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Construction of adjusting coefficients for sewing time of GSD system for knit products in Vietnam

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Abstract: The article presents the results of determining the adjustment coefficient between the actual values and theoretically calculated values according to both the MTM method and GSD predetermined time standard system of sewing time on the machine, and preparation time when sewing Polo-Shirt and T-Shirt from Single Jersey fabric. The study was conducted at Fashion Star Limited Company (Ha Noi) and Hanosimex Single Share-Holder Limited Company (Ha Nam). The simultaneous influence of stitch length (cm) and stitch density (stitch/cm) on sewing time was studied for the Polo-Shirt and T-Shirt products. The research was done on 4 kinds of machine, including single needle lockstitch machine, overlocking machine (1 needle and 3 threads), sewing machine (2 needles and 4 threads), and hemming machine (2 needles and 3 threads); and 3 kinds of single jersey fabrics, which are thin, medium, and thick fabrics. Besides, simultaneous influences of two factors, the size of the shirt and distance of semi-finished products (cm) to the sewing machines, on the sewing time were investigated. Experiment results were analzyed and processed using Design Expert 11.0. The results were used to construct the experimental regression equations, which showed correlations between the research factors,which are sizes and distances, and sewing time or preparation time. The optimal values of sizes and distances were determined to achieve the goal of minimizing preparation time. The adjustment coefficients between the theoretical calculation according to both MTM method and the GSD system and the practical results were identified. In addition, the formulae to calculate sewing time based on stitch density and stitch length values for 4 types of sewing machines and single jersey fabric with 3 thickness were built using orthogonal experimental planning method and multivariate optimization.

Keywords: Motion study; time study GSD; MTM; polo-shirt; T-shirt; sewing time, preparation time

1 Introduction

According to the statistical figures, Vietnam's garment exports were projected as 3.08 billion USD in December 2020, going up 9.74 percent from November 2020 but down 13.40 percent from December 2019. Overall, Vietnam's garment export turnover is expected to be 35.29 billion USD in 2020, down 10.91 percent from 2019. Although Vietnam's textile and garment export turnover fell sharply in 2020 compared to 2019, the export result was still optimistic and far lower than the forecast 15 percent drop in June 2020. Due to the global outbreak of the COVID-19, Vietnam's textile exports are facing multiple difficulties and obstacles in 2021. However, with the contributions of companies, as well as the participation of the government and management agencies in encouraging exports, mitigating chaos, and promoting the industry's advantages, expertsanticipatethat Vietnamese textile industry would be promising[1]. The sewing operation is still not fully effective; there are several unnecessary processes that can be cut off to streamline it. Additionally, the sewing time for a particular product has not been correctly calculatedand thus sabotages the productivity. As a result, identifying the factors that influence operative time to adjust has become a major industrial target. Moreover, having a time calculatingsystem that is compatible with Vietnamese workers is a pressing need for optimize the sewing processes.

Laboringmovementscan be generally divided into operations, motions, and activities [2]. Operation is a generic term, made up of human movements on an item to modify its original structure to produce a complete product.A collection of workers' tasks aimed at achieving a certain technological goal. It includes main operations and sub-operations. The major operations affect the work object's physical, chemical, form, size, or spatial position to acquire the technical process's goal. Sub-operations are operations that just provide the necessary conditions for the major operation to be carried out. Operations are thensplit into motions. A motion is represented by a worker's limbs and body activities in order to remove or move something. Activities are parts of a motion represented by a one-time change in the position of the worker's body.Thus, the activity is the smallest human action that cannot be subdivided further and is carried out in a continuous, non-directional way. All human actions are made up of the same fundamental activities. According to the findings, there are 21 fundamental activities in total, comprising 9 finger activities, 10 body movements, and two visional actions [3].

The MTM work measurement system has been studied and developed in the United States since 1948 based on a scientific study of the worker's labor process [4]. It has been studied and developed built onstandard timetables for entire human body movements during laboring process, taking into account the circumstances, and is applied to construct time standards for work at different levels. In the MTM method, time units (TMU's) are used. TMU is specified as 36 $\times 10^{-3}$ seconds or 6×10^{-4} minute or 10^{-5} hours. The GSD (General Sewing Data) Pre Determined Time Standard System was first released in 1978 by GSD Limited corporate and was specially developed for the textile industry in 1976 using MTM core data. And the systemhas beenused topredetermine the standardized time. Besides, it provides a number of methods for analyzing sewing operations as well as time analysis ingarment manufacturing, including cutting, decorating, sewing, quality checking, and packaging. In the GSD system, the time consumption includes the preparation time (tp) and the sewing time (tm). The GSD method has developed a formulaetomeasure sewing time that shows the influence between stitch length (cm), stitch density (stitches/cm), maximum machine speed (sti/min), sewing speed, the degree of seam complexity, the level of accuracy required, the preparation time, and the stopping time. In order to determine the preparation time and the sewing time, the operations are analyzed into motions, each of which is shown by a code. Each code has its own time value, expressed in Time Measurement Units (TMU’s). This allows us to quickly calculate the sewing operation time. In theory, human motions are normally independent, and the time taken by each particular motion is dictated by the its nature and acertain scenario [4].

In the garment industry, the sewing time only accounts for around 20-30% of the product completing time, while the rest (70-80%) is spent for the preparation. The key of the GSD system is to precisely decideall the movements related to clothing manufacturing. It has been used to standardize processes, eliminate unnecessary operations and idle time in the manufacturing course, thus boost worker productivity. It is an easy-to-use application, providing quick calculation, and can be modified with computer software. However, besides its benefits, the GSD system has some drawbacks, providing the pre-determined time values for laboring movements but ignoring the real impact of factors such as materials, machinery, and the sizes ofsemi-finished products (or size of the items), and placement gaps (cm). As a result, the needed time is always longer than the theoretically calculated ones. In addition, the GSD system is not fully correct for a variety of product types and complex materials like knitted fabrics. Therefore, there have been a couple of researches on this issue. Mst. Murshida Khatun [5] performed a survey on the main operating time and the operation time to do auxiliary jobs in order to enhance the activity and determine the technological coefficients to find the standard time. The time spent on performing auxiliary jobs including tasks like setting up machines, preparing, shifting semi-finished items, changing threads, and so on. It is important to increase labor productivity by determining the correct standard time and analyzing the sewing movements. Authors D.M.Huong and P.T. Thao investigate the impacts of the factors of semi-finished product distance and size on the auxiliary operations for knitted items [6-9]. V.T.Nhu and P.T. Thao offered possible solutions to improve sewing movements and the working speed of employees [10]. Authors P.T. Thao and L.T. Trang recommended standard sewing procedures and sewing time for knitted product assemblies in Phuong Nam Garment Trading Import – Export Joint Stock Company, Thanh Cong Textile Garment Investment Trading Joint Stock Company, Fashion Vina Produce Trading Co., Ltd [11].Furthermore, authors P.T. Thao, N.Q. Thoai, T.V. Tung, T. T. Yen have achieved significant results in reducing the sewing time of knitted fabrics by studying and analyzing the sewing process [12-15].

