evaluation result is determined by its interval division, and qualitative index is evaluated by questionnaire survey. 20 industrial engineering experts are invited to evaluated qualitative index ($U_{11}, U_{12}, U_{13}, U_{14}, U_{23}, U_{31}, U_{32}$ and U_{33}) according to the assigned evaluation standards, and then calculate the frequency μ of each evaluation index U to evaluation grade V in term of Eq. (20). The assessment results in detail are shown as Table 4, Table 5 and Table 6.

$$\mu_{v_j}(U_i) = \frac{m_{ij}}{\sum_{j=1}^5 m_{ij}} \quad (20)$$

Table 4. Evaluation result of sewing operation

	U_{11}	U_{12}	U_{13}	U_{14}	U_{21}	U_{22}	U_{23}	U_{31}	U_{32}	U_{33}
v_1	0.15	0.25	0.2	0.15	0	0	0	0.2	0.25	0.3
v_2	0.85	0.65	0.75	0.7	1	0	0.2	0.2	0.3	0.1
v_3	0	0	0.05	0.1	0	0	0.2	0.4	0.05	0.25
v_4	0	0.1	0	0	0	1	0.35	0.15	0.15	0.2
v_5	0	0	0	0.05	0	0	0.25	0.05	0.25	0.15

Table 5. Evaluation result of ironing operation

	U_{11}	U_{12}	U_{13}	U_{14}	U_{21}	U_{22}	U_{23}	U_{31}	U_{32}	U_{33}
v_1	0.5	0.7	0.75	0	0	0	0	0	0	0
v_2	0.15	0.2	0.15	0	1	0	0	0.1	0.1	0.2
v_3	0.2	0.1	0.1	0.4	0	0	0.7	0.2	0.2	0.5
v_4	0.15	0	0	0.4	0	1	0.3	0.4	0.55	0.15
v_5	0	0	0	0.2	0	0	0	0.3	0.15	0.15

Table 6. Evaluation result of clipping operation

	U_{11}	U_{12}	U_{13}	U_{14}	U_{21}	U_{22}	U_{23}	U_{31}	U_{32}	U_{33}
v_1	0.5	0.7	0.75	0	0	0	0	0	0	0
v_2	0.15	0.2	0.15	0	1	0	0	0.1	0.1	0.2
v_3	0.2	0.1	0.1	0.4	0	0	0.7	0.2	0.2	0.5
v_4	0.15	0	0	0.4	0	1	0.3	0.4	0.55	0.15
v_5	0	0	0	0.2	0	0	0	0.3	0.15	0.15

3.2 Experimental results and analysis

Optimal index sets of sewing, ironing and clipping operation are calculated by Eq. (15).

$$X_s^* = \{x_{11}, x_{12}, x_{13}, x_{14}, x_{21}, x_{22}, x_{23}, x_{31}, x_{32}, x_{33}\} = \{0.85, 0.65, 0.75, 0.7, 1, 1, 0.35, 0.4, 0.3, 0.3\}.$$

$$X_i^* = \{x_{11}, x_{12}, x_{13}, x_{14}, x_{21}, x_{22}, x_{23}, x_{31}, x_{32}, x_{33}\} = \{0.5, 0.7, 0.75, 0.4, 1, 1, 0.7, 0.4, 0.55, 0.5\}.$$

$$X_c^* = \{x_{11}, x_{12}, x_{13}, x_{14}, x_{21}, x_{22}, x_{23}, x_{31}, x_{32}, x_{33}\} = \{0.4, 0.5, 0.7, 0.8, 1, 1, 0.7, 0.6, 0.4, 0.5\}.$$

The difference matrix of sewing, ironing and clipping operation can be obtained by Eq. (16).

