Hindawi
Complexity
Volume 2022, Article ID 4075358, 16 pages
https://doi.org/10.1155/2022/4075358

Research Article

Method for Evaluation and Application of Production Process Chain Complexity in Sewing Workshops considering Human Factor

Huimin Li[1,2] **Fansen Kong**[1,2,3] **Taibo Chen**[2,4] **and Liang Kong**[2,5]

[1]*School of Mechanical and Aerospace Engineering, Jilin University, Changchun 130025, China*
[2]*Jilin Provincial Key Laboratory of Designing and Planning for Factory, Jilin University, Changchun 130022, China*
[3]*Key Laboratory of CNC Equipment Reliability, Ministry of Education, Jilin University, Changchun, Jilin, China*
[4]*School of Management, Jilin University, Changchun 130025, China*
[5]*Warwick Business School, University of Warwick, Coventry CV4 7AL, UK*

Correspondence should be addressed to Fansen Kong; kongfs@jlu.edu.cn

Received 30 May 2021; Accepted 19 January 2022; Published 23 February 2022

Academic Editor: Sheng Du

Existing methods for evaluating manufacturing process chain complexity consider the number of machines, state of machines, number of parts, operation time, and processing sequence of parts. However, such evaluation methods ignore human factors. To consider human factors, human cognitive decision-making process factors are considered in the complexity evaluation of production processes. Accordingly, a new objective evaluation method of the human factor complexity is proposed. In the proposed method, sewing operations are taken as an example, and the human factor complexity is classified into perceived and cognitive complexity. Information entropy is used to measure cognitive complexity according to the type and quantity of sewing workers' cognitive activities. The results show that various methods have significant differences in the evaluation of the complexity level of the production process chain. Specifically, the calculation results of the proposed evaluation method are much greater than those of other methods. This indicates that human cognitive and perceived complexities account for a large proportion. Therefore, human factor complexity cannot be omitted.

1. Introduction

Currently, the applications of manufacturing system complexity are an active research area. However, complexity has no clear definition [1]. Scholars have defined manufacturing system complexity from different perspectives [2]. Isik [3] argued that complexity may have adverse effects, such as high operating costs, delivery delays, and inventory shortages. Complexity also negatively impacts the attributes of manufacturing systems, such as productivity [4], profit [5], and quality [6]. The research on the complexity of manufacturing systems mainly focuses on processing and assembly. Processing is the process of machining raw materials and semifinished products into target requirements through certain processes and methods. Processing complexity is usually divided into static complexity and dynamic complexity. Static complexity is structural complexity, which is related to the structure and configuration of manufacturing systems. It includes various elements such as people, machines, cache, logistics, and the relationship among them. Dynamic complexity refers to the uncertain factors and system probability in a specific period, such as the adjustment of a plan, change in the order, and task deviation [7]. Frizelle and Woodcock [2] were the first to use information entropy to evaluate manufacturing system complexity. However, there is no in-depth analysis of applicability and effectiveness with respect to complexity. Deshmukh [8] used information entropy to evaluate structural complexity and provided the basis for static and dynamic complexity evaluation. Modrak and Zuzana [9] proposed a method for evaluating static complexity and analysed the complexities of two different manufacturing layouts using the method. This method mainly considered factors such as equipment, parts, and processing sequences, but human factors were ignored. Zhang [10] proposed a method for evaluating static complexity by considering the system's structure and components based on information entropy. Zhang et al. [11] established the static and dynamic entropy models of a cell manufacturing system to reduce its structural complexity. Most of these studies developed complexity models and evaluation methods by describing the state of a manufacturing system. However, manufacturing systems are complex and dynamic; therefore, a method to accurately describe the actual state of a system still needs further research. Complexity theories are most widely used in assembly. As assembly is the final process of a manufacturing system, assembly workers need to complete assembly tasks within a limited time. The complexity of the assembly process is mainly related to uncertainty, work content, and time pressure [12]. It is also related to the diversity of products or parts under a customised production mode [6, 13]. The complexity caused by product diversity and operation complexity in assembly has been the focus of various studies. Falck et al. [14] proposed the basic criteria of assembly system complexity evaluation from 16 dimensions, such as material, operation instruction, and operation time. However, these basic criteria mainly consider objective factors. He et al. [15] proposed a method for modelling and evaluating the structural complexity, process complexity, and operation complexity of an assembly system, but this method only analyses the simple mixed flow assembly system. Zhu et al. [16] proposed a measurement method of operator selection complexity, mainly considering product diversity and information in the assembly process, and developed a complexity model of a multilevel mixed-model assembly system suitable for serial structures. This mathematical model reveals the propagation mechanism of complexity in multilevel mixed-model assembly systems. Based on the modular arrangement of predetermined time standards (MOD method), Alkan et al. proposed a method to measure the operation complexity of a manual assembly system from three aspects, namely, action effort, operation diversity, and operation scale, and verified the effectiveness of this method through simulation [17]; however, the actual case was not analysed. Zaeh et al. [18] argued that workers' participation in a task is based on three interrelated factors, namely, time, cognition, and knowledge. However, the knowledge and cognitive factors still need to be further adjusted to ensure that they are applicable to any assembly operation. As the garment industry belongs to the fast fashion industry, it is characterized by multiple varieties and small batches. The garment production is still labor-intensive and the production process is highly complex. Weaving production has the characteristics of processing and assembly, which requires high technical level of sewing workers. Sewing is an important part of the weaving production system. During the sewing process, the sewing worker works synchronously with the machine, and the sewing worker plays a leading role in the production process. In weaving production system, weaving complexity has an important impact on production efficiency and product quality. However, little is known about the effect of weaving complexity on task performance. The research results of manufacturing system complexity based on process or assembly cannot be directly applied to the field of weaving. To address this, in this study, a new production process complexity measurement method with both processing and assembly characteristics is developed to provide theoretical support for improving the production management and decision-making level of garment weaving industry.

2. Related Studies

Complexity measurement is the basis for managing and controlling complexity. Every manufacturing company should have the most appropriate level of complexity. Before adjusting the level of complexity to an appropriate or ideal level, it is necessary to measure the complexity [19–21]. However, the quantification of complexity is difficult [21]. Brinzer and Schneider [23] classified the measurement methods of manufacturing system complexity into two types: objective and subjective complexity measurements. Objective complexity considers the measurement of the internal factors of a manufacturing system, such as the configuration and structure of the system. Objective complexity is measured using information entropy [2], mathematical modelling [24], and information technology [25]. Subjective complexity measurement considers human factors, such as human perception and cognitive complexity. The methods for measuring subjective complexity are information entropy [26] and questionnaire methods [27], as shown in Figure 1.

Information entropy is frequently used to evaluate manufacturing system complexity. The existing methods for assessing production process chain complexity are as follows.

Method 1 (static complexity evaluation method proposed by Deshmukh et al. [24]): this method is relatively simple. It considers three parameters of a manufacturing system, namely, the number of machines, number of operations, and number of parts. Its formula is as follows [24]:

$$C_{s1} = \log_2 m^2 nr, \quad (1)$$

where r, m, and n represent the numbers of machines, operations, and parts, respectively.