Herein, the authors investigated the effects of stitch length (cm) and stitch density (sit/cm) on Polo-Shirt sewing time and T- Shirt sewing time on 4 sewing machines, single needle lockstitch machine, overlocking machine (1 needle and 3 threads), overlocking machine (2needles and 4 threads), hemming machine (2 needles and 3 threads); and on 3 kinds of Single Jersey's thickness (thin, medium, and thick fabrics). Moreover, the two-factor impacts of the scale and distance of semifinished product placement (cm) on the preparation time of basic Polo-Shirt and basic T-shirt items were also explored. From the results of building an empirical regression equation, itsuggested the influential rules of the research factors on the sewing time on the machine and the preparation time. We determined the optimal value of the factors in order to reduce sewing time. In addition, we have determined the time value adjustment coefficients between the theoretical calculation by the MTM method and the GSD system with the experimental research results. We also created a data set for sewing time values on 4 machines,single needle lockstitch machine, overlocking machine (1 needle and 3 threads), overlocking machine (2needles and 4 threads), hemming machine (2 needles and 3 threads) corresponding to particular values of two variables, stitch density and stitch duration for three different thicknesses of single jersey fabric at Fashion Star Limited Company (Ha Noi) and Hanosimex Single Share-Holder Limited Company (Ha Nam).

2. Experimental

2.1. Knit products

Polo-Shirt: collar bands, buttons, deviatedplacket, hem and cuffs sewn in two parallel sections by the hemming machine. Figure 1 (a) depicts the final product.

T-Shirt: short-sleeved, hem and cuffs quilted in two parallel stitches, and collar. Figure 1 (b) depicts the final product.

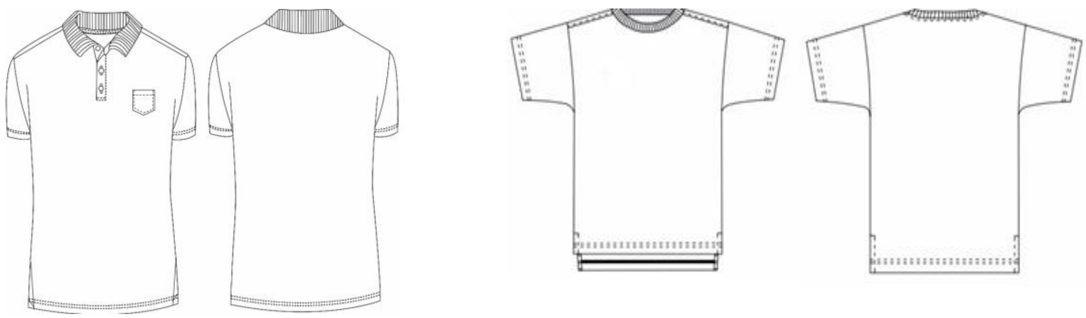


Figure 1. (a) Polo-Shirtand (b) T-Shirt

2.2. Sewing Time

According to MTM method and GSD system (1), The sewing completion time is determined by a formula:

$$\mathbf{t} = \boldsymbol{t_m} + \boldsymbol{t_p} \qquad (1)$$

t_m :sewing time on machine, t_p:preparation time.

The formula used to measure the theoretical sewing time on a sewing machine.

$$\boldsymbol{t_m} = \frac{\boldsymbol{l} \times \boldsymbol{m}}{\boldsymbol{n} \times \mathbf{0.0006}} \text{ x } \boldsymbol{h_n} \text{ x } \boldsymbol{h_c} + \alpha + 17 \qquad (2)$$

l: stitch length (cm)

m: stitch density (stitches/cm)

n: machine speed (rpm per minute)

0.0006: conversion between minute and TMU, 1 minute = 1667 TMU

h_n: speed factor (the coefficient denotes the machine speed, corresponding to the machine speed range)

h_c: level of difficulty

α: time adjustment

17 TMU: time for start and stop a machine

To research the influence of stitch length and density on sewing time. Two variables were changed, seam length (cm) and stitch density (stitches/cm) while maintainingother factors.Preparation time (t_p) was divided into 7 distinct categories, containing 39 codes, according to the MTM process and GSD system as follows [4].

+ Get and Put data: G or P,

+ Obtaining and Matching: M,

+ Aligning and adjusting: A,

+ Forming shapes: F,

+ Trimming and tool use: T,

+ Asiding: A

+ Handling machine: M.

Furthermore, 14 codes that represent 5 distinct categories with the highest repetition level in the technological process that produce Polo-Shirts and T-Shirts were selected, Table 1a.

Table 1a: List of categories of preparation activities and codes [4]

No.	Categories	Code	TMU	Code	TMU	Code	TMU	Code	TMU
1	Obtaining and Matching	MG2S	107	FOOT	38	MAP2	69	MAPE	50
2	Aligning and adjusting	AM2P	6	ARPN	75	APSH	24		
3	Forming shapes	FFLD	43	FCRS	28				
4	Asiding	AS2	42						

		H							
5	Get and Put data	GP1H	20	GP2H	33	PPAL	10	PPST	14

The authors used the interpolation approach to calculate and determine the code that has not yet been tested as follows.

Table 1b: List of categories of preparation activities and codesthat have not yet been tested

No.	Categories	Code	TMU	Code	TMU	Code	TMU	Code	TMU
1	Obtaining and Matching	MG2T	76	MAP1	56				
2	Aligning and adjusting	AJPT	43	ARPN	75				
3	Forming shapes	FUNF	23						
4	Asiding	AS1H	23						
5	Get and Put data	GPCO	9	GPOH	6	GPAG	10	GP1E	14
		PPL1	27	PPL2	47	PPOH	6		

2.3. Materials

In the study, three different types of single Jersey knit fabrics' thickness were used, thin, medium, and thick fabrics, listed in Table 2.

Table 2. Fabric specifications

NO.	Fabric sample	Fabric specifications
V1	Thin fabric	Fabric structure: single jersey, yarn: 30/1, composition: 100% cotton, ends per centimeter: 170 loop course/10 cm, picks per centimeter: 160 loop wale/10cm, weight (GSM): 130g/m^2, thickness: 0.445 mm
V2	Medium fabric	Fabric structure: single jersey, yarn: 30/1, composition: 100% cotton, ends per centimeter: 220 loop course/10 cm, picks per centimeter: 160 loop wale/10cm, weight (GSM): 160g/m^2, thickness: 0.502 mm
V3	Thick fabric	Fabric structure: single jersey, yarn: 30/1, composition: 100% cotton, ends per centimeter: 250 loop course/10 cm, picks per centimeter: 280 loop wale/10cm, weight (GSM): 198g/m^2, thickness: 1.09 mm

2.4. Device

The study was done on various machines, one-needle flatbed sewing machine, overlocking machine (1needle and 3 threads), overlocking machine (2needles and 4 threads), and hemming machine.