$$D_s = \begin{bmatrix} 0.7 & 0.4 & 0.55 & 0.55 & 1 & 1 & 0.35 & 0.2 & 0.05 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0.15 & 0.2 & 0 & 0.2 \\ 0.85 & 0.65 & 0.7 & 0.6 & 1 & 1 & 0.15 & 0 & 0.25 & 0.05 \\ 0.85 & 0.55 & 0.75 & 0.7 & 1 & 0 & 0 & 0.25 & 0.15 & 0.1 \\ 0.85 & 0.65 & 0.75 & 0.65 & 1 & 1 & 0.1 & 0.35 & 0.05 & 0.15 \end{bmatrix}$$

$$D_i = \begin{bmatrix} 0 & 0 & 0 & 0.4 & 1 & 1 & 0.7 & 0.4 & 0.55 & 0.5 \\ 0.35 & 0.5 & 0.6 & 0.4 & 0 & 1 & 0.7 & 0.3 & 0.45 & 0.3 \\ 0.3 & 0.6 & 0.65 & 0 & 1 & 1 & 0 & 0.2 & 0.35 & 0 \\ 0.35 & 0.7 & 0.75 & 0 & 1 & 0 & 0.4 & 0 & 0 & 0.35 \\ 0.5 & 0.7 & 0.75 & 0.2 & 1 & 1 & 0.7 & 0.1 & 0.4 & 0.35 \end{bmatrix}$$

$$D_c = \begin{bmatrix} 0 & 0.2 & 0 & 0.8 & 1 & 1 & 0.7 & 0.6 & 0.4 & 0.5 \\ 0.1 & 0 & 0.5 & 0.8 & 0 & 1 & 0.7 & 0.45 & 0.05 & 0.3 \\ 0.3 & 0.4 & 0.6 & 0.65 & 1 & 1 & 0 & 0 & 0 & 0 \\ 0.3 & 0.5 & 0.7 & 0 & 1 & 0 & 0.4 & 0.45 & 0.15 & 0.35 \\ 0.3 & 0.5 & 0.7 & 0.75 & 1 & 1 & 0.7 & 0.5 & 0.4 & 0.35 \end{bmatrix}$$

The gray correlation coefficient matrix of sewing, ironing and clipping operation can be determined by Eq. (17).

$$\xi_s = \begin{bmatrix} 0.42 & 0.56 & 0.48 & 0.48 & 0.33 & 0.33 & 0.59 & 0.71 & 0.91 & 1.00 \\ 1.00 & 1.00 & 1.00 & 1.00 & 1.00 & 0.33 & 0.77 & 0.71 & 1.00 & 0.71 \\ 0.37 & 0.43 & 0.42 & 0.45 & 0.33 & 0.33 & 0.77 & 1.00 & 0.67 & 0.91 \\ 0.37 & 0.48 & 0.40 & 0.42 & 0.33 & 1.00 & 1.00 & 0.67 & 0.77 & 0.83 \\ 0.37 & 0.43 & 0.40 & 0.43 & 0.33 & 0.33 & 0.83 & 0.59 & 0.91 & 0.77 \end{bmatrix}$$

$$\xi_i = \begin{bmatrix} 1.00 & 1.00 & 1.00 & 0.56 & 0.33 & 0.33 & 0.42 & 0.56 & 0.48 & 0.50 \\ 0.59 & 0.50 & 0.45 & 0.56 & 1.00 & 0.33 & 0.42 & 0.63 & 0.53 & 0.63 \\ 0.63 & 0.45 & 0.43 & 1.00 & 0.33 & 0.33 & 1.00 & 0.71 & 0.59 & 1.00 \\ 0.59 & 0.42 & 0.40 & 1.00 & 0.33 & 1.00 & 0.56 & 1.00 & 1.00 & 0.59 \\ 0.50 & 0.42 & 0.40 & 0.71 & 0.33 & 0.33 & 0.42 & 0.83 & 0.56 & 0.59 \end{bmatrix}$$

$$\xi_c = \begin{bmatrix} 1.00 & 0.71 & 1.00 & 0.38 & 0.33 & 0.33 & 0.42 & 0.45 & 0.56 & 0.50 \\ 0.83 & 1.00 & 0.50 & 0.38 & 1.00 & 0.33 & 0.42 & 0.53 & 0.91 & 0.63 \\ 0.63 & 0.56 & 0.45 & 0.43 & 0.33 & 0.33 & 1.00 & 1.00 & 1.00 & 1.00 \\ 0.63 & 0.50 & 0.42 & 1.00 & 0.33 & 1.00 & 0.56 & 0.53 & 0.77 & 0.59 \\ 0.63 & 0.50 & 0.42 & 0.40 & 0.33 & 0.33 & 0.42 & 0.50 & 0.56 & 0.59 \end{bmatrix}$$