Method 2 (static complexity evaluation method proposed by Frizelle and Woodcock [2]): this method uses information entropy to evaluate static complexity. However, it only considers the processing state of machines. When the machine processes different parts, it is regarded to be in different states. Its formula is as follows [2]:

$$C_{s2} = -\sum_{j=1}^{M}\sum_{i=1}^{S_j} P_{ij}\log_2 P_{ij}, \quad (2)$$

where M represents the number of machines, S_j represents the number of possible planned states of the j th machine can be in, and P_{ij} represents the possibility that the j th machine

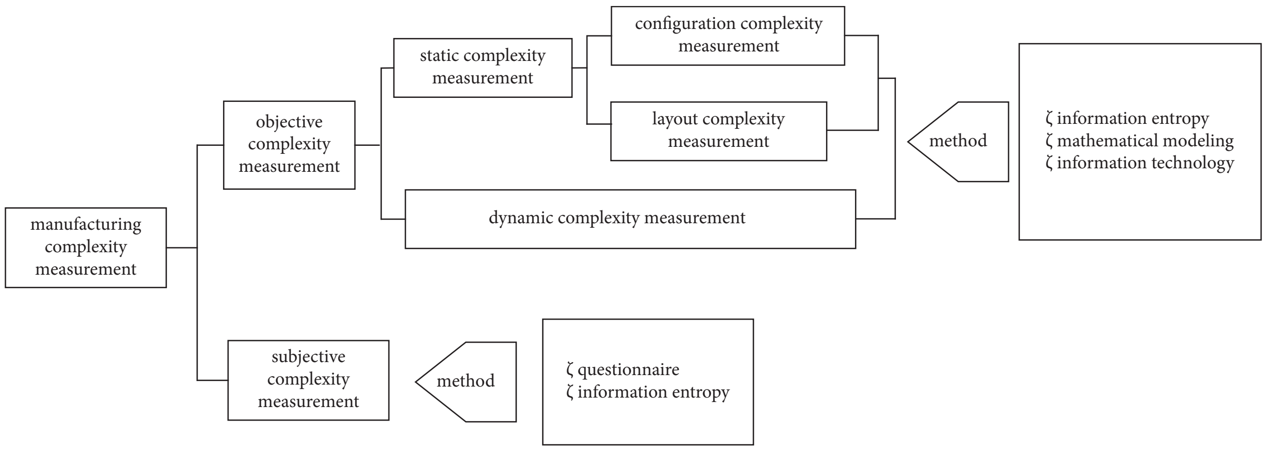


FIGURE 1: Content and methods of complexity measurement of the manufacturing system.

is in state i. In other words, P_{ij} is expressed as the ratio of the machine operation time to the production cycle.

Method 3 (static complexity evaluation method proposed by Zhang [10]): this method also uses information entropy to evaluate the static complexity of a manufacturing system. In this method, the processing and idle states of the machine are considered. However, similar to Method 2, when different machines process different parts, they are regarded to be in different states. Its formula is as follows [10]:

$$C_{s3} = -\sum_{j=1}^{M}\sum_{i=1}^{S_j} P_{ij}\log_2 P_{ij}, \quad (3)$$

where M represents the number of machines, S_j represents the number of possible planned states of the j th machine can be in, and P_{ij} represents the possibility that the j th machine is in state i. Method 4 (static complexity of a manufacturing process chain considering the processing sequence [8]): this method considers the processing sequence of parts based on two assumptions. First, in the manufacturing process chain, machines are usually arranged in series or parallel. According to the two layouts, the probability of the kth part being processed on the j th machine is expressed as P_{jk}. Second, when the part is processed on a serial machine, the value of P_{jk} is $1/M_S$, where M_S is the number of serial machines. When the part is processed on a parallel machine, the value of P_{jk} is $1/M_P$, where M_P is the number of parallel machines. When the part is processed on a parallel machine with a serial/parallel mixed layout, P_{jk} is expressed as $1/(M_S\,M_P)$. Its formula is as follows [9]:

$$C_{s4} = -\sum_{j=1}^{M}\sum_{k=1}^{N} P_{jk}\log_2 P_{jk}, \quad (4)$$

where P_{jk} expresses the probability that the kth part is processed on the j th machine, according to the processing sequence of the parts. N represents the number of parts processed in the manufacturing process chain, and M represents the number of machines involved in the manufacturing process chain.

A summary of the aforementioned evaluation methods is provided in Table 1.

3. Method for Evaluating Sewing Process Chain Complexity considering Human Factors

Based on Method 4, we evaluate the manufacturing process chain complexity of garment production considering human factors. Because sewing plays a crucial role in garment production, we mainly discuss the method for evaluating sewing production process chain complexity. The evaluation framework is shown in Figure 2.

The perception and cognitive complexities are mainly discussed when considering human factors. The perception and cognitive processes can be regarded as processes of information processing, as shown in Figure 3. The information input is considered a perception process and considers the relationship among products, tools, processes, and work areas. Information processing and information output are classified as cognitive processes. The cognitive process has four cognitive functions based on the second-generation human reliability analysis method: observation, interpretation, planning, and execution. These cognitive functions correspond to 15 cognitive activities. According to the types and quantity of cognitive activities corresponding to sewing operations, information entropy is used to evaluate cognitive complexity. The flow chart of the human factor complexity evaluation is shown in Figure 4.

3.1. Method for Evaluating the Perceived Complexity of Sewing Workers. In the garment production process, information input is classified as a perception process. Sewing workers' perception of information is influenced by many factors, such as the quantity and diversity of information [26]. The production process mainly involves four types of information: product information ($X1$), process information ($X2$), tools and equipment information ($X3$), and workplace information ($X4$). For any information variable X, which has n possible values ($Y1$, $Y2$, . . . , Yn), we assume that the information variables have specific relationships

Table 1: Summary of methods for evaluating manufacturing process chain complexity.

Evaluation method	Input parameters
Method 1	The number of machines, the number of operations, and the number of parts
Method 2	The number of machines and the state of machines (only the processing state is considered)
Method 3	The number of machines and the state of machines (both the processing state and idle state of the machines are considered)
Method 4	The number of machines, the state of machines, the number of parts, and the processing order of the parts

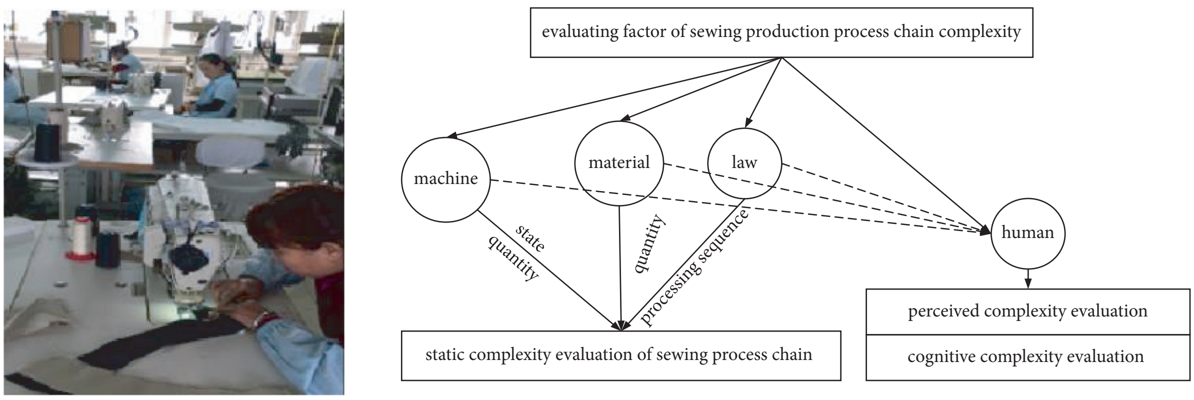


Figure 2: Evaluation framework of sewing process chain complexity.