Table 3: Specifications of sewing machines

NO.	Machine Tyle	Technical specifications
1	Single needle lockstitch machine	Name: DDL-5550N; max sewing speed: 5500stitch/min; max stitch length: 5mm; lift of the presser foot 13mm; needle: DBx1(#14), 134 (Nm90)
2	Overlocking machine (1 needle and 3 threads)	Name: MO-6704DA; max sewing speed: 7000stitch/min; stitch length: 0.8-4mm; overedging width (mm): 1.6, 3.2, 4.0, 4.8mm; needle: DCx27.
3	Overlocking machine (2 needles and 4 threads)	Name: MO-6804S; max sewing speed: 7000stitch/min; stitch length: 0.6-3.8mm (4.5mm); needle gauge (mm) 2.0,3.0, 5.0; overedging width (mm): 1.5, 4.0, 3.2, 4.0, 3.0, 5.0; bottom

		differential feed ratio: gathering 1:2 (max 1:4), stretching 1:0.7 (max 1:0.6); needle: DCx27
4	Hemming machine (2 needles and 3 threads)	Name: MF-7500/U11; max sewing speed: 6500stitch/min; needle gauge (mm): 3.2, 4.0, 4.8, 5.6, 6.4mm; stitch length: 1.2-3.6mm; needle: UY128 GAS (#10) #9S - #12S

2.5. Experimental methods

Experimental and optimization method: The author used multivariable orthogonal experimental planning method with a single goal by using Design Expert 6.0 software to design the experiment, process data, and build an empirical regression equation to study the simultaneous influence of 2 factors on sewing time on machine and preparation time. Then we solved the optimization problem to determine the value of two factors in order to minimize sewing time and preparation time when sewing Polo-Shirt and T-Shirt. Number of experiments $N= 2^k + n_0 +2k = 2^2 + 2 + 2x2$ (n_0=2), thus N=10 experiments. There are 4 basic experiments, 2 experiments at the center, and 4 experiments around the center. Each experiment was carried out three times [16]. The changes in the values of the study variables are determined on the basis of the actual production of Polo-Shirt and T-Shirt products. Tables 4.a and b show the ranges of variance for the factors.

Table 4.a: The range of variation (real variable and coded variable) of the two variables affects sewing time on machine.

Variable	**Corresponding value** (α =1.41)				
	-α	-1	0	+1	+α
X_1 - Size	S	M	L	XL	XXL
X_2 - Distance of semi-finished products (cm)	11	15	25	35	39

Table 4.b: The range of variation (real variable and coded variable) of the two variables affects preparation time

Variable	**Corresponding value** (α =1.41)				
	-α	-1	0	+1	+α
X'_1 – stitch density (Stitch Per Inch)	3.1	3.5	4.5	5.5	5.9
X'_2 – Seam length (cm)	8.9	15	30	45	51.2

- Experimental method for determining preparation time and sewing time on the machine.

Using the camera method to record images, time, and worker operating procedures. When sewing, use the stopwatch to determine the total time spent.

- Data processing method: Information will be obtained and analyzed using Excel 10 and Design Exper 6.0 software following the experimental phase.

- Determining the adjustment coefficient $K_{TN/LT}$between the actual value and the theoretically calculated value according to the MTM method and the GSD pre-determined time standard system. The $K_{TN/LT}$ adjustment coefficient is determined using the formula (3).Y_{TN} is sewing time on machine or preparation time (TMU) determined from experimental study. Y_{LT} is the sewing time on the machine or the preparation time (TMU) determined by the MTM method and the GSD system. The authors use the interpolation approach to validate codes that have not been checked. The average $K_{TN/LT}$coefficient of the class of the codes was calculated, then the Y_{TN} interpolated value of these codes according to the formulas4 and 5 was determined.

$$K_{TN/LT} = \frac{Y_{TN}}{Y_{LT}} \, (3); \overline{K}_{TN/LT} = \frac{1}{m}\sum_{j=1}^{m} K_j \;\; (4); Y_{TN} = \overline{K}_{TN/LT}.Y_{LT} \; (5)$$

The method of determining the data set of the sewing time valuesforvarious machines corresponding to the particular values of the variables wasbased on the empirical regression equations.The simultaneous influence of 2 factors (the stitches density and the seam length) on the sewing time using Design-Expert software was determined the value of the sewing time objective function on the machine (Y') when assigning a particular value to each level at the coding stages, as seen in Table 4.b.

3. Results and discussion

3.1 The impact of several parameters on preparation time

3.1.1 The survey results and the design of the empirical regression equation demonstrate the law of simultaneous influence of factors on the sewing preparation time of workers during the sewing process

By using filming and timekeeping with an experimental matrix of 10 ways with 14 codes of preparation procedures, the experimental findings decided the preparation time in the sewing phase of 2 test materials,shown in the tables 5, 7, 9, 11, 13, and 15.To analyze the outcomes of the experiments, the Design Expert 6.0 tools was used, the program created experimental regression equations. The law of two variables had parallel effects among the size of the sewing component (size), the size of the semi-finished product, and the preparation time. The general structure of a two-variable regression equation is like Y= $a_0 + a_1x_1 + a_2x_2$. Y is the preparation time, x_1 and $x_2$are the imaginary variable of the size of sewing parts (shirt size) and the distance to position the semi-finished piece, respectively. The coefficient of the regression equation for level 1 is $a_1$and a_o, $a_2$is the average value of the preparation time. The results of the empirical regression equations for 14 codes of preparation time are presented in Tables 6, 8, 10, 11, 14 and 16.

- Aligning and adjusting - A codes

Table 5: The preparation time for the active codes "aligning and adjusting"

NO.	Encrypted variable		Real variable		Y_{TN} (TMU)			
	x_1	x_2	X_1	X_2	AM2P	AJPT	ARPN	APSH
1	-1	-1	M	15	149.4	-	75.8	23.7
2	1	-1	XL	15	152.4	-	79.2	26.7
3	-1	+1	M	35	185.1	-	87.2	28.1
4	+1	+1	XL	35	189.2	-	89.4	31.4
5	-α	0	S	25	165.1	-	80.1	24.4
6	+α	0	XXL	25	173.2	-	85.4	25.1
7	0	-α	L	11	128.3	-	74.4	22.4
8	0	+α	L	39	200.1	-	95.8	35.8
9	0	0	L	25	169.1	-	82.1	26.1
10	0	0	L	25	169.2	-	82.1	26.1

Table 6: The results of building the empirical regression equation with the rule of simultaneous effects of 2 factors on the preparation time for the active code "aligning and adjusting".