The data in Table 4-6 is standardized according to Eq.(2) and Eq.(3), and corresponding entropy value and variation coefficient of second order index can be acquired by Eq. (4) and Eq. (5).

$$e_s^{(2)} = \{0.26, 0.53, 0.43, 0.57, 0, 0, 0.84, 0.79, 0.83, 0.8\}$$

$$e_i^{(2)} = \{0.77, 0.5, 0.45, 0.66, 0, 0, 0.38, 0.8, 0.72, 0.77\}$$

$$e_c^{(2)} = \{0.42, 0.58, 0.5, 0.38, 0, 0, 0.38, 0.69, 0.67, 0.77\}$$

$$d_s^{(2)} = \{0.74, 0.47, 0.57, 0.43, 1, 1, 0.16, 0.21, 0.17, 0.2\}$$

$$d_i^{(2)} = \{0.23, 0.5, 0.55, 0.34, 1, 1, 0.62, 0.2, 0.28, 0.23\}$$

$$d_c^{(2)} = \{0.58, 0.42, 0.5, 0.62, 1, 1, 0.62, 0.31, 0.33, 0.23\}$$

In terms of formula (5), objective weight vector of second order index is calculated.

$$W_s^{(2)} = \{0.33, 0.21, 0.26, 0.20, 0.46, 0.46, 0.07, 0.36, 0.29, 0.35\}$$

$$W_i^{(2)}=\{0.14,0.31,0.34,0.21,0.38,0.38,0.24,0.29,0.39,0.32\}$$

$$W_c^{(2)}=\{0.27,0.20,0.24,0.29,0.38,0.38,0.24,0.36,0.38,0.26\}$$

The first order index is calculated by Eq. (7), and then is disposed with normalization. Furthermore, the corresponding entropy value, variation coefficient and weight vector of first order index can be obtained by Eq. (4), Eq. (5) and Eq. (6).

$$e_s^{(1)}=\{0.47,0.52,0.96\}$$

$$e_i^{(1)}=\{0.8,0.64,0.82\}$$

$$e_c^{(1)}=\{0.83,0.64,0.74\}$$

$$d_s^{(1)}=\{0.53,0.48,0.04\}$$

$$d_i^{(1)}=\{0.20,0.36,0.18\}$$

$$d_c^{(1)}=\{0.17,0.36,0.26\}$$

$$W_s^{(1)}=\{0.5,0.46,0.04\}$$

$$W_i^{(1)}=\{0.27,0.48,0.24\}$$

$$W_c^{(1)}=\{0.22,0.46,0.32\}$$

The priority order of evaluation index at all levels is determined by the questionnaire survey: $U_{21}>U_{11}>U_{14}>U_{23}>U_{12}>U_{22}>U_{13}>U_{31}>U_{33}>U_{32}$; $U_{11}>U_{14}>U_{12}>U_{13}$; $U_{21}>U_{23}>U_{22}$; $U_{31}>U_{33}>U_{32}$; $U_2>U_1>U_3$, and interval judgment matrix of each order can be constructed by Eq. (8).