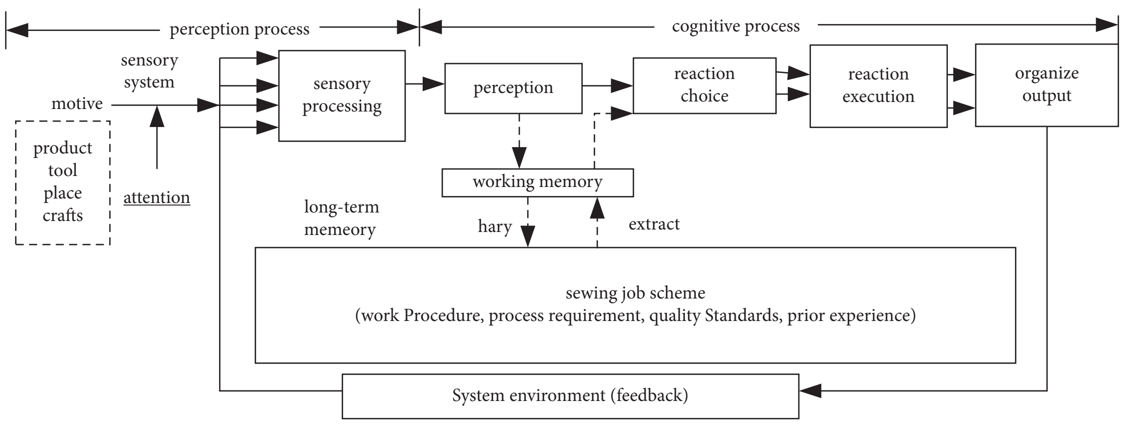


Figure 3: Model of sewing operation information process.

among them, such as calling, being-called, self-relation, and no-relation. The relationship can be defined as R = (self-relation, calling, being-called, no-relation) = (1, 1, 1, 0). R_{ij} ($i = 1, 2, \ldots, n_j$; $j = 1,2,3,4$) represents the relationship between a perceived information variable and other perceived information variables. According to Kong (2018), the formula for calculating the perception complexity of the m th sewing process is expressed as follows [26]:

$$C_{pm} = -\sum_{j=1}^{4}\sum_{i=1}^{n_j} P_{ij}\log_2 P_{ij}, \tag{5}$$

where

$$P_{ij} = \frac{R_{ij}}{R_j}, \tag{6}$$

$$R_j = \sum_{i=1}^{n_j} R_{ij}. \tag{7}$$

3.2. Method for Evaluating the Cognitive Complexity of Sewing Workers. The cognitive process involves information processing and information output based on the process shown in Figure 3. The second-generation human reliability analysis method classifies cognitive functions into four categories: observation, interpretation, planning, and

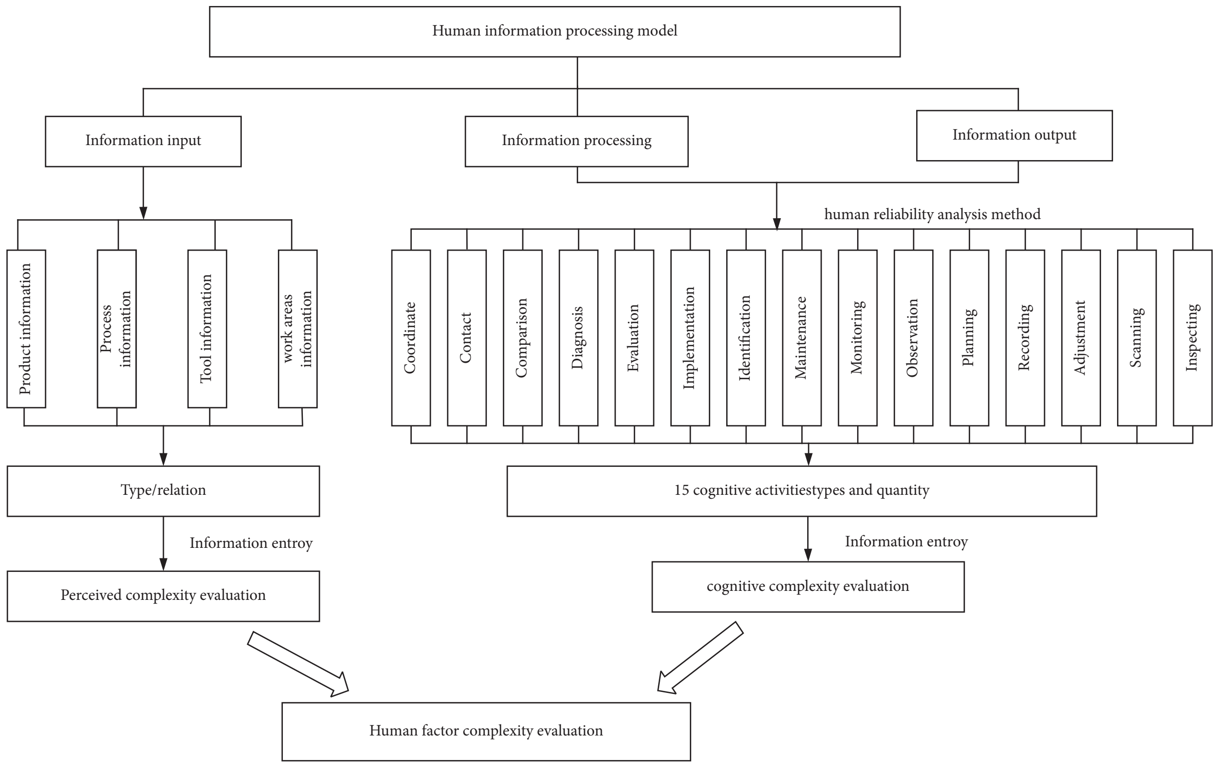


FIGURE 4: Flow chart of the human factor complexity evaluation.

execution. These cognitive functions can be further divided into 15 cognitive activities: coordination, contact, comparison, diagnosis, evaluation, identification, implementation, maintenance, monitoring, observation, planning, recording, adjustment, scanning, and inspection. When any cognitive activity belongs to any cognitive function, it is represented by "√." The corresponding relationship among them is shown in Table 2.

s is used to indicate work step. The mth sewing process is decomposed into n_s work steps. According to the second-generation human reliability analysis method, the type of cognitive activity and cognitive function are judged for each work step, CO_{saf} represents the ath cognitive activity and the fth cognitive function of the sth work step, as shown in Table 3. According to Table 2, when the sth work step is judged as the ath cognitive activity and this cognitive activity belongs to the fth cognitive function, $CO_{saf} = 1$; otherwise, $CO_{saf} = 0$. CO_f represents the sum of the ath cognitive activity and this cognitive activity belongs to the fth cognitive function. P_{cof} represents probability of the fth cognitive function in the mth sewing process. According to Table 3, cognitive complexity of the mth sewing process is quantified using information entropy, which can be expressed as follows:

$$C_{cm} = -\sum_{f=1}^{4} P_{cof} \log_2 P_{cof}. \quad (8)$$

3.3. Method for Evaluating Sewing Production Process Chain Complexity. Based on the aforementioned qualified method, the sewing production process chain complexity is defined and quantified as follows:

$$C_l = C_{s4} + C_g + C_r, \quad (9)$$

where

$$C_p = \sum_{m=1}^{n_p} C_{pm}, \quad (10)$$

$$C_c = \sum_{m=1}^{n_c} C_{cm}. \quad (11)$$

n_p represents the number of perceived complexities. n_c represents the number of cognitive complexities.

