STATE PROBLEM OF BALANCING SEWING LINE OF INDUSTRIAL KNITTED PRODUCTS

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ABSTRACT

Line balancing is always a big problem appearing in industrial production. Manual balancing of industrial sewing products takes a long time to give results, which depends on the experience of the sewing line manager, moreover, the efficiency is not necessarily optimal. Digital conversion will help find a solution to balance the sewing line more quickly, accurately, and optimally. This study presents the statements of the problem of balancing knitted garment lines in the industry with the line balancing process according to the method of Hanoi University of Science and Technology (HUST) and BSL-HUST-1 software, which is the software designed and built by our research group. For the balancing calculation, three groups of input data were defined for the comparison of balancing efficiency among the HUST method, the software method, and the method used traditionally by the companies. The line's capacity is determined as the total production amount in a shift, and the shift time is figured accordingly following each factory's rules. The total number of workers is an essential factor. Also, the cycle time is one of the important factors for balancing the sewing line.

KEYWORDS

Line Balancing; Sewing Line Balancing; Knitted Garments.

INTRODUCTION

2022 is the time when textile enterprises gradually recover after two years of being heavily affected by the global Covid-19 pandemic. In the first six months of 2022, textile and garment export turnover is estimated at 22.3 billion USD, increasing 17.7% compared to the same period in 2021. While the main export items are garments with a turnover of 16.94 billion USD, up 19.5% over the same period; fabric export reached 1.4 billion USD, up 20.8%; fiber exports reached USD 2.76 billion, up 4.4%; export of textiles and garment accessories reached USD 734 million, up 22.3%; exports of nonwovens reached US$452 million, up 25.5%. The total import turnover of textile raw materials and accessories in the first six months of 2022 was estimated at 13.4 billion USD, up 9.8% over the same period in 2021. The trade surplus reached 8.86 billion USD, up 32% compared to the first six months of 2021. It can be seen as a great effort of Vietnamese textile and garment enterprises in the context of the world's economic difficulties [1]. The outbreak of Covid 19 has caused many Vietnamese businesses to fall into difficulties, the digital transformation becomes a "survival" opportunity to restore business and increase the possibility of breakthroughs. The program "Supporting businesses in digital transformation for the period 2021-2025" of the Ministry of Planning and Investment aims to promote digital transformation in enterprises through technology integration and application to improve production and business activities, capacity, and competitive advantage [2].

In the garment industry, line balancing is always a big problem that needs to be addressed. When the sewing line is balanced, the product creation process is a continuous flow, wastes will be gradually eliminated, creating fairness in labor, increasing worker productivity and quality garment products. The development of information technology and mathematics effectively supports solving practical problems in life in general and in industrial garment production in particular, particularly in production conditions in Vietnam. Various IoT-based monitoring solutions have been developed recently to monitor individual workers. The data was transmitted to computers using a Wi-Fi connection to optimize smart garment manufacturing at a real-time scale and reduce cost levels [3]. In 2021, Phan Thanh Thao, Le Thi Mai Anh, et al. [4] conducted research and applied five methods: ranked position weighted method (RPW), probabilistic line balancing technique (PLB), longest task time method (LTT), most following tasks method (MFT), and the most reasonable line balancing method of Hanoi University of Science and

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Technology with T-Shirt products. In February 2021, Phan Thanh Thao and other researcher [5] established, modeled, and proposed algorithms for three optimization problems of sewing line balance: given capacity, given the number of workers, and the cycle time to maximize the line balancing efficiency and minimize the number of workers. The sewing line balance software was developed at that time called ALBS V1.0 built especially for Polo-Shirts.

Following that development trend, this study will provide the results of stating the problem of sewing line balancing of knitted products based on real-life conditions of garment industry products such as customers' requirement for the number of products; order and delivery time, the number of workers, or the characters of each sewing products. We propose suitable algorithms and design the sewing line balancing software with each input parameter. Other authors have stated the problem and built a sewing line balancing software with various drawbacks, solving that this software used the method and process of line balancing according to the Hanoi University of Science and Technology principles, which are different from previous research [5]. This research result will be an important reference in the group of studies promoting digital transformation in the garment industry to help Vietnamese garment enterprises develop sustainably in the trend of integration and globalization.

EXPERIMENTAL

Research subjects

The sewing line is the production line of the technological process of sewing products, which is a basic stage in the garment industry. It is a form of organizing the process of sewing products, thereby creating a workstation system that is unified in terms of time or capacity.

Workstations are arranged to be performed simultaneously at the workplaces, by the technological sequence. Semi-finished products are moved from one job site to another at equal intervals of time using manual or motorized transport. Tasks are the basic unit of the technological process of sewing products, which is completed continuously and completely in one workplace. Workstations are organized in coordination with one or several tasks.

+ Single workstation: This is the production process performed by one worker at one workplace.

+ Multi-workstation: It is a production process performed by several workers at several workplaces.

Standardization

Documentary research methods

Synthesize and analyze published documents related to the research problem, as a basis for developing research contents.

Methods of designing and balancing sewing lines [4], [5], [6]

Calculation of sewing line parameters [4], [5], [6]

- Product processing time:

T_{sp} is determined as follows:

$$T_{sp} = \sum t_i \text{ [s]} \quad (1)$$

where t_i is the processing time of task i, T_{sp} is product sewing time.

- Cycle time

Cycle time is the average time between two products leaving the line, or after which the production steps are repeated and a product is produced. Cycle time is one of the important data to balance the sewing line. The symbol is R. The formula for calculating cycle time:

+ $R = T_{sp}/N$ [s] with N is the total number of workers.