$$R_1^{(1)} = \begin{bmatrix} 1.00, 1.00, 5.00, 7.00, 7.00, 9.00, 3.00, 5.00 \\ 0.14, 0.20, 1.00, 1.00, 3.00, 5.00, 0.20, 0.33 \\ 0.11, 0.14, 0.20, 0.33, 1.00, 1.00, 4.00, 5.00 \\ 0.20, 0.33, 3.00, 5.00, 0.20, 0.25, 1.00, 1.00 \end{bmatrix} \quad R_2^{(1)} = \begin{bmatrix} 1.00, 1.00, 5.00, 7.00, 3.00, 5.00 \\ 0.14, 0.20, 1.00, 1.00, 0.25, 0.33 \\ 0.20, 0.33, 3.00, 4.00, 1.00, 1.00 \end{bmatrix}$$

$$R_3^{(1)} = \begin{bmatrix} 1.00, 1.00, 5.00, 7.00, 3.00, 5.00 \\ 0.14, 0.20, 1.00, 1.00, 0.20, 0.33 \\ 0.20, 0.33, 3.00, 5.00, 1.00, 1.00 \end{bmatrix} \quad R^{(2)} = \begin{bmatrix} 1.00, 1.00, 0.20, 0.33, 3.00, 5.00 \\ 3.00, 5.00, 1.00, 1.00, 4.00, 5.00 \\ 0.20, 0.33, 0.20, 0.25, 1.00, 1.00 \end{bmatrix}$$

Each indexes comprehensive weight can be calculated via Eq. (14).

$$W_{1s}^{(1)}=\{0.50,0.15,0.21,0.13\}$$

$$W_{2s}^{(1)}=\{0.64,0.32,0.04\}$$

$$W_{3s}^{(1)}=\{0.46,0.20,0.35\}$$

$$W_s^{(1)}=\{0.44,0.54,0.02\}$$

$$W_{1i}^{(1)}=\{0.25,0.26,0.32,0.17\}$$

$$W_{2i}^{(1)}=\{0.57,0.28,0.15\}$$

$$W_{3i}^{(1)}=\{0.38,0.28,0.34\}$$

$$W_i^{(1)}=\{0.25,0.60,0.15\}$$

$$W_{1c}^{(1)}=\{0.43,0.15,0.20,0.21\}$$

$$W_{2c}^{(1)}=\{0.57,0.28,0.15\}$$

$$W_{3c}^{(1)}=\{0.46,0.27,0.27\}$$

$$W_c^{(1)}=\{0.21,0.59,0.21\}$$

Multi-order gray relational degree is calculated by Eq. (18) and Eq. (19).

$$L_{1s}^{(1)} = \zeta_{1s} \cdot [W_{1s}^{(1)}]^T = \{0.46, 1.00, 0.40, 0.40, 0.40\}$$

$$L_{2s}^{(1)} = \zeta_{2s} \cdot [W_{2s}^{(1)}]^T = \{0.34, 0.78, 0.35, 0.57, 0.35\}$$

$$L_{3s}^{(1)} = \zeta_{3s} \cdot [W_{3s}^{(1)}]^T = \{0.85, 0.77, 0.90, 0.74, 0.71\}$$

$$L_s^{(2)} = [L_{1s}^{(1)}, L_{2s}^{(1)}, L_{3s}^{(1)}] \cdot [W_s^{(1)}]^T = \{0.41, 0.88, 0.39, 0.50, 0.38\}$$

$$L_{1i}^{(1)} = \zeta_{1i} \cdot [W_{1i}^{(1)}]^T = \{0.93, 0.52, 0.58, 0.55, 0.48\}$$

$$L_{2i}^{(1)} = \zeta_{2i} \cdot [W_{2i}^{(1)}]^T = \{0.35, 0.73, 0.43, 0.56, 0.35\}$$

$$L_{3i}^{(1)} = \zeta_{3i} \cdot [W_{3i}^{(1)}]^T = \{0.51, 0.60, 0.77, 0.86, 0.67\}$$

$$L_i^{(2)} = [L_{1i}^{(1)}, L_{2i}^{(1)}, L_{3i}^{(1)}] \cdot [W_i^{(1)}]^T = \{0.52, 0.65, 0.52, 0.60, 0.43\}$$

$$L_{1c}^{(1)} = \zeta_{1c} \cdot [W_{1c}^{(1)}]^T = \{0.83, 0.70, 0.54, 0.64, 0.52\}$$