3.4. Case Analysis of the Sewing Process Chain Complexity Evaluation. Currently, most garment production enterprises adopt the bundle mode. Owing to the increasing demand for multiple varieties and small batches, the complexity continues to increase. In production workshops, each cut piece is processed according to an arranged order. Sewing workers and machines work synchronously. Particularly, sewing workers play a significant role in ensuring efficiency and quality. Therefore, throughout the evaluation of the sewing production process chain complexity, we must consider the processing sequence of cut pieces and human factors. In this study, we investigate garment enterprise A and adopt the production process of a women's clothing workshop as an example. We use the

Table 2: Corresponding relationship of cognitive activity and cognitive function.

Cognitive activity		Cognitive function			
	Denotation	Observation	Explanation	Plan	Execution
Coordinate	Ca1			√	√
Contact	Ca2				√
Comparison	Ca3		√		
Diagnosis	Ca4		√	√	
Evaluation	Ca5		√	√	
Implementation	Ca6				√
Identification	Ca7		√		
Maintenance	Ca8			√	√
Monitoring	Ca9	√	√		
Observation	Ca10	√			
Planning	Ca11			√	
Recording	Ca12		√		√
Adjustment	Ca13	√			√
Scanning	Ca14	√			
Inspecting	Ca15	√	√		

evaluation methods mentioned earlier to evaluate the production chain complexity. These evaluation methods are compared and analysed to determine the differences between them. The layout of the women's clothing workshop is shown in Figure 5.

As shown in Figure 6, the machines found in the women's clothing sewing workshop mainly include the following types:

(a) Sewing machines: they are the most important machines in garment production, as shown in Figures 6(a) and 6(b)

(b) Instruments for ironing: they are used for flat ironing, shaping, and other operations, as shown in Figure 6(c)

(c) Special equipment: they are used to complete special sewing operations, such as sewing buttonholes, attaching sleeves, and pressing, as shown in Figures 6(d)–6(h)

Group A, which processes windbreakers (18SSF-1), is used as an example for evaluating the production process complexity. The cut pieces of women's windbreakers are shown in Table 4, where J represents the machine labels. The machines are arranged in series: $J1$, $J2$, …, $J18$ ($J1$–$J7$ represent the sewing machines or ironing equipment, and $J8$–$J18$ represent the special machines).

3.5. Evaluation Results of Method 1. According to Method 1, in the women's clothing sewing workshop A, with $m = 96$, $n = 28$, and $r = 18$, the sewing production process chain complexity is calculated using (1) as follows:

$$\begin{aligned} C_{s1} &= \log_2 m^2 \\ nr &= 22.1472. \end{aligned} \quad (12)$$

3.6. Evaluation Results of Method 2. The windbreaker (18SSF-1) production in the women's clothing workshop A is used as an example, and the standard operation time for sewing the windbreaker is shown in Table 5.

According to Method 2, the sewing production process chain complexity is calculated using (2) as follows:

$$C_{s2} = -\sum_{j=1}^{M}\sum_{i=1}^{S_j} P_{ij}\log_2 P_{ij} = 6.80. \quad (13)$$

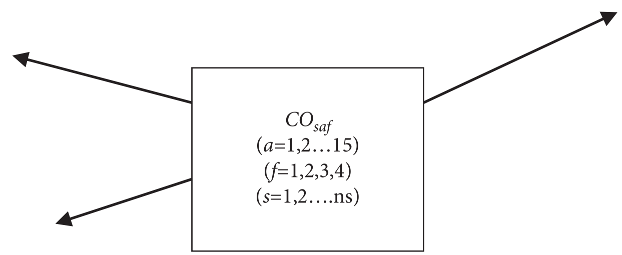
3.7. Evaluation Results of Method 3. Method 3 considers the processing and idle states of a machine. The sewing production process chain complexity can be calculated using (3) as follows:

$$C_{s3} = -\sum_{j=1}^{M}\sum_{i=1}^{S_j} P_{ij}\log_2 P_{ij} = 50.25. \quad (14)$$

3.8. Evaluation Results of Method 4. The sewing process is similar to the assembly process, and the cut pieces can be regarded as individual parts. Accordingly, the method proposed by Modrak and Zuzana [9] for evaluating manufacturing process chain complexity is used to present the process chain diagram of cut pieces using sewing equipment, as shown in Figure 7. Cut pieces are indicated by " ," sewing equipment is indicated by " ," and the processing route of cut pieces is indicated by " ." The cut piece is indicated by a solid line in the sewing equipment processing and by a dotted line in special machine processing. Taking 18SSF-1 as an example, its cut pieces comprise 28 pieces, including eight sleeve cut pieces ($X1$–$X8$), six pocket cut pieces ($D1$–$D6$), four front cut pieces ($Q1$–$Q4$), two rear cut pieces ($H1$ and $H2$), four collar cut pieces ($L1$–$L4$), two hanging cut pieces ($G1$ and $G2$), and two belt cut pieces ($Y1$ and $Y2$). The processing of each cut piece needs to be

Table 3: Cognitive activity and cognitive function of the mth sewing process.

Cognitive activity	Cognitive function: Observation $f = 1$	Explanation $f = 2$	Plan $f = 3$	Execution $f = 4$	
Ca1	CO $_{111}$ ...	...	...	CO_{114} ...	
	CO ns 11				CO n_s $_{14}$
Ca2	...				
...	...				...
Ca15	CO n_{s} $_{151}$ ...				... ...
	CO1151				...
CO_f	$CO_1 = \sum_{a=1}^{15}\sum_{s=1}^{n_s} CO_{sa1}$	$CO_2 = \sum_{a=1}^{15}\sum_{s=1}^{n_s} CO_{sa2}$	$CO_3 = \sum_{a=1}^{15}\sum_{s=1}^{n_s} CO_{sa3}$	$CO_4 = \sum_{a=1}^{15}\sum_{s=1}^{n_s} CO_{sa4}$	
P_{cof}	$P_{co1} = \sum_{a=1}^{15}\sum_{s=1}^{n_s} CO_{sa1} / \sum_{f=1}^{4}\sum_{a=1}^{15}\sum_{s=1}^{n_j} CO_{saf}$	$P_{co2} = \sum_{a=1}^{15}\sum_{s=1}^{n_s} CO_{sa2} / \sum_{f=1}^{4}\sum_{a=1}^{15}\sum_{s=1}^{n_j} CO_{saf}$	$P_{co3} = \sum_{a=1}^{15}\sum_{s=1}^{n_s} CO_{sa3} / \sum_{f=1}^{4}\sum_{a=1}^{15}\sum_{s=1}^{n_j} CO_{saf}$	$P_{co4} = \sum_{a=1}^{15}\sum_{s=1}^{n_s} CO_{sa4} / \sum_{f=1}^{4}\sum_{a=1}^{15}\sum_{s=1}^{n_j} CO_{saf}$	