Code	AM2P	ARPN	APSH
Y_{TN}	Y= 168.3+ $2.3x_1+21.8x_2 R^2$=0.96	Y= 8.1+ $1.6x_1+6.5x_2 R^2$=0.95	Y= 27+ $0.9x_1+3.5x_2 R^2$=0.7.4

- Obtaining and Matching - M codes

Table 7: The preparation time for the active codes "obtaining and matching"

NO.	Encrypted variable		Real variable		Y_{TN} (TMU)					
	x_1	x_2	X_1	X_2	MG2T	MG2S	FOOT	MAP1	MAP2	MAPE
1	-1	-1	M	15	-	125.1	38.6	-	85.2	60.1
2	1	-1	XL	15	-	135.1	52.4	-	87.2	63.4
3	-1	+1	M	35	-	183.2	43.6	-	102.8	77.9
4	+	+1	XL	35	-	193.2	58.1	-	110.1	80.1
5	-α	0	S	25	-	175.1	48.1	-	90.2	65.1
6	+α	0	XXL	25	-	180.1	57.1	-	98.1	71.1
7	0	-α	L	11	-	120.4	32.4	-	79.4	53.1
8	0	+α	L	39	-	203.4	65.1	-	120.1	86.3
9	0	0	L	25	-	178.1	50.2	-	95.1	68.2
10	0	0	L	25	-	178.1	50.2	-	95.2	68.3

Table 8: The results of building the empirical regression equation with the rule of simultaneous effects of 2 factors on the preparation time for the active code "obtaining and matching"

Code	MG2S	FOOT	MAP2	MAPE
Y_{TN}	$Y= 165.8+3.4\ x_1+629.2\ x_2$ $R^2= 0.95$	$Y= 49.3+ 5.1x_1+7.1x_2$ $R^2= 0.75$	$Y= 96.3+ 5.6x_1+12.3\ x_2$ $R^2= 0.94$	$Y= 69.5+ 1.7x_1+10.2x_2$ $R^2= 0.97$

- Forming shapes - Fcodes

Table 9: The preparation time for the active codes "forming shapes"

NO.	Encrypted variable		Real variable		Y_{TN} (TMU)		
	x_1	x_2	X_1	X_2	FFLD	FCRS	FUNF

1	-1	-1	M	15	116.6	31.1	-
2	1	-1	XL	15	120.1	31.8	-
3	-1	+1	M	35	140.1	46.8	-
4	+	+1	XL	35	146.8	48.1	-
5	-α	0	S	25	130.2	36.8	-
6	+α	0	XXL	25	137.1	40.1	-
7	0	-α	L	11	111.4	30.6	-
8	0	+α	L	39	160.1	56.4	-
9	0	0	L	25	133.4	38.2	-
10	0	0	L	25	133.5	38.2	-

Table 10: The results of building the empirical regression equation with the rule of simultaneous effects of 2 factors on the preparation time for the active code "forming shapes"

Code	**FFLD**	**FCRS**
Y_{TN}	$Y= 132.5+ 2.6x_1+15.0x_2$ $R^2= 0.97$	$Y=39.8 + 0.83 x_1+8.6x_2$ $R^2= 0.93$

- Get codes -G:

Table 11: The preparation time for the active codes "get"

NO.	**Encrypted variable**		**Real variable**		**Y_{TN} (TMU)**					
	x_1	x_2	X_1	X_2	GP1E	GP1H	GP2H	GPCO	GPOH	GPAG
1	-1	-1	M	15	-	21.6	34.1	-	-	-
2	1	-1	XL	15	-	22.1	35.2	-	-	-
3	-1	+1	M	35	-	26.4	39.1	-	-	-
4	+	+1	XL	35	-	27.1	40.1	-	-	-
5	-α	0	S	25	-	23.1	36.4	-	-	-
6	+α	0	XXL	25	-	25.2	38.3	-	-	-

7	0	-α	L	11	-	19.4	31.7	-	-	-
8	0	+α	L	39	-	30.2	43.1	-	-	-
9	0	0	L	25	-	24.2	37.6	-	-	-
10	0	0	L	25	-	24.3	37.5	-	-	-

Table 12: The results of building the empirical regression equation with the rule of simultaneous effects of 2 factors on the preparation time for the active code "get"

Code	**GP1H**	**GP2H**
Y_{TN}	$Y= 24.35+ 0.5x_1+3.1x_2.\ R^2= 0.94$	$Y= 37.2+ 0.6\ x_1+3.3x_2.\ R^2= 0.94$

- Put codes - P:

Table 13: The preparation time for the active codes "put"

NO.	**Encrypted variable**		**Real variable**		**Y_{TN} (TMU)**				
	x_1	x_2	X_1	X_2	PPAL	PPOH	PPST	PPL1	PPL2
1	-1	-1	M	15	9.7	-	13.6	-	-
2	1	-1	XL	15	10.2	-	13.5	-	-
3	-1	1	M	35	16.7	-	16.5	-	-
4	+	1	XL	35	17.7	-	16.4	-	-
5	-α	0	S	25	14.6	-	14.3	-	-
6	+α	0	XXL	25	16.2	-	14.4	-	-
7	0	-α	L	11	9.1	-	11.1	-	-
8	0	+α	L	39	18.2	-	17.2	-	-
9	0	0	L	25	15.3	-	14.7	-	-
10	0	0	L	25	15.2	-	14.8	-	-

Table 14: The results of building the empirical regression equation with the rule of simultaneous effects of 2 factors on the preparation time for the active code "put"

Mã code	**PPAL**	**PPST**
Y_{TN}	$Y= 14.2+ 0.5x_1+3.4x_2$ $R^2= 0.96$	$Y= 14.7-0.01x_1+1.8x_2$ $R^2= 0.95$

- Asiding- A codes

Table 15: The preparation time for the active codes "asiding"

NO.	**Encrypted variable**		**Real variable**		**Y_{TN} (TMU)**	
	x_1	x_2	X_1	X_2	AS2H	AS1H
1	-1	-1	M	15	53.6	-
2	1	-1	XL	15	53.8	-
3	-1	1	M	35	56.4	-
4	1	1	XL	35	56.8	-
5	-1.41	0	S	25	54.8	-
6	1.41	0	XXL	25	55.4	-
7	0	-1.41	L	11	50.4	-
8	0	1.41	L	39	66.1	-
9	0	0	L	25	55.2	-
10	0	0	L	25	55.1	-

