Prediction of the sewing standard time based on process difficulty coefficient

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ABSTRACT – REZUMAT

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In garment production, the standard time is a unit widely used for production planning and calculating cost. It is very difficult to prepare manufacturing plans, short term and long-term forecasts, pricing, and other technical and managerial activities in a garment company without true standard time data. Therefore, standard time prediction as the core of standard time quota management is directly related to economic accounting, production schedule control, resource optimization, production cycles shortening, cost control and product quotation. The sewing process can be regarded as the most critical step for the entire garment production, substantially completing the shape of the garment. To achieve fast and accurate sewing process standard time prediction, this paper established the evaluation indicators for sewing process difficulty, obtained the weight of each expert to indicators analysed with analytic hierarchy process, and made group utility function to calculate the difficulty coefficient. The relationship between the sewing processes standard time and the difficulty coefficient was determined to predict the unknown standard time by curve fitting. The effectiveness and usability of this method were verified by examples. The results demonstrated that the proposed method could be a good alternative to existing prediction methods.

Keywords: *analytic hierarchy process, group utility function, garment sewing process, process difficulty coefficient, standard time*

Predicția timpului standard de coasere pe baza coeficientului de dificultate a procesului

În producția de îmbrăcăminte, timpul standard este o unitate utilizată pe scară largă pentru planificarea producției și calcularea costurilor. Este foarte dificil să se pregătească planuri de producție, previziuni pe termen scurt și lung, calcularea prețurilor și alte activități tehnice și manageriale într-o companie de îmbrăcăminte fără date reale de timp standard. Prin urmare, predicția timpului standard ca nucleu al gestionării normelor de timp standard este direct legată de contabilitatea economică, controlul programului de producție, optimizarea resurselor, scurtarea ciclurilor de producție, controlul costurilor și cotația produselor. Procesul de coasere poate fi considerat cel mai critic pas pentru întreaga producție de îmbrăcăminte, completând substanțial forma îmbrăcămintei. Pentru a realiza o predicție rapidă și precisă a timpului standard al procesului de coasere, această lucrare a stabilit indicatorii de evaluare a dificultății procesului de coasere, a obținut ponderea fiecărui expert la indicatorii analizați cu procesul de ierarhie analitică și a realizat funcția de utilitate de grup pentru a calcula coeficientul de dificultate. Relația dintre timpul standard al proceselor de coasere și coeficientul de dificultate a fost determinată pentru a preconiza timpul standard necunoscut prin ajustarea curbei. Eficacitatea și utilitatea acestei metode au fost verificate prin exemple. Rezultatele au demonstrat că metoda propusă ar putea fi o alternativă eficientă la metodele de predicție existente.

Cuvinte-cheie: *proces de ierarhie analitică, funcție de utilitate de grup, proces de coasere a articolelor de îmbrăcăminte, coeficient de dificultate a procesului, timp standard*

INTRODUCTION

In recent years, due to greater competition in the market, the patterns of product have become more diversified and their life cycle shorter. Adapting to the enterprise environment changes, improving the enterprise's agility and responding quickly to the customer's requirements is becoming more and more important. In such a context, the importance of efficient determination of standard time needs to be stressed even further. It is very difficult to prepare manufacturing plans, short term and long term forecasts, pricing, and other technical and managerial activities in a company without true standard time [1]. Standard time not only directly affects the working time, the utilization rate of the equipment, but also is the basic unit for calculating cost, and is widely used for cost management in manufacturing enterprises. Therefore, standard time prediction is directly related to economic accounting, production schedule control, resource optimization, production cycles shortening, cost control and product quotation. Besides, it ultimately promotes the improvement of labour productivity of enterprises and enhances their market competitiveness [2]. The term "standard time" is used to refer to the time required by an average skilled operator, working at a normal pace, to perform a specified task using a prescribed method [3]. It includes appropriate allowances to allow the person to recover from fatigue and, where necessary, an additional allowance to cover contingent elements which may occur but have not been observed.