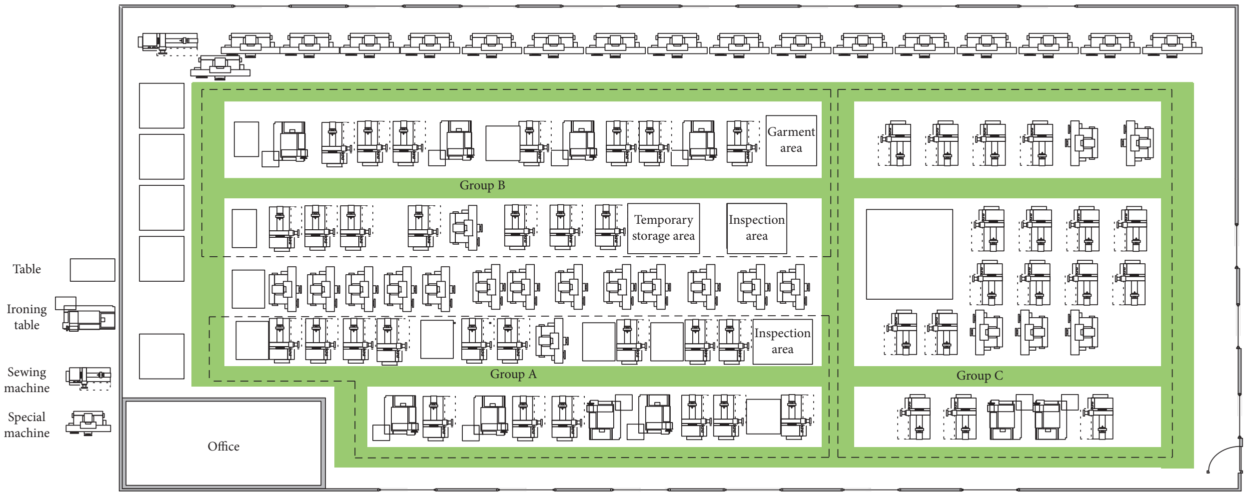


Figure 5: Layout of the women's wear workshop.

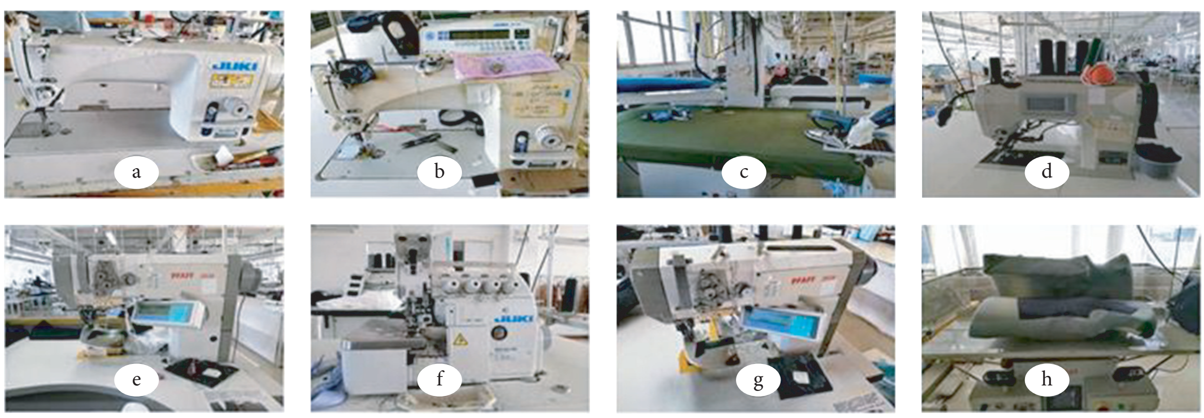


Figure 6: Sewing equipment in the women's clothing workshop.

completed using $J1$–$J18$ sewing equipment. We draw the process chain of each cut piece in each sewing equipment according to the cutting process and processing sequence. Taking the sleeve cut piece $X1$ of 18SSF-1 as an example, according to its process requirements, the processing of $X1$ needs to be performed on the sewing equipment $J2$, $J1$, $J6$, $J12$, $J10$, $J3$, and $J5$. The processing sequence is $J2 \longrightarrow J1 \longrightarrow J6 \longrightarrow J12 \longrightarrow J10 \longrightarrow J3 \longrightarrow J5 \longrightarrow J10$. The process chain of cut piece X1 is drawn according to the processing sequence. Then, the process chains of all cut pieces are drawn using the same method. Consequently, the manufacturing process chain of 18SSF-1 is formed.

The example shown in Figure 7 for cut piece $X1$ has the following processing order: $J2 \longrightarrow J1 \longrightarrow J6 \longrightarrow J12 \longrightarrow J10 \longrightarrow J3 \longrightarrow J5 \longrightarrow J10$. These machines are all arranged in series, and the probability of each machine being used is equal, equal to 1/8 (e.g., $P_{j1} = 1/8$). Therefore, the process static complexity of cut piece $X1$ is calculated using (4) as follows:

$$-\sum_{j=1}^{s} P_{j1}\log_2 P_{ji} = 8 \times \frac{1}{8} \times \log_2 \frac{1}{8} = 3. \tag{15}$$

The production process static complexity of the other cut pieces is calculated similarly. The calculation results are shown in Table 6.

Based on (4), the production process chain static complexity for group A is calculated as follows:

$$C_{s4} = -\sum_{j=1}^{M}\sum_{i=1}^{N} P_{jk}\log_2 P_{jk} = 47.06. \tag{16}$$

4. Results of Evaluating Production Process Chain Complexity considering Human Factors

4.1. Perception Complexity Evaluation. The information entropy method is used to evaluate the perception complexity. The production characteristics and basic attributes of the resources required by sewing workers to complete the sleeve setting process are described in Table 7.

The four product information variables in the information acquisition phase of the setting of the sleeve operation are as follows: $X1 =$ (three product variables:

Table 4: Type of cut pieces.

No.	Type	Denotation
1	Top sleeve (left)	*X*1
2	Top sleeve (right)	*X*2
3	Sleeve tab (left 1)	*X*3
4	Sleeve tab (left 2)	*X*4
5	Sleeve tab (right 1)	*X*5
6	Sleeve tab (right 2)	*X*6
7	Pocket flap (left 1)	*D*1
8	Pocket flap (left 1)	*D*2
9	Pocket flap (right 1)	*D*3
10	Pocket flap (right 2)	*D*4
11	Pocket (left)	*D*5
12	Pocket (right)	*D*6
13	Under sleeve (left)	*X*7
14	Under sleeve (right)	*X*8
15	Front piece 1	*Q*1
16	Front piece 2	*Q*2
17	Front piece 3	*Q*3
18	Front piece 4	*Q*4
19	Back piece 1	*H*1
20	Back piece 2	*H*2
21	Collar 1	*L*1
22	Collar 2	*L*2
23	Collar stand 1	*L*3
24	Collar stand 2	*L*4
25	Facing	*G*1
26	Facing	*G*2
27	Waistband 1	*Y*1
28	Waistband 2	*Y*2

Table 5: Sewing process and machine operation time for women's garment (*18SSF-1*).