Table 16: The results of building the empirical regression equation with the rule of simultaneous effects of 2 factors on the preparation time for the active code "asiding"

Code	**AS2H**
Y_{TN}	$Y= 55.7+0.2x_1+3.5x_2$ $R^2= 0.7$

The relationamong the Y_{TN}, x_1 and x_2 is represented by the R_2 coefficient. R value varies from 0.7 to 0.97, whichdemonstrates a strong connection between the experimental and theoretical models.As a result, it can ensure the preparation time (MG2S, FOOT, MAP2, MAPE, AM2P, ARPN, APSH, FFLD, FCRS, AS2H, GP1H, GP2H, PPAL, PPST) and x_1, x_2 have a strong relationship.The general structure of a two-variable regression equation is $Y= a_0 +a_1x_1 +a_2x_2$. Considering the coefficients of the regression equation lever 1 a_1, a_2, the absolute value of the coefficient a_2 is larger than a_1, $|a_1| <|a_2|$. Therefore, it can be deduced that x_2 or the distance has the most impact on the preparation time Y.

3.1.2. The results of determining the optimal value of the factors to ensure that the preparation sewing time of workers in the process of sewing is minimal

The optimization problem was solved using the Design Expert 6.0 program, based on the analytical regression equation, the impact law of two variables, namely the size of the sewing part and the distance of the sewing part so that thepreparation time Y_{TN} was min. Then, using formula number (2) for 14 codes (MG2S, FOOT, MAP2, MAPE, AM2P, ARPN, APSH, FFLD, FCRS, AS2H, GP1H, GP2H, PPAL, PPST) to determine the adjusted coefficients between the experimental values and the theoretical calculation time values on the preparation time ($K_{TN/LT}$). For the codes that has not been tested, the authors used the interpolation method to determine the coefficient K by formula number (3) and Y_{TN} by formula number (4). Tables 17, 18, 19, 20, 21 and 22 show the results of the calculations.

Table 17: The results of calculating the adjustment coefficient between real-time and the theoretical calculation time for "aligning and adjusting"

	Code AM2P				**Code ARPN**				**Code APSH**				$\bar{K}_{TN/LT}$	**Code AJPT**
x_1	x_2	Y_{TN}	Y_{LT}	$K_{TN/LT}$	x_2	Y_{TN}	Y_{LT}	$K_{TN/LT}$	x_2	Y_{TN}	Y_{LT}	$K_{TN/LT}$	$\mathbf{K_{TN/LT}}$	$\mathbf{Y_{TN}}$
S	15.0	134.3	61.0	2.2	15.1	74.4	75.0	1.0	15.1	64.2	24.0	2.7	**2.0**	**84.1**
M	15.0	135.3	61.0	2.2	15.1	75.1	75.0	1.0	15.1	64.6	24.0	2.7	**2.0**	**84.7**
L	15.0	137.6	61.0	2.3	15.1	76.7	75.0	1.0	15.1	65.5	24.0	2.7	**2.0**	**86.1**
XL	15.0	139.9	61.0	2.3	15.1	78.3	75.0	1.0	15.1	66.4	24.0	2.8	**2.0**	**87.5**

XXL	15.0	134.3	61.0	2.2	15.1	74.4	75.0	1.0	15.1	64.2	24.0	2.7	**2.0**	**84.1**

Table 18: The results of calculating the adjustment coefficient between real-time and the theoretical calculation time for "obtaining and matching"

	Code MG2S				**Code FOOT**			
x_1	x_2	Y_{TN}	Y_{LT}	$K_{TN/LT}$	x_2	Y_{TN}	Y_{LT}	$K_{TN/LT}$
S	15.0	131.8	107.0	1.2	15.0	35.0	38.0	0.9
M	15.0	133.2	107.0	1.2	15.0	37.1	38.0	1.0
L	15.0	136.6	107.0	1.3	15.0	42.2	38.0	1.1
XL	15.0	140.0	107.0	1.3	15.0	47.3	38.0	1.2
XXL	15.0	131.8	107.0	1.2	15.0	35.0	38.0	0.9

	Code MAP2				**Code MAPE**			
x_1	x_2	Y_{TN}	Y_{LT}	$K_{TN/LT}$	x_2	Y_{TN}	Y_{LT}	$K_{TN/LT}$
S	15.0	76.1	69.0	1.1	15.0	56.9	50.0	1.1
M	15.0	78.4	69.0	1.1	15.0	57.6	50.0	1.2
L	15.0	84.0	69.0	1.2	15.0	59.3	50.0	1.2
XL	15.0	89.6	69.0	1.3	15.0	61.0	50.0	1.2
XXL	15.0	76.1	69.0	1.1	15.0	56.9	50.0	1.1

Table 19: The results of calculating the adjustment coefficient between real-time and the theoretical calculation time for "aligning and adjusting"

	Code FFLD				**Code FCRS**				$\bar{K}_{TN/LT}$	**Code FUNF**
x_1	x_2	Y_{TN}	Y_{LT}	$K_{TN/LT}$	x_2	Y_{TN}	Y_{LT}	$K_{TN/LT}$	$\mathbf{K_{TN/LT}}$	$\mathbf{Y_{TN}}$

S	15.0	113.8	43.0	2.6	15.2	30.2	28.0	1.1	**1.9**	**42.8**
M	15.0	114.9	43.0	2.7	15.2	30.5	28.0	1.1	**1.9**	**43.3**
L	15.0	117.5	43.0	2.7	15.2	31.4	28.0	1.1	**1.9**	**44.3**
XL	15.0	120.1	43.0	2.8	15.2	32.2	28.0	1.2	**2.0**	**45.3**
XXL	15.0	113.8	43.0	2.6	15.2	30.2	28.0	1.1	**1.9**	**42.8**

Table 20: The results of calculating the adjustment coefficient between real-time and the theoretical calculation time for "get data"

	Code GP1H				**Code GP2H**				$\overline{K}_{TN/LT}$	**Code GP1E**	**Code GPCO**	**Code GPOH**	**Code GPAG**
x_1	x_2	Y_{TN}	$K_{TN/LT}$	$K_{TN/LT}$	x_2	Y_{TN}	Y_{LT}	$K_{TN/LT}$	$\mathbf{K_{TN//LT}}$	$\mathbf{Y_{TN}}$	$\mathbf{Y_{TN}}$	$\mathbf{Y_{TN}}$	$\mathbf{Y_{TN}}$
S	15.0	20.5	20.0	1.0	15.0	33.1	33.0	1.0	**1.0**	**14.2**	**9.1**	**6.1**	**10.1**
M	15.0	20.8	20.0	1.0	15.0	33.3	33.0	1.0	**1.0**	**14.3**	**9.2**	**6.1**	**10.2**
L	15.0	21.3	20.0	1.1	15.0	33.9	33.0	1.0	**1.0**	**14.6**	**9.4**	**6.3**	**10.4**
XL	15.0	21.8	20.0	1.1	15.0	34.5	33.0	1.0	**1.1**	**14.9**	**9.6**	**6.4**	**10.7**
XXL	15.0	20.5	20.0	1.0	15.0	33.1	33.0	1.0	**1.0**	**14.2**	**9.1**	**6.1**	**10.1**