The joining together of garment components, known as the sewing process, is the most labour intensive part of garment manufacturing [4]. The sewing process needs to be carried out strictly by the production plan, which includes not only the distribution of the production site, equipment and resources but also the arrangement of standard time. Standard time is a key indicator to measure the production efficiency of the sewing department [5]. Standard time is a common language between fashion brands and manufacturers for discussions on cost, time and floor capacity. A manager should know the time consumption of a new product processing exactly before acceptance. Industrial engineers take responsibility for measuring standard time for the given garment samples. The standard time of the same operation will be different if the working condition is changed, like the operator using a different machine, the operator sewing a bigger component, an operator using attachment and work-aids when sewing a garment. With the constant development and application of computer technology, more and more advanced manufacturing technology, scientific and digital management have been generally accepted in the clothing industry. The advantages of the standard time estimation method can effectively help clothing enterprises to reduce costs and improve production efficiency. In this study, we propose a sewing process standard time prediction method based on regression analysis, which involves difficulty coefficient variables that can be utilized for sewing standard time prediction at actual garment production. The process difficulty coefficient can be defined as the difficulty value of a certain process reaching a certain standard. The proposed approach offers the manager the possibility to easily formulate the sewing process standard time. In addition, the new method demonstrates an aided tool for decision in the field of standard time.

RELATED WORKS

Since Taylor defined standard time as the most fundamental way to represent productivity under the basic concept of "A Fair Day's Work", many methods on the determination of standard time have been performed such as time study, activity sampling, synthetic timing, analytical estimating, predetermined motion time systems(PTS) [6]. Chen et al proposed a synthetic timing method to solve the problem of making standard time of customized parts in a mass customization environment [7]. Pan et al. established standard time in the die manufacturing process using the activity sampling method [8]. Wang et al suggested the estimation procedure of standard time for companies manufacturing multi-pattern and extremely small quantity items [9]. Li et al. use the time study method to establish the man-hour quota calculation model, data structure and work improvement circulation model for an enterprise specialized in producing nuclear power pipes [10]. Hee et al. use the predetermined motion time systems method to establish a standard time for agricultural work in Korea [11].

There were also many studies to apply the above-mentioned approach to predict the standard time of the process in making clothes. Ye et al established standard time in the garment manufacturing process using the synthetic timing method [12]. Wu et al. propose an analytical estimating method for standard time based on the similarity of sewing processes [13]. Du et al. make use of the predetermined motion time systems method to calculate the standard time of the template sewing process [14]. Liu et al. performed a traditional time study method by using a stopwatch for garment producing companies [15]. However, these methods have their limitations. For instance, the results of the analytical estimating method depend on human knowledge and experience, so different people obtain different results of standard time estimation. The synthetic timing method needs a lot of work to build up books of times, it is not easy to update those books. Predetermined motion time systems are labour consumption methods, so it is not often used in pre-production especially in small-lot production. In this sense, the reliable, easy to update and reasonable way of sewing process standard time determination method is essential for efficient production planning and control under such a varying production environment.

METHODS

The procedure of garment sewing process standard time prediction based on difficulty coefficient

In this study, our goal is to build a sewing process standard time prediction model by using data from garment manufacturing companies as well as variables we considered. The main steps are as follows.

1. The evaluation model of garment sewing difficulty coefficient is constructed by using the analytic hierarchy process (AHP) and group decision theory.
2. Matlab software is used to curve fitting the process difficulty coefficient and standard time.
3. Estimating of sewing standard time by the regression equation.