Cut pieces type	Standard machine operation time (min)
*X*1	*J*2 (1.6), *J*3 (5), *J*5 (13.9), *J*6 (1.2), *J*13 (1.4), *J*11 (5.6)
*X*2	*J*2 (1.6), *J*3 (5), *J*5 (13.9), *J*6 (1.2), *J*13(1.4), *J*11 (5.6)
*X*3	*J*2 (2), *J*3 (2.7), *J*10 (2.8), *J*17 (4.4), *J*18 (1.5)
*X*4	*J*2 (2), *J*3 (2.7), *J*10 (2.8), *J*17 (4.4), *J*18 (1.5)
*X*5	*J*2 (2), *J*3 (2.7), *J*10 (2.8), *J*17 (4.4), *J*18 (1.5)
*X*6	*J*2 (2), *J*3 (2.7), *J*10 (2.8), *J*17 (4.4), *J*18 (1.5)
*D*1	*J*9 (1.6), *J*1 (2.5), *J*5 (2.8)
*D*2	*J*9 (1.6), *J*1 (2.5), *J*5 (2.8)
*D*3	*J*9 (1.6), *J*1 (2.5), *J*5 (2.8)
*D*4	*J*9 (1.6), *J*1 (2.5), *J*5 (2.8)
*D*5	*J*3 (1.5), *J*5 (5.8), *J*3 (2.2)
*D*6	*J*3 (1.5), *J*5 (5.8), *J*3 (2.2)
*X*7	*J*2 (1.6), *J*6 (1.2), *J*12 (1.4), *J*11 (5.6)
*X*8	*J*2 (1.6), *J*6 (1.2), *J*12 (1.4), *J*11 (5.6)
*Q*1	*J*2 (5.4), *J*3 (1.9), *J*12 (1.4), *J*11 (5.6)
*Q*2	*J*2 (5.4), *J*3 (1.9), *J*12 (1.4), *J*11 (5.6)
*Q*3	*J*2 (5.4), *J*4 (1.2), *J*16 (4.8), *J*11 (5.6), *J*3 (1.9), *J*4 (3)
*Q*4	*J*2 (5.4), *J*4 (1.2), *J*16 (4.8), *J*11 (5.6), *J*3(1.9), *J*4 (3)
*H*1	*J*6 (2.5), *J*1(1.2), *J*11 (2.2), *J*15 (0.7)
*H*2	*J*6 (2.5), *J*1(1.2), *J*11 (2.2), *J*15 (0.7)
*L*1	*J*6 (1.8), *J*4 (5.65), *J*14 (1.5), *J*1 (1.5), *J*4 (6.5), *J*7 (2.5)
*L*2	*J*6 (1.8), *J*4 (5.65), *J*14 (1.5), *J*1 (1.5), *J*4 (6.5), *J*7 (2.5)
*L*3	*J*6 (1.8), *J*4 (5.65), *J*14 (1.5), *J*1 (1.5), *J*4 (6.5), *J*7 (2.5)
*L*4	*J*6 (1.8), *J*4 (5.65), *J*14 (1.5), *J*1(1.5), *J*4 (6.5), *J*7 (2.5)
*G*1	*J*7 (0.8), *J*4 (2.7), *J*1 (1.6)
*G*2	*J*7 (0.8), *J*4 (2.7), *J*1 (1.6)
*Y*1	*J*7 (3.2), *J*1(1.6), *J*5 (0.8)
*Y*2	*J*7 (3.2), *J*1(1.6), *J*5 (0.8)

semifinished clothes, sleeves, and thread), $X2$ = (four process variables: alignment, suturing, thread removal, and inspection), $X3$ = (three tooling variables: sewing machine, scissors, and mannequins), and $X4$ = (two workplace variables: workbench and mannequins' area).

The relationship matrix can be obtained from the information relationship diagram shown in Figure 8. Table 8 lists the relationships between the different information variables and the perception complexity results of the product information variables ($X1$). The method for evaluating the perception complexity of the other production information variables ($X2$, $X3$, and $X4$) is the same as that of $X1$. The perception complexity of the mth sewing process is obtained using equation (5)–(7) as follows:

$$\begin{aligned} C_{pm} &= -\sum_{j=1}^{4}\sum_{i=1}^{n_j} P_{ij}\log_2 P_{ij} \\ &= 1.584 + 1.984 + 1.52 + 1 \\ &= 6.088. \end{aligned} \quad (17)$$

4.2. Cognitive Complexity Evaluation. Take setting in sleeve process as an example, the operation of setting in sleeve is decomposed into 23 work steps. According to the second-generation human reliability analysis method, the type of cognitive activity and cognitive function are judged for each work step. The 23 work steps are analysed; when the work step belongs to cognitive activity, it is represented by " √ "; the results as shown in Tables 9 and 10.

According to Tables 2, 3, 9, and 10, the cognitive complexity for setting the sleeve is then calculated by (8); the results are shown in Table 11.

$$C_{cm} = -\sum_{f=1}^{4} P_{cof}\log_2 P_{cof} = 1.8516. \quad (18)$$

The sewing process of the women's windbreaker involves 96 processes. The same method as the one for setting the sleeves is adopted using (5) and (6). The perception complexity and cognitive complexity of each sewing process are calculated. The calculation results are summarised in Table 12.

According to equations (10)–(13),

$$\begin{aligned} C_l &= C_{s4} + \sum_{m=1}^{n_p} C_{pm} + \sum_{m=1}^{n_c} C_{cm} \\ &= 47.06 + 224.269 + 165.072 \\ &= 436.40. \end{aligned} \quad (19)$$

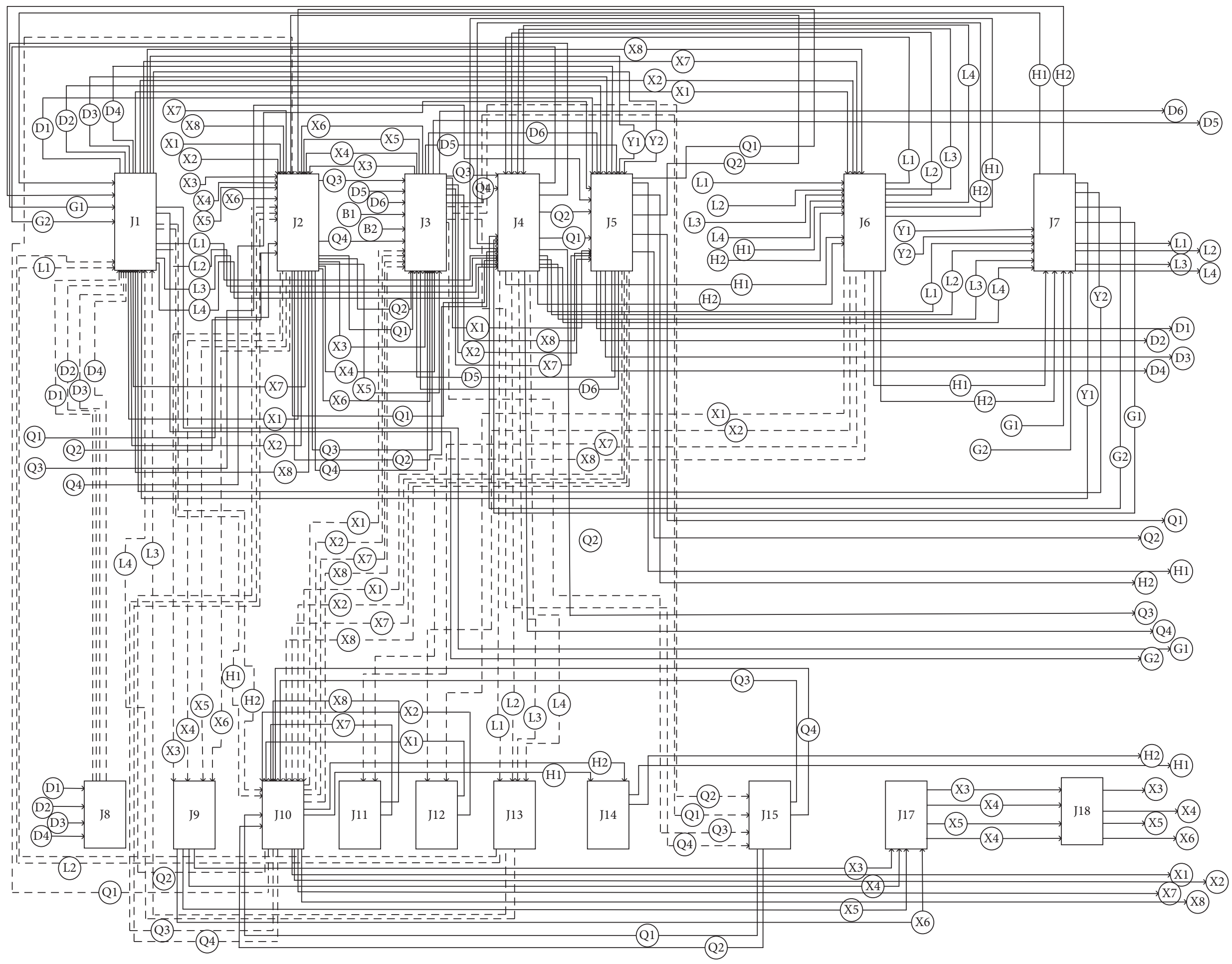


Figure 7: Manufacturing process chain of group A in women's clothing workshop.