Table 21: The results of calculating the adjustment coefficient between real-time and the theoretical calculation time for "put data"

	Code PPAL				**Code PPST**				$\overline{K}_{TN/LT}$	**Code PPL 1**	**Code PPL 2**	**Code PPO H**
x_1	x_2	Y_{TN}	$K_{TN/LT}$	$K_{TN/LT}$	x_2	Y_{TN}	Y_{LT}	$K_{TN/LT}$	$\mathbf{K_{TN//LT}}$	$\mathbf{Y_{TN}}$	$\mathbf{Y_{TN}}$	$\mathbf{Y_{TN}}$
S	15.0	10.1	10.0	1.0	15.0	12.9	14.0	0.9	**1.0**	**26.1**	**45.4**	**5.8**
M	15.	10.	10.0	1.0	15.	12.	14.	0.9	**1.0**	**26.4**	**45.9**	**5.9**

	0	3			0	9	0					
L	15.0	10.8	10.0	1.1	15.0	12.9	14.0	0.9	**1.0**	**27.0**	**47.0**	**6.0**
XL	15.0	11.3	10.0	1.1	15.0	12.9	14.0	0.9	**1.0**	**27.7**	**48.2**	**6.2**
XXL	15.0	10.1	10.0	1.0	15.0	12.9	14.0	0.9	**1.0**	**26.1**	**45.4**	**5.8**

Table 22: The results of calculating the adjustment coefficient between real-time and the theoretical calculation time for "asiding"

	Code AS2H				$\overline{K}_{TN/LT}$	**Code AS1H**
x_1	x_2	Y_{TN}	$K_{TN/LT}$	$K_{TN/LT}$	$K_{TN//LT}$	Y_{TN}
S	15.0	51.9	42.0	1.2	**1.2**	**28.4**
M	15.0	52.0	42.0	1.2	**1.2**	**28.5**
L	15.0	52.2	42.0	1.2	**1.2**	**28.6**
XL	15.0	52.4	42.0	1.2	**1.2**	**28.7**
XXL	15.0	51.9	42.0	1.2	**1.2**	**28.4**

From the resultant table, we could determine the optimum values of factors x_1 and x_2 to ensure that the preparation time minimal,while finding sets of numbers related to the stitching distance, size of the product, and making sure the preparation time is always feasible. The real-time and the theoretical time are vastly different. Table 23 shows the adjusting coefficient of time values $K_{TN/LT}$ for the codes when sewing Polo-Shirt and T-Shirt items from single fabrics.

Table 23: The results of calculating the adjustment coefficient between real-time and the theoretical calculation time for preparation codes

Code	$K_{TN/LT}$	Code	$K_{TN/LT}$	Code	$K_{TN/LT}$	Code	$K_{TN/LT}$	Code	$K_{TN/LT}$	Code	$K_{TN/L}$

											T
AM2P	**2.2÷2.3**	MG2S	**1.2÷1.3**	FFLD	**2.6÷2.8**	GP1H	**1.0÷1.1**	PPAL	**1.0÷1.1**	AS2H	**1.2**
ARPN	**1**	FOOT	**0.9÷1.2**	FCRS	**1.1÷1.2**	GP2H	**1.0**	PPST	**0.9**	AS1H	**1.2**
APSH	**2.7÷2.8**	MAP2	**1.1÷1.3**	FUNF	**1.9÷2.0**	GP1E	**1.0÷1.1**	PPL1	**1.0**		
AJPT	**2**	MAPE	**1.1÷1.2**			GPCO	**1.0÷1.1**	PPL2	**1.0**		
		MG2T	**1.1÷1.3**			GPOH	**1.0÷1.1**	PPOH	**1.0**		
		MAP1	**1.1÷1 .3**			GPAG	**1.0÷1.1**				
$\overline{K}_{TN/LT}$	**2**		**1.2**		**1.93**		**1.05**		**1**		**1.2**

As can be seen from the table, $K_{TN/LT} \geq 1$, so when sewing Polo-Shirt and T-Shirt items products from single fabrics, the real-time is often longer than the theoretical calculation time. This demonstrates that in the sewing process, there are often a variety of factors influencing the preparation time. For certain product types and materials, the standard time values defined for preparation operations in the GSD system are not fully correct.

3.2. The influence of various factors on sewing time for various sewing machines

3.2.1. The survey results and the design of the empirical regression equation demonstrate the law of simultaneous influence of factors on the sewing time for different machines during the sewing process

Table 24shows an experiment to study the effect of 2 factors, stitch density (number of stitches/cm) X'_1 and seam length (cm) X'_2, on 3 fabrics and 4 types of sewing machine. We constructed experimental regression equations and 3D graphs that visually reflect the rule of simultaneous effects of two variables X'_1 and X'_2 on sewing time on 3 types of fabric and 4 kinds of the sewing machine by using Design Expert 6.0 software. The general structure of a two-variable regression equation $Y' = a'_0 + a'_1 x'_1 + a'_2 x'_2$. Y is the sewing time on a machine. The coefficient of the regression equation for level 1 is a_i; a_o is the average value of the sewing time on machine. The results to determine the empirical regression equations of sewing time on machines are presented in tables 25, 26, 27, and 28.