Index system of sewing process difficulty

The difficulty coefficient of each sewing process is predicted in advance by comprehensively taking into account the characteristics of the sewing process, the environment, and past experiences. Therefore, even for identical sewing processes, different standard time can be predicted depending on several different factors. In general, many objective or subjective factors are involved in the complicated garment manufacturing process. Firstly, the complexity of a garment sewing process is determined primarily by clothing style, such as type of fabric, type of seams, and the size and shape of cutting patterns. Yukari et al study on the relationship between the seam ability and mechanical properties of wool fabrics showed that the mechanical properties of fabrics affect the quality and difficulty of garment productions [16]. Secondly, stable garment manufacturing processes requires advanced production equipment and good production condition. Thirdly, workers' level of effort and skill proficiency directly impact the production efficiency and actual standard time in garment manufacturing. It is well demonstrated in the garment industry that providing training for new workers or offering a pre-production process is effective to improve workers' ability to operate the equipment. Finally, professional management team and management practices also affect standard time. Higher wages or rewards motivate workers to maintain high levels of effort, encourage them to keep work interests and develop relationships with managers or colleagues. To summarize, the index system of sewing process difficulty consists of 5 primary factors including component character, production configuration, staff, management, environment, and 15 secondary indexes (table 1).

Table 1

INFLUENCE FACTORS OF SEWING PROCESS DIFFICULTY

First-level indicators	Second-level indicators
Component character	Fabric and accessory
	Cuttings shape
Production configuration	Equipment
	Delivery tool, template, et
	Technologic content
Staff	Staff training
	Proficiency
	Employee effort
	Multi-skilled worker
	Salary system
Management	Professional management team
	Good collaboration in the department
Environment	Stability of production conditions
	Flexibility of production line
	Production environment

Questionnaire investigation and weights of expert to indicators

A questionnaire-based survey methodology has been adopted. In the questionnaire, every indicator was classified and assigned score of 0 to 5, with 5 being the highest effect on standard time and 0 meaning no effect. In order to make the pairwise comparison, every expert is asked to select one of two elements according to a nine-point scale that indicates the degree to which one element is more important, preferred, or dominant. We make sure that each expert should provide pairwise comparisons preference information on the entire set of objects. The analytical hierarchy process (AHP) was used in this study to determine the weight coefficients of each expert to indicators. The analytic hierarchy process is the most popular multi criteria decision-making method that quantitatively measures the expert's opinion in the form of weights. The AHP initially involves a pair-wise comparison matrix wherein the relative dominance of each factor (or sub-factor) is compared with respect to the common variable. The consistency of derived weights (eigenvectors) is checked by calculating the consistency ratio (CR). A preference vector (w_{i1}, w_{i2}, …, w_{i15}) will be generated for each expert (W_1, W_2, …, W_m).

Weight of each expert

We can identify any group members "i" and "j" who share agreement by using the cosine method: finding the cosine of the angle between their corresponding weight vector W_i and W_j. We define this agreement indicator as:

$$cos\, a_{ij} = \frac{W_i W_j}{||W_i|| \times ||W_j||} \tag{1}$$

where $W_i W_j$ is the dot product of the two vectors, and $||W_i||$, $||W_j||$ are the 2-norms of W_i, W_j, respectively. If W_i and W_j are fairly similar, then $cos\, a_{ij}$ will be fairly close to 1. If the two vectors are very dissimilar (i.e., almost orthogonal), then $cos\, a_{ij}$ will be close to 0. If we specify threshold values a (for strong agreement) and b (for strong disagreement), then group members "i" and "j" will be said to have strong agreement if $cos\, a_{ij} > a$, and strong disagreement if $cos\, a_{ij} < b$. A possible value for a is 0.67, and a possible value for b is 0.33. Hence, the group strong agreement quotient (GSAQ) value may thus be computed as follows:

$$GSAQ = \frac{\sum_{i \in T} \sum_{i<j} 2\eta(i,j)}{m(m-1)} \tag{2}$$

where $\eta(i,j) = 1$ if $cos\, a_{ij} > a$, and $\eta(i,j) = 0$ if $cos\, a_{ij} < a$, "T" is the index set for the group members, and "m" is the number of members in the group. Similarly, the group strong disagreement quotient (GSDQ) is computed as follows:

$$GSDQ = \frac{\sum_{i \in T} \sum_{i<j} 2\gamma(i,j)}{m(m-1)} \tag{3}$$

where $\gamma(i,j) = 1$ if $cos\, a_{ij} < b$, and $\gamma(i,j) = 0$ if $cos\, a_{ij} > b$. The individual consensus indicators may be calculated as follows:

$$ISAQ_i = \frac{\sum_{(i \in T,\, i \neq j)} \eta(i,j)}{m-1} \tag{4}$$

$$ISDQ_i = \frac{\sum_{(i \in T,\, i \neq j)} \gamma(i,j)}{m-1} \tag{5}$$

To sum up, the weight coefficients of each expert is obtained:

$$\lambda_i^* = \frac{ISAQ_i(1 - ISDQ_i)}{GSAQ(1 - GSDQ)} \quad (6)$$

Normalize the weight of experts, and the normalization formula is:

$$\lambda_i = \frac{\lambda_i^*}{\sqrt{\sum_{i=1}^{m} \lambda_i^{*2}}} \quad (7)$$

Calculation of difficulty coefficient

In group decision-making, how to attribute the preferences of each group member to the preferences of the group, and then construct the utility function of the group, is the key problem of group decision-making method based on the utility function. The group utility function is introduced to calculate the difficulty coefficient. The general form of the group utility function is:

$$U(x) = \sum_{i=1}^{m} \lambda_i U_i(x) \quad (8)$$

$U_i(x)$ (i = 1,2,…,m) represents the individual utility function of the ith evaluator in the group, λ_i is the weight of $U_i(x)$. Based on group utility function addition model, the difficulty coefficient is:

$$\text{difficulty coefficient} = \sum_{i=1}^{m} [\lambda_i \sum_{j=1}^{n} (w_{ij} x_{ij})] \quad (9)$$

"n" is the number of evaluation indicators, x_{ij} represents the ith (i = 1,2,…,m) expert's score to the jth (j = 1,2,…,n) secondary indexes.

Curve fitting of the difficulty coefficient and standard time

Curve fitting is the process of constructing a curve or mathematical function that has the best fit to a series of data points, possibly subject to constraints. Curve fitting can involve either interpolation, where an exact fit to the data is required, or smoothing, in which a "smooth" function is constructed that approximately fits the data. Fitted curves can be used as an aid for data visualization, to infer values of a function where no data are available, and to summarize the relationships among two or more variables. MATLAB (matrix laboratory) is a multi-paradigm numerical computing environment and fourth-generation programming language. In this paper, MATLAB curve fitting toolbox is used to establish the regression function between sewing process difficulty coefficient (independent variables or predictors) $U = [A_1, A_2, A_3, \ldots, A_m]$ and standard time (dependent variable) $T = [B_1, B_2, B_3, \ldots, B_m]$. The regression function between the two variables can be determined by the following steps:

1. Input data in MATLAB:

   >> $U = [A_1, A_2, A_3, \ldots, A_m]$

   >> $T = [B_1, B_2, B_3, \ldots, B_m]$

2. Enters the fitting window to fit the curve and select the best fitting curve.
3. Determines the regression function between sewing process difficulty coefficient and standard time.

Case study

ZS is a privately held family-owned clothing company based in China. The company was founded in 1989 and has 4 brands. The company has accumulated a lot of sewing process standard time data in many years of production. Take the linen dress produced by ZS company as an example, the assembly line has 25 people in total, and the order quantity is 820 pieces. We selected 13 sewing processes in the production of linen dress. The sewing process information and standard time are shown in table 2.

Table 2

PROCESS INFORMATION OF LINEN DRESS

Sewing process	Standard time (second)
Sewing darts	79
Joining shoulder seam	101
Top-stitching under collar	42
Joining under the collar and top collar	75
Sewing collar on and down	48
Joining sleeve seam	67
Setting in sleeve	64
Joining centre back seam	59
Stitching waistband and lining	66
Joining side seam	54
Attaching sleeve tab	Unknown
Attaching pocket to the garment	22
Attaching zipper	120