Table 6: Static complexity of cut pieces.

No.	Denotation	C_{s4}
1	$X1$	3
2	$X2$	3
3	$X3$	2.3219
4	$X4$	2.3219
5	$X5$	2.3219
6	$X6$	2.3219
7	$D1$	1.585
8	$D2$	1.585
9	$D3$	1.585
10	$D4$	1.585
11	$D5$	1.585
12	$D6$	1.585
13	$X7$	2.8074
14	$X8$	2.8074
15	$Q1$	3
16	$Q2$	3
17	$Q3$	3.1699
18	$Q4$	3.1699
19	$H1$	3
20	$H2$	3
21	$L1$	2.585
22	$L2$	2.585
23	$L3$	2.585

Table 6: Continued.

No.	Denotation	C_{s4}
24	$L4$	2.585
25	G1	1.585
26	$G2$	1.585
27	$Y1$	1.585
28	$Y2$	1.585

Table 7: Description of the sleeve setting process.

Classification	Element	Description
Production characteristics	System	Sewing
	Part	Sleeve, semifinished clothes
	Process	Setting in sleeve
	Procedure	Alignment, remove thread, suture, inspection
Resources required	Material	Sleeve (one piece), semifinished clothes (one item), thread
	Person	Sewing worker (one person)
	Tool	Sewing machine, scissors, mannequin
	Workplace	Bench, mannequin's area

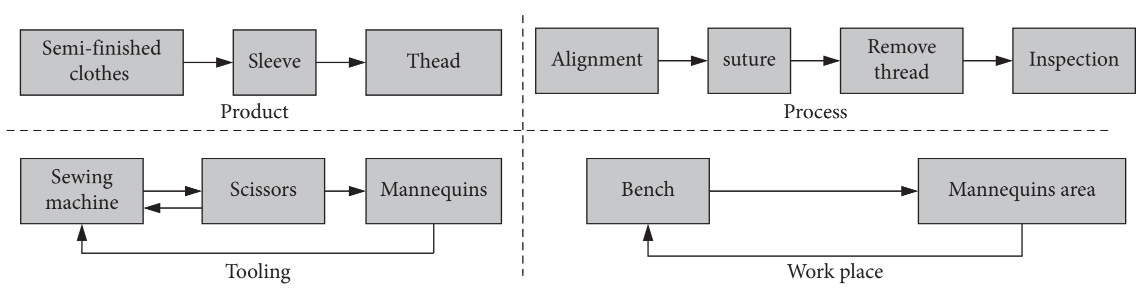


Figure 8: Four types of production information relationships of setting in sleeves.

Table 8: Perception complexity result of product information variables.

Variables	Relationship $R_i = (1, 0)$			Subtotal	P_{ij}	$-P_{ij}\ log_2 P_{ij}$
	Semifinished clothes	Sleeve	Thread			
Semifinished clothes	1	1	1	3	0.333	0.528
Sleeve	1	1	1	3	0.333	0.528
Thread	1	1	1	3	0.333	0.528
Total				9	1	1.584

Table 9: Cognitive activities (Ca1-Ca8) of setting in sleeve.

No.	Working step	Ca1	Ca2	Ca3	Ca4	Ca5	Ca6	Ca7	Ca8
1	Pick up the sleeve pieces					√	√		
2	Pick up bodice					√	√		
3	Inspect the cutting pieces					√	√		
4	Align the sleeve top and armhole			√		√			
5	Confirm alignment				√	√			√
6	Align sleeves and bodice						√		
7	Align sleeve top and armhole						√		√
8	Hold and sew sleeve top and armhole						√		√
9	Move the sleeve and the bodice						√		
10	Align and sew the sleeve and bodice						√		

Table 9: Continued.

No.	Working step	Ca1	Ca2	Ca3	Ca4	Ca5	Ca6	Ca7	Ca8
11	Remove the thread ends using scissors					√	√		
12	Hold and sew sleeve top and armhole						√		√
13	Move the sleeve and armhole						√		
14	Hold and sew the sleeve and armhole						√		√
15	Move the sleeve and armhole						√		
16	Hold and sew the sleeve and armhole						√		√
17	Move the sleeve and the bodice						√		
18	Hold and sew the sleeve and armhole						√		
19	Remove the thread ends using scissors					√	√		
20	Hold and sew the sleeve and armhole						√		√
21	Remove the sleeve and bodice						√		
22	Inspect the cutting pieces					√	√		
23	Inspection						√		

Table 10: Cognitive activities (Ca9-Ca15) of setting in sleeve.

No.	Working step	Ca9	Ca10	Ca11	Ca12	Ca13	Ca14	Ca15
1	Pick up the sleeve pieces		√					
2	Pick up bodice		√					
3	Inspect the cutting pieces		√					
4	Align the sleeve top and armhole		√			√		√
5	Confirm alignment							√
6	Align sleeves and bodice					√		
7	Align sleeve top and armhole					√		
8	Hold and sew sleeve top and armhole					√		
9	Move the sleeve and the bodice					√		
10	Align and sew the sleeve and bodice					√		
11	Remove the thread ends using scissors		√					
12	Hold and sew sleeve top and armhole					√		
13	Move the sleeve and armhole					√		
14	Hold and sew the sleeve and armhole					√		
15	Move the sleeve and armhole					√		
16	Hold and sew the sleeve and armhole					√		
17	Move the sleeve and the bodice					√		
18	Hold and sew the sleeve and armhole					√		
19	Remove the thread ends using scissors		√					
20	Hold and sew the sleeve and armhole					√		
21	Remove the sleeve and bodice							
22	Inspect the cutting pieces		√					√
23	Inspection							√

Table 11: Cognitive complexity of setting in sleeve.

Cognitive activity	Cognitive function				Total
	Observation ($f = 1$)	Explanation ($f = 2$)	Plan ($f = 3$)	Execution ($f = 4$)	
CO_f	25	14	16	42	97
P_{cof}	0.2577	0.1443	0.1649	0.4331	1
$-P_{cof}\, log_2\, P_{cof}$	0.5030	0.4030	0.4228	0.5228	1.8516

The evaluation results show that Method 1 considers the machines, parts, and operations in the production process. Method 2 considers the machines and operations. Method 3 considers machines and parts and operations. Method 4 considers machines, operations, and processing sequence of parts. And method 5 (proposed in this study) incorporates the human factors based on Method 4, as shown in Table 13. With the addition of the human factors, the complexity of the production process chain increases significantly. This indicates that human cognitive and perceived complexities

Table 12: Calculation results of perception complexity and cognitive complexity.