Table 24: The sewing time on the computer (performed on 4 types of sewing machines and single fabric with 3 different thicknesses)

NO.	Encrypted variable		Real variable		Y' Single needle lockstitch machine			Y' Overlocking machine (1 needle and 3 thread)			Y' Overlocking machine (2 needles and 4 thread)			Y' Hemming machine (2 needles and 3 thread)		
	x'_1	x'_2	X'_1	X'_2	V1	V2	V3	V1	V2	V3	V1	V2	V3	V1	V2	V3
1	-1	-1	15	3.5	71.5	61.9	75.5	83.7	79.9	76.4	83.7	79.9	76.4	92.1	65.5	107.6
2	1	-1	45	3.5	177.4	183.4	190.2	174.1	172.2	172.7	174.1	172.2	172.7	196.1	184.1	188.9
3	-1	+1	15	5.5	92.5	79.4	73.7	96.8	84.7	95.8	96.8	84.7	95.8	121.6	103.2	101.1
4	1	+1	45	5.5	207.8	189.1	210.6	216.9	199.8	196.7	216.9	199.8	196.7	265.9	218.6	224.3
5	-α	0	8.9	4.5	43.6	37.3	36.7	50.7	51.2	51.7	50.7	51.2	51.7	44.8	44.5	48.3
6	+α	0	51.2	4.5	203.3	189.7	202.2	222.6	192.2	185.6	222.6	192.2	185.6	266.8	210.2	220.3
7	0	-α	30	3.1	104.1	99.4	96.8	110.3	99.6	108.1	110.3	99.6	108.1	154.7	137.7	124.3
8	0	+α	30	5.9	180.02	173.9	169.4	105.8	148.8	145.6	105.8	148.8	145.6	238.1	191.1	200.3
9	0	0	30	4.5	146.8	122.9	110.3	152.4	142.8	133.5	152.4	142.8	133.5	161.5	162.3	140.2
10	0	0	30	4.5	146.9	123	110.1	152.3	142.7	133.4	152.3	142.7	133.4	161.7	162.4	140.3

Table 25: The results of building the empirical regression equation with the rule of simultaneous effects of 2 factors on Single needle lockstitch sewing machine

Fabric type	**V1**	**V2**	**V3**
Y'	$Y'=137.4+55.9x'_1+19.8x'_2$	Y'= 126.4+55.8	Y'= 129.2 + 60.7x'_1 + 15.2

	R^2= 0.96	$x'_1+16.1x'_2$ R^2= 0.96	x'_2 R^2= 0.96

Table 26:The results of building the empirical regression equation with the rule of simultaneous effects of 2 factors on overlocking machine (1 needle and 3 threads)

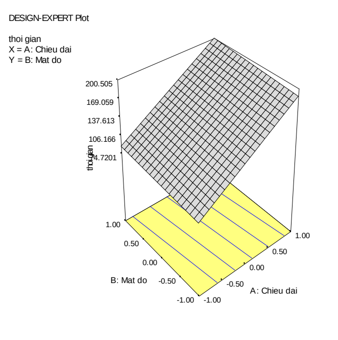
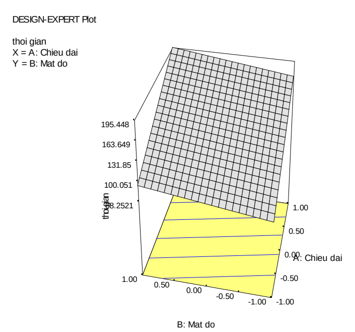
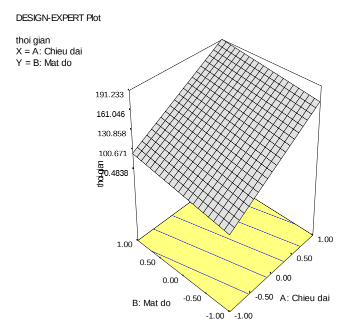
Fabric type	**V1**	**V2**	**V3**
Y’	$Y' = 137.6 + 56.7x'_1 + 6.2x'_2$ R^2= 0.90	$Y' = 131.8 + 50.8x'_1 + 12.7x'_2$ R^2= 0.96	$Y' = 130.8 + 48.3x'_1 + 12.1x'_2$ R^2= 0.98
3D Graph			

Table 27: The results of building the empirical regression equation with the rule of simultaneous effects of 2 factors on on overlocking machine (2needles and 4 threads)

Fabric type	V1	V2	V3
Y’	$Y' = 137.6 + 56.7x'_1 + 6.2x'_2$ R^2= 0.90	$Y' = 131.9 + 50.9x'_1 + 12.7x_2$ R^2= 0.96	$Y' = 130.9 + 48.3x'_1 + 12.1x'_2$ R^2= 0.99

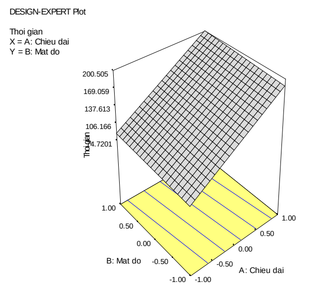
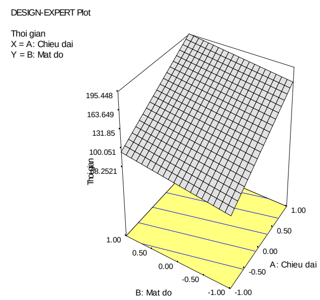
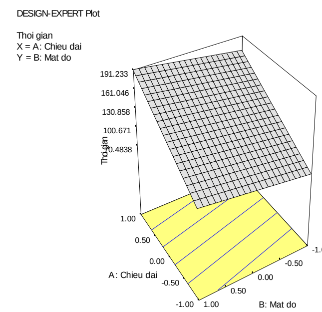
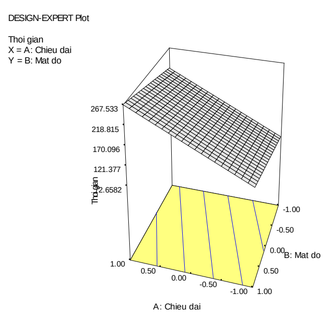
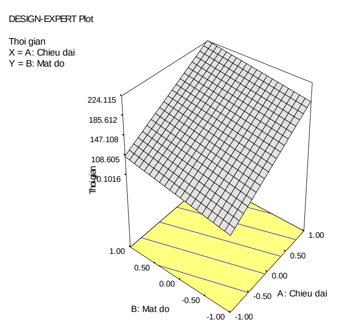
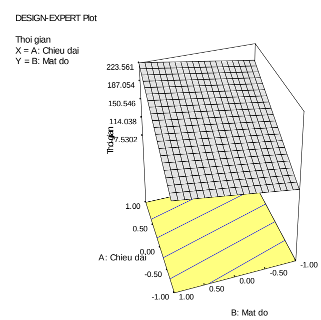
3D Graph			

Table 28: The results of building the empirical regression equation with the rule of simultaneous effects of 2 factors on the hemming machine (2 needles and 3 threads)

Fabric type	**V1**	**V2**	**V3**
Y'	Y= 170.1+ 70.3 X'$_1$ + 27.2 X'$_2$ R^2= 0.94	Y= 147.2+ 58.5X'$_1$+18.5X'$_2$ R^2= 0.95	Y= 150.5+ 56.0X'$_1$+17.0 X'$_2$ R^2= 0.92
3D Graph			

From the analysis of the practical sewing time on 4 types of sewing machines at 3 types of the single fabric thickness (thin, medium, and thick fabric). The R_2 coefficients, which display the association between sewing time machine Y' and two variables x_1 and x_2, are greater than 0.9. This demonstrates a strong connection between the experimental and theoretical models. As a result, it can be inferred that there is a close relationship between sewing time on 4 different types of sewing machines on 3 kinds of fabric thicknesses. Looking at the chart in more detail, we see the general structure of a two-variable regression equation $Y'=a_0+a'_1x'_1+a'_2x'_2$. Considering the coefficients of the regression equation lever 1: a_1, a_2, the absolute values of the coefficient a'_2 is higher than a'_1($|a'_1| > |a'_2|$). Thus, x'_1 or stitch density has the most impact on the preparation time Y. The explanation for this is that by sewing with a higher stitch density, the shorter the stitch length and the fabric would be pulled quicker with the presser foot.