Based on the Influence factors of sewing standard time shown in table 1, five experts who have been a wide experience of 10 to 25 years in sewing processing are selected to fill in the questionnaire. According to equations 2 and 3, the group strong agreement quotient (GSAQ) and the group strong disagreement quotient (GSDQ) are calculated, and GSAQ = 0.751 > 0.67, which demonstrate that the group opinions of the experts are consistent, and the survey data can be used. Firstly, the survey data were standardized to get the evaluation value of each indicator, shown in table 3, the standardized value calculation formula is:

$$x_i' = (x_i - x_{min}) / (x_{max} - x_{min}) \quad (10)$$

where, x_i is the ith item in the sequence of scores; x_{min} is the minimum value of the sequence; and x_{max} is the maximum value of the sequence. Then using the AHP method to construct pairwise comparison matrices for each response among all the components in the extent of the hierarchy system, and obtain 5 groups of sorting vectors through single-level sorting, general level sorting and consistency detection, shown in table 4.

According to equations 4–7, calculate the individual strong agreement quotient, the individual strong disagreement quotient, weight of experts λ_i^* and standard weight of experts λ_i, as shown in table 5.

Table 3

STANDARDIZED SCORES OF SUB-FACTORS FOR EACH EXPERT					
i = 1,2,3,4,5	$X_{i=1}$	$X_{i=2}$	$X_{i=3}$	$X_{i=4}$	$X_{i=5}$
x_{i1}	0.67	1.00	0.67	0.67	1.00
x_{i2}	1.00	1.00	1.00	0.67	1.00
x_{i3}	0.67	1.00	0.67	0.67	0.67
x_{i4}	0.33	0.67	0.33	0.67	1.00
x_{i5}	1.00	0.67	0.33	0.67	0.33
x_{i6}	0.33	0.67	0.67	1.00	0.33
x_{i7}	0.67	1.00	0.67	0.33	0.33
x_{i8}	0.00	0.33	0.67	0.33	0.33
x_{i9}	0.33	0.67	0.33	0.67	0.67
x_{i10}	0.33	0.33	0.67	0.67	1.00
x_{i11}	0.67	1.00	0.67	0.67	1.00
x_{i12}	0.33	0.67	0.67	0.33	0.67
x_{i13}	0.33	0.33	0.67	0.33	0.33
x_{i14}	0.33	0.33	1.00	0.67	0.67
x_{i15}	0.33	0.67	0.00	0.67	0.67

Table 4

WEIGHTS OF SUB-FACTORS FOR EACH EXPERT					
i = 1,2,3,4,5	$W_{i=1}$	$W_{i=2}$	$W_{i=3}$	$W_{i=4}$	$W_{i=5}$
w_{i1}	0.076	0.082	0.078	0.078	0.090
w_{i2}	0.084	0.095	0.110	0.071	0.088
w_{i3}	0.053	0.073	0.076	0.069	0.064
w_{i4}	0.081	0.066	0.055	0.059	0.079
w_{i5}	0.101	0.077	0.052	0.066	0.050
w_{i6}	0.063	0.059	0.069	0.119	0.049
w_{i7}	0.047	0.090	0.071	0.047	0.047
w_{i8}	0.063	0.035	0.062	0.054	0.054
w_{i9}	0.078	0.059	0.049	0.079	0.067
w_{i10}	0.055	0.033	0.067	0.072	0.078
w_{i11}	0.087	0.080	0.068	0.066	0.084
w_{i12}	0.084	0.068	0.069	0.048	0.069
w_{i13}	0.043	0.057	0.056	0.043	0.056
w_{i14}	0.045	0.059	0.087	0.066	0.062
w_{i15}	0.047	0.076	0.038	0.073	0.068
CR	0.031	0.076	0.018	0.035	0.036

Table 5

WEIGHT OF EXPERT					
Index	**Expert**				
	1	**2**	**3**	**4**	**5**
$ISAQ_i$	0.565	0.637	0.603	0.897	0.732
$ISDQ_i$	0.108	0.093	0.111	0.057	0.078
GSAQ	0.751				
GSDQ	0.095				
λ_i^*	0.742	0.850	0.789	1.245	0.993
λ_i	0.167	0.192	0.178	0.281	0.224