No.	Sewing process	C_{pm}	C_{cm}
1	Pressing flap	2	1.6072
2	Pressing elbow seam	2	1.7445
3	Pressing shoulder seam	2	1.6336
4	Pressing facing	2	1.7824
5	Folding sleeve hem	2.584	1.4956
6	Pressing gorge line	2.584	1.6753
7	Pressing back vent	2.584	1.4956
8	Pressing inseam	2	1.7592
9	Sewing collar	2.584	1.6067
10	Pressing sleeve triangle*2	2	1.6506
11	Folding facing interlining	2.584	1.4956
12	Check waistband	2	1.6072
13	Pressing back	2	1.7824
14	Pressing collar	2	1.6506
15	Pressing waistband	2	1.6753
16	Check collar	2	1.7660
17	Pressing collar stand	2	1.6506
18	Sewing waistband mouth reserved	2.584	1.7469
19	Marking front edge	3.186	1.6067
20	Top-stitching sleeve tab	2	1.8009
21	Top-stitching front seam	2	1.8009
22	Joining elbow seam	2	1.8009
23	Joining inseam	2	1.8009
24	sewing front edge	2	1.7982
25	Binding elbow seam	2.584	1.7469
26	Binding inseam and cuff	2.584	1.7469
27	Basting front piece	2	1.7469
28	Top-stitching elbow seam	2	1.8099
29	Binding hem	2.584	1.7634
30	Attaching brand	3.186	1.5513
31	Stitching sleeve tab	2.584	1.5513
32	Joining front seam	2	1.8099
33	Sewing hem 1/6	2.584	1.7982
34	Pressing sleeve tab	2.584	1.6655
35	Marking patch pocket position	3.186	1.5513
36	Blocking front piece	2	1.6655
37	Sewing cuff	3.186	1.7982
38	Sewing flap	2	1.7660
39	Pressing side seam	2	1.7592
40	Pressing front seam	2	1.7824
41	Sewing patch pocket up side	2	1.7982
42	Making French tack	2	1.5513
43	Pressing patch pocket up side	2	1.6655
44	Check the front edge	2.584	1.7660
45	Sewing hem 3/6	3.186	1.7982
46	Pressing patch pocket	3.186	1.6655
47	Pressing front edge	2	1.6072
48	Marking armhole position	2.584	1.6067
49	Stitching flap	3.186	1.7838
50	Top collar stitching	2	1.8099
51	Joining shoulder seam	2	1.5450
52	Sewing facing	2	1.7982
53	Basting collar	2.584	1.7469
54	Sewing collar on and down	5.1550	1.8516
55	Joining facing	2	1.5450
56	Marking collar stand	2.584	1.6067
57	Binding armhole	2.584	1.8118
58	Ticking collar	3.186	1.7952
59	Sewing collar stand	2.584	1.7952
60	Sewing hem 1/6	3.186	1.7982

Table 12: Continued.

No.	Sewing process	C_{pm}	C_{cm}
61	Bundling armhole	2	1.6506
62	Attaching pocket to garment	2	1.7982
63	Basting armhole	2	1.7469
64	Top-stitching flap	2	1.8009
65	Attaching flap	2.584	1.7660
66	Making waistband clip	2	1.6655
67	Stitching patch pocket mouth	2.584	1.7982
68	Top-stitching flap mouth	2	1.8009
69	Basting and stitching patch pocket	2	1.7469
70	Setting in sleeve	6.088	1.8516
71	Cutting flap	2.584	1.7660
72	Joining back seam	2.584	1.8099
73	Basting side facing interlining	2.584	1.7469
74	Joining back center seam	2	1.8099
75	Top-stitching back seam	2	1.8099
76	Sewing side seam	2	1.8099
77	Binding back seam	2.584	1.7469
78	Basting side facing interlining	2	1.7469
79	Binding side seam	2.584	1.7469
80	Stitching sleeve triangle*2	2	1.7982
81	Cutting collar	2.584	1.7660
82	Sewing wash care label	2	1.8092
83	Top-stitching back center seam	2	1.7982
84	Cutting collar stand	2	1.7660
85	Top-stitching back vent	2	1.7982
86	Binding back seam	2.584	1.7469
87	Basting waistband	2	1.7982
88	Top-stitching waistband	2	1.8099
89	Identifying and bundling	2	1.5513
90	Sewing buttonhole of sleeve tab*4	3	1.4200
91	Sewing hem 1/6	2.584	1.7982
92	Sewing buttonhole of front edge*5	3	1.4200
93	Edging facing	2	1.7660
94	Sewing back vent	2.584	1.7982
95	Pressing collar stand	2	1.6506
96	Pressing hanging loop	2.584	1.6655
	Total	224.269	165.072

Table 13: Comparison of five production chain complexity evaluation methods.

Evaluation items/results	Method 1	Method 2	Method 3	Method 4	Method 5
Machines	√	√	√	√	√
Parts	√	—	√	√	√
Operations	√	√	√	—	√
Processing sequences	—	—	—	√	√
Human factors	—	—	—	—	√
C_l	22.15	6.80	50.25	47.06	436.40

account for a large proportion. Therefore, human factor complexity cannot be omitted.

5. Conclusions, Discussion, and Future Studies

5.1. Conclusions and Discussion. Sewing operations are highly dependent on the workers. During the sewing process, cognition and perception complexities have an impact on weaving efficiency and garment quality. In this study, complexity theory is applied to garment production. A new evaluation method of the production process chain complexity considering human factors is proposed. Based on the quantitative results of human factor complexity shown in Table 12, changes in perceived complexity and cognitive complexity are not necessarily synchronous. That is, for any process, if the perceived complexity is high, then the cognitive complexity is not necessarily high, and vice versa. However, for processes with relatively complex sewing processes and difficult operations, such as setting in sleeves, the perceived complexity and cognitive complexity are relatively high. Meanwhile, if the operation time of a sewing process is long, its perceptual complexity and cognitive complexity are not necessarily high. For example, the operation time of ironing bag covers is 150 s, and its perceptual complexity is 2, whereas the operation time of cufflink folding is 36 s and its perceived complexity is 2.584. Based on the comparative analysis results in Table 13, the complexity of the production and manufacturing process chains significantly increases when human factors are considered. The proposed evaluation method is very useful for the complexity evaluation of the production process chain, especially for manual manufacturing systems. Furthermore, factors in the manufacturing process, such as machines, parts, operation, and human factors, are all considered in the proposed method. Human factors are particularly described in detail.

5.2. Future Studies. From this analysis, the proposed evaluation method provides theoretical support and evaluation tools for garment shops. Although this study did not investigate how complexity affects weaving system efficiency and product quality, the proposed method provides an algorithm tool for further research in this field. Vidal and Hernandez [28] argued that it is necessary to reduce complexity in manufacturing systems. In future studies, we shall focus on reducing the complexity of sewing production chains using mathematical modelling, simulations, and other methods to improve production efficiency and reduce the defect rate. [22].

Data Availability

The data that support the findings of this study are available from (third party) (W&F Bird Group co.,Ltd.). Restrictions apply to the availability of these data, which were used under license for this study. Data are available from http://user52060.nz86.com/.

Conflicts of Interest

The authors do not have any conflicts of interest to declare regarding the publication of this paper.

Acknowledgments

The authors also would like to thank Jilin W&F Bird Group Co., Ltd., for allowing the use of the research sites. This study was supported by the Scientific and Technological Development Plan of Jilin Provincial Science and Technology Department (Grant ID 2020122355JC).

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