$$L_{2c}^{(1)} = \zeta_{2c} \cdot [W_{2c}^{(1)}]^T = \{0.35, 0.73, 0.43, 0.56, 0.35\}$$

$$L_{3c}^{(1)} = \zeta_{3c} \cdot [W_{3c}^{(1)}]^T = \{0.49, 0.66, 1.00, 0.61, 0.54\}$$

$$L_c^{(2)} = [L_{1c}^{(1)}, L_{2c}^{(1)}, L_{3c}^{(1)}] \cdot [W_c^{(1)}]^T = \{0.48, 0.70, 0.57, 0.58, 0.42\}$$

The comparison between three operations evaluation in each of the four methods is plotted in Fig.3. There is a similarity in evaluation result of four methods, and the gray correlation degree intervals of the methods belongs to $[0.4 \pm \varepsilon, 0.8 \pm \varepsilon]$, and the upper boundary of IAHP method is relatively smaller. According to the maximum membership criteria, $L = \max(L_j^{(2)}(k))$ $j \in \{s, i, c\}, k=1, 2, \dots, 5$. Where, $j=s, k=2$. Thus it can be seen that sewing operation ergonomic evaluation result belongs to v2 grade (poor), and it is worst in three production operation ergonomic evaluation. The results in Fig. 3 demonstrate that, the hybrid method with IAHP and gray entropy is the most effective, and AHP method is difficult to distinguish worst operation from sewing, ironing and clipping operation.

The index weight distribution analysis is shown in Fig. 4. Note that, the weight of index U_2 (working characteristics) in first level indicators (U_1-U_3) is maximum. Besides, weight of index U_{21} (working duration) and U_{22} (working difficulty) takes a big part of second level indicators ($U_{11}-U_{33}$). Therefore, it is important to reduce the fatigue and improve the work efficiency by improving the working posture of operators.

Fig. 3. Comparison of evaluation result for the four methods

Fig. 4. Analysis of index weight distribution for the four methods

4 Conclusions and future work

Most processes of suit production line depend on manual handling, and it's regarded as a major cause of injury and an import contributor to the etiology of LBP in particular for workers. Therefore, it is urgent to solve above man-machine engineering problem. However, ergonomic comprehensive evaluation is a prerequisite for the human engineering improvement. There are qualitative and quantitative in suit operation ergonomic evaluation factors, and most indexes are fuzzy and gray at the same time. In the paper, the ergonomic evaluation index system of suit operation is constructed according to production practice, and man-machine engineering comprehensive assessment of suit sewing, ironing and clipping operation is realized by gray correlation analysis theory, IAHP and entropy method. The evaluation method in the paper is helpful to verify the feasibility and effectiveness of the operation system improvement demonstration. The focus of the further research in the paper is to determine the optimum working posture and evaluate productibility of operation system.

Our future work is to improve algorithm efficiency by parameter sensitivity test, and realize operation ergonomic optimization with ergonomic simulation analysis.

ABBREVIATIONS

IAHP:Interval analytic hierarchy process

MMH:Manual Materials Handling

LBP:Low-Back Pain

sEMG:surface Electromyography

DHM:Digital Human Models

FCAM:Fuzzy Comprehensive Assessment Method

GCA:Gray Correlation Analysis

EM:Entropy Method

IAHP:Interval Analytic Hierarchy Process

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Not applicable

CONSENT FOR PUBLICATION

Not applicable

AVAILABILITY OF DATA AND MATERIAL

The labeled dataset used to support the findings of this study are available from the corresponding author upon request.

COMPETING INTERESTS

The authors declare that they have no competing interests.

FUNDING

This research was supported by Scientific Research Project of Shanxi Provincial Department of Education(18JK0401).

AUTHORS' CONTRIBUTIONS

Laihong Du, as the primary contributor, completed the analysis, paper writing.

Hua Chen and Yadong Fang Participate in experiments that helped improve typography and English language

ACKNOWLEDGEMENTS

Not applicable.