Table 6

DIFFICULTY COEFFICIENT OF THE SEWING PROCESS		
Sewing process	**Standard time4 (seconds)**	**Difficulty coefficient**
Sewing darts	79	0.46
Joining shoulder seam	101	0.53
Top-stitching under collar	42	0.38
Joining under the collar and top collar	75	0.45
Sewing collar on and down	48	0.4
Joining sleeve seam	67	0.42
Setting in sleeve	64	0.41
Joining centre back seam	59	0.37
Stitching waistband and lining	66	0.42
Joining side seam	54	0.36
Attaching sleeve tab	unknown	0.37
Attaching pocket to the garment	22	0.27
Attaching zipper	120	0.59

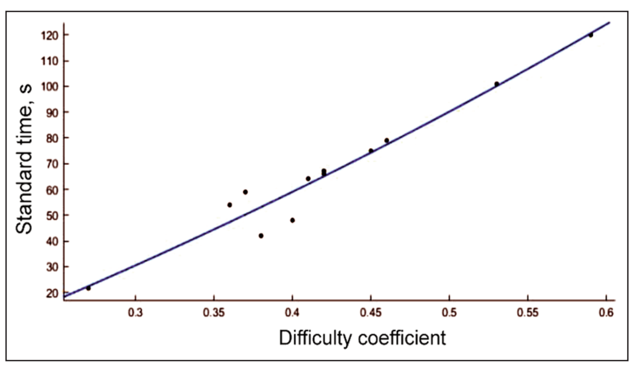

Fig. 1. The fitting curve of Exponential function

According to equation 9 calculate the difficulty coefficient, as shown in table 6. Based on MATLAB curve fitting toolbox and table 6 data, curve fitting is carried out with Exponential function (number of terms: 2), Gaussian function (number of terms: 1) and Polynomial function (degree: 2), the R-square are 0.9487, 0.9474 and 0.9464 respectively. It can be seen that the fitting effect of the Exponential function is the best for the standard time and difficulty coefficient of the sewing processes, shown in figure 1. The regression model for sewing process standard time and difficulty coefficient (x) as follows:

$$f(x) = -29120\, exp\,(0.4516x) + 29080\, exp\,(0.4593x) \quad (11)$$

The difficult coefficient of attaching the sleeve tab is 0.27. According to formula (11), the standard time of attaching the sleeve tab is 50.8 seconds. It can be seen from table 7 that the predicted standard time based on the process difficulty coefficient method is close to the actual standard time. Therefore, after establishing the functional relationship between standard time and sewing process difficulty coefficient, we only need to determine the unknown sewing process difficulty coefficient, and then we can predict the standard time conveniently and accurately.

Table 7

COMPARATIVE ANALYSIS OF FORECAST STANDARD TIME AND ACTUAL STANDARD TIME	
Method	**Seconds**
Actual standard time	51.6
PTS method	49.9
A method based on process difficulty coefficient	50.8

CONCLUSIONS

The sewin process is crucial for garment production. To arrange the resources and make a production plan reasonably. It requires effective prediction of standard time at the beginning of the production; therefore, a model is proposed to predict the standard time of the garment sewing process in this study, which provides a valuable guideline and provides a useful reference for engineers and managers in the production process. Firstly, 15 influencing factors related to the standard time of sewing are identified by using the literature review. Then, analysed with analytic hierarchy process (AHP), obtained the weight of each index, and made group utility function to calculate the difficulty coefficient. Finally, the MATLAB curve fitting toolbox is used to establish the regression function between the sewing process difficulty coefficient and standard time. An example is used to demonstrate the efficiency of the proposed approach.

The predictive model can effectively forecast the standard time of different sewing processes according to their difficulty coefficient. The proposed regression model with a very limited calculation time is very easy to use in the estimation of standard time for any garment production department of a company. The companies that do not know the exact sewing standard time of their products due to measurement difficulties can easily obtain these time values with the benefits of lower cost, shorter time, and higher accuracy for use in production planning.

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