3.2.2. The results of constructing data of the sewing time for different sewing machines under particular conditions

The mutual effects of two variables, stitch density and stitch lengths, on sewing time for four different types of machines, single needle lockstitch machine, overlocking machine (1 needle and 3 threads), overlocking machine (2 needles and 4 threads), and hemming machine (2 needles and 3 threads) were investigated. From analytical regression equations, when assigning a particular value to each variable when sewing 3 varied thicknesses on Polo-Shirt and T-Shirt items, the value of the sewing time for function Y' could be calculated. The results are listed in the table below.

Table 29: The data set indicates the value of sewing time on the machine when sewing 3 kinds of thickness of single fabric on single needle lockstitch machine that correspond to each value of the stitch density and the seam length

	V1					V2					V3				
	-1.41	-1	0	1	1.41	-1.41	-1	0	1	1.41	-1.41	-1	0	1	1.41
-1.41	30.7	38.8	58.6	78.4	86.5	25.0	31.6	47.7	63.8	70.4	22.2	28.4	43.6	58.8	65.0
-1	53.6	61.7	81.5	101.3	109.4	47.9	54.5	70.6	86.7	93.3	47.1	53.3	68.5	83.7	89.9
0	109.5	117.6	137.4	157.2	165.3	103.7	110.3	126.4	142.5	149.1	107.8	114.0	129.2	144.4	150.6
1	165.4	173.5	193.3	213.1	221.2	159.5	166.1	182.2	198.3	204.9	168.5	174.7	189.9	205.1	211.3
1.41	188.3	196.4	216.2	236.0	244.1	182.4	189.0	205.1	221.2	227.8	193.4	199.6	214.8	230.0	236.2

- Overlocking machine(1 needle and 3 threads)

Table 30: The data set indicates the value of sewing time on the machine when sewing 3 kinds of thickness of single fabric on overlocking machine(1 needle and 3 threads)that correspond to each value of the stitch density and the seam length

	V1	V2	V3

	3.1	3.5	4.5	5.5	5.9	3.1	3.5	4.5	5.5	5.9	3.1	3.5	4.5	5.5	5.9
8.9	48.9	51.5	57.7	63.9	66.4	42.3	119.1	60.2	72.9	78.1	45.6	50.6	62.7	74.8	79.8
15	72.2	74.7	80.9	87.1	89.6	63.1	119.1	81.0	93.7	98.9	65.4	70.4	82.5	94.6	99.6
25	128.9	131.4	137.6	143.8	146.3	113.9	119.1	131.8	144.5	149.7	113.7	118.7	130.8	142.9	147.9
35	185.6	188.1	194.3	200.5	203.0	164.7	119.1	182.6	195.3	200.5	162.0	167.0	179.1	191.2	196.2
51.2	208.8	211.3	217.5	223.7	226.3	185.5	119.1	203.4	216.1	221.3	181.8	186.8	198.9	211.0	216.0

- Overlocking machine(2needles and 4 threads)

Table 31: The data set indicates the value of sewing time on the machine when sewing 3 kinds of thickness of single fabric on overlocking machine(2 needles and 4 threads) that correspond to each value of the stitch density and the seam length

	V1					V2					V3				
	3.1	3.5	4.5	5.5	5.9	3.1	3.5	4.5	5.5	5.9	3.1	3.5	4.5	5.5	5.9
8.9	48.9	51.5	57.7	63.9	66.4	42.2	47.4	60.1	72.8	78.0	45.7	50.7	62.8	74.9	79.9
15	72.2	74.7	80.9	87.1	89.6	63.1	68.3	81.0	93.7	98.9	65.5	70.5	82.6	94.7	99.7
25	128.9	131.4	137.6	143.8	146.3	114.0	119.2	131.9	144.6	149.8	113.8	118.8	130.9	143.0	148.0
35	185.6	188.1	194.3	200.5	203.0	164.9	170.1	182.8	195.5	200.7	162.1	167.1	179.2	191.3	196.3
51.2	208.8	211.3	217.5	223.7	226.3	185.8	191.0	203.7	216.4	221.6	181.9	186.9	199.0	211.1	216.1

- Hemming machine (2 needles and 3 threads)

Table 32: The data set indicates the value of sewing time on the machine when sewing 3 kinds of thickness of single fabric on hemming machine (2 needles and 3 threads) that correspond to each value of the stitch density and the seam length

	V1					V2					V3				
	3.1	3.5	4.5	5.5	5.9	3.1	3.5	4.5	5.5	5.9	3.1	3.5	4.5	5.5	5.9
8.9	32.6	43.8	71.0	98.2	109.3	38.6	46.2	64.7	83.2	90.8	47.6	54.5	71.5	88.5	95.5
15	61.4	72.6	99.8	127.0	138.2	62.6	70.2	88.7	107.2	114.8	70.5	77.5	94.5	111.5	118.5

25	131.7	142.9	170.1	197.3	208.5	121.1	128.7	147.2	165.7	173.3	126.5	133.5	150.5	167.5	174.5
35	202.0	213.2	240.4	267.6	278.8	179.6	187.2	205.7	224.2	231.8	182.5	189.5	206.5	223.5	230.5
51.2	230.9	242.0	269.2	296.4	307.6	203.6	211.2	229.7	248.2	255.8	205.5	212.5	229.5	246.5	253.4

From these data, clothing manufacturer can conveniently give the standard sewing time values forvarious sewing machines,knowing the stitch density and the seam length.

4. Conclusion

The results aid researchers and textile producers in proposing measures to optimize the sewing time of knitted garment products, thereby, reducing the production time cycle, increasing productivity and product quality at Start Fashion Co., Ltd. and Hanosimex Co., Ltd. in particular, and knitwear manufacturing businesses in general. The study results can also be used as a scientific basis for correctly calculating the cost of the time spent for preparation as well as the sewing time at the specific machine. This study suggests the inaccuracy of the GSD Pre-determined Time Standard System's values and proposes better systems for assessing sewing time. These systems ensure the precision of technological standard principles and the reliability of production planning in Vietnamese garment factories.

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