References

1. Vincent M. Ciriello: The effects of box size, vertical distance, and height on lowering tasks for female industrial workers. *International Journal of Industrial Ergonomics*, vol. 35, pp. 857—863 (2005)
2. Demet Gonen, Ali Oral and Mehmet Yosunlukaya: Computer-aided ergonomic analysis for assembly unit of an agricultural device. *Human Factors and Ergonomics in Manufacturing and Service Industries*, vol. 26, pp. 615--626 (2016)

3. Yang Jun, Zhu Yu, and Shan. Xiaofen: Rationality evaluation of ergonomic simulation in ship cabin design. *Ship Engineering*, vol. 41, pp. 105--109 (2019)
4. Chen Jing, Wang Lei, and Xia Yun: Work load evaluation of lifting mawl and rwl in males. *Industrial Hygiene and Occupational Diseases*, vol. 33, pp. 136--169 (2007)
5. Bugra Alkan, Daniel Vera, Mussawar Ahmad, Bilal Ahmad, and Robert Harrison: A lightweight approach for human factor assessment in virtual assembly designs: An evaluation model for postural risk and metabolic workload. *Procedia CIRP*, vol. 44, pp. 26--31 (2016)
6. Thaneswer Patel, J. Sanjog, and Sougata Karmakar: Ergonomics perspective in agricultural research: A user-centred approach using cad and digital human modeling (DHM) technologies. *Journal of the Institution of Engineers*, vol. 97, pp. 333--342 (2016)
7. Thaneswer Patel, J. Sanjog, Abhirup Chatterjee, Arvind Shroff, Siddharth Shankar Prusty, Sibasis Mohapatra, and Sougata Karmakar: Virtual ergonomics evaluation of a design concept of manual powered portable paddy thresher suitable for hilly region agriculture. In *International Conference on Research Into Design*, pp. 503--512 (2017)
8. Yin Hang, Liu Gang, and Yan Yang: Improving design method of loader cockpit through ergonomics simulation and analysis. *Journal of Mechanical Design*, vol. 34, pp. 120--123 (2017)
9. Zhang Jie, Fang Yu, and Pang Jiazhen: Evaluation of equipment layout in virtual cockpit based on flight operation process. *Computer Integrated Manufacturing System*, vol. 26, pp. 655--663 (2020)
10. Yi Qingsong, Liao Qianfang, and Zhou Qianxiang: Analysis of lower limb joint torque and comfort in driving posture based on jack. *Space Medicine and Medical Engineering*, vol. 29, pp. 440--445 (2016)
11. Parisa Mojaver, Shahram Khalilarya, Ata Chitsaz, and Mohsen Assadi: Multi-objective optimization of a power generation system based sofocusing taguchi/ahp/topsis triple method. *Sustainable Energy Technologies and Assessments*, vol. 38, pp.100674 (2020)
12. Levent Yagmur: Multi-criteria evaluation and priority analysis for localization equipment in a thermal power plant using the ahp (analytic hierarchy process). *Energy*, vol. 94, pp.476-482 (2016)
13. Xueling Wu and Fang Hu: Analysis of ecological carrying capacity using a fuzzy comprehensive evaluation method. *Ecological Indicators*, vol.113, pp.106243 (2020)
14. Yadong Fang, Shan Yang, Hu Qiao, and Laihong Du: Product manufacturability evaluation method based on grey correlation algorithm extension theory. *Industrial Engineering and Management*, 25(1), pp.69-78 (2020)
15. Huanhuan Li, Diyi Chen, Ehsan Arzaghi, Rouzbeh Abbassi, Beibei Xu, Edoardo Patelli, and Silvia Tolo: Safety assessment of hydro-generating units using experiments and grey-entropy correlation analysis. *Energy*, 165, pp.222-234 (2018)

Figures

Figure 1
Production process of suit

Figure 2
Construction of ergonomic evaluation system

Figure 3

Comparison of evaluation result for the four methods

Figure 4

Analysis of index weight distribution for the four methods