+ $R = (T_{sx} \times 3600)/P$ [s] with T_{sx} [h/day] total working time in a day, P [products/day] total production amount in a day.

- The fluctuation of the cycle time ΔR depends on the organizational form of the chain of each enterprise, which is the initial data of the problem.

+ The sewing line has a tight cycle time:

$$0 \le \Delta R \le 0.05\ R \quad (2)$$

$$Rmin = 0{,}95R;\ Rmax = 1{,}05R$$

+ The sewing line has a free cycle time:

$$0.10\ R < \Delta R \le 0.15\ R \quad (3)$$

$$Rmin = 0{,}9\ R;\ Rmax = 1{,}15R$$

The sequence of designing and balancing the sewing line

It is carried out according to the method currently being researched and taught at the Department of Garment Technology & Fashion, School of Textile – Leather and Fashion, Hanoi University of Science and Technology [4], [5], [6] including the following steps:

- Preliminary determination of the parameters of the line.

- Building the diagram of production and processing production and line balanc-ing.

- Accurate parameters of the line.

- Workplace planning and line layout.

- Calculate the economic - technical indicators of the line.

Principles when organizing the tasks into workstations.

- Ensure the path of semi-finished products line is straight and the shortest technological journey:

+ Requirement 1: To comply with the maximum technological sequence, follow the principle of serialization coordination of serial tasks on the same processing branch.

+ Requirement 2: Follow the principle of parallelism pairing tasks on different processing branches but without affecting the technological sequence. The tasks have not been assigned are selected into workstation, which does not affect the technological sequence.

Note:

+ Prioritize the pairing of tasks according to the principle of serialization.

+ When joining tasks according to the principle of parallelism (joining operations on different detail groups should only combine tasks in the same detail group – e.g., front, back, neck, brace, arm), no tasks on the processing branches should be coupled with tasks on the assembly branches because the semi-finished products will be upstream of the transport and thus will violate the principle of straight-line technology.

- Requirements for machines and operation grade:

+ Requirement 1: Coordinate the tasks with the same equipment, and the same worker's rank or take the highest grade.

+ Requirement 2: Can coordinate tasks using equipment with manual tasks.

+ Requirement 3: Each workstation has a maximum of 2 different types of equipment.

- Ensuring the time conditions of the workstations:

$$u.R_{min} \le t_{sxj} \le u.R_{max} \quad (4)$$

where t_{sxj}: the time of the *j* workstation

+ Requirement 1: Select the workstations having *tsxj* satisfy the condition *u* = 1, *u* = 2 and *u* = 3. *u* is the number of workers.

+ Requirement 2: Each workstation allows maximum three workers.

+ Requirement 3: Each workstation is allowed to be formed from a maximum of three tasks.

+ Requirement 4: To avoid the phenomenon of production process being stalled or stopped, priority should be given to under-loaded workstations rather than overloaded ones.

+ Requirement 5: However, it is necessary to limit the organization of a workstation from many tasks or has multiple workers, which is lower the specialization, coordination of semi-finished products and line layout complicated.

Parameters of workstations [4], [5], [6]:

$$t_{sxj} = \sum_{i=1}^{mi} t_{ij} \text{ [s]} \quad (5)$$

where m_i is the number of tasks forming the *j* workstation, t_{ij} is the time of *i* task allocated to the *j* workstation.

- The number of workers for each workstation is N_j calculated by the formula: $N_j = t_{sxj}/R$

- Choose the number of *j* workstation according to the rounding principle, N_{cj} is the number of workstation selected, *m* is the integer part of N_{tj}

+ If $N_j \le 1$, choose $N_{cj}=1$

+ If $m \le N_j < (m+0.5)$, then choose $N_{cj} = m$

+ If $(m+0.5) \le N_j \le (m+1)$, then choose $N_{cj} = m+1$

- The cycle time of workstation *j* is R_j calculated by the formula: $R_j = t_{sxj}/N_{cj}$ [s]

The total number of workers needed after combining is:

$$N = \sum_{i=1}^{n} N_{cj} \text{ [worker]} \quad (6)$$

Indicators to evaluate the effectiveness of sewing line balancing [4], [5], [6], [7]:

In this paper, the following criteria are used to evaluate the efficiency of sewing line balancing:

+ The ratio of the number of workstations having their specific cycle time lied within the allowed interval of cycle time, *K* is calculated by the formula:

$$K = \frac{k1}{k} \times 100\ [\%] \quad (7)$$

where *K*: Balance efficiency, k_1: Number of balance workstations, *k*: Total number of workstations.

$K \ge 60\%$, the line is balanced. $K < 60\%$, the line is not balanced, it is necessary to carry out balancing the line according to the new plan [6].

+ Line efficiency *H* is in the range of 98% to 102% is the optimum:

$$H = \frac{\sum ti}{N \times R} \times 100\% \quad (8)$$

where *H* is line efficiency, $\sum t_i = Tsp$ - Product sewing time [s], *N* is Total number of workers, *R* is Cycle time [s].

Sewing line balancing optimization algorithm

Dinh Mai Huong [8], [9] proved that the Meta-Heuristic algorithm is suitable to solve the problem of balancing sewing lines for garment products in general and knitted products in particular. The authors Dinh Mai Huong [8], [9] used Meta-Heuristic algorithms including Tabu Search (Tabu), Genetic Algorithms (GA), Simulated Annealing Algorithm (SA) and binary search algorithm used in sewing line balancing studies. Special attention is paid to SA algorithm first introduced by S. Krikpatrick et al. [10].

In order to create a basis for choosing algorithms and learning algorithms suitable for sewing line balancing problems, the authors will focus on establishing the content of the statement of the problem of balancing the sewing line of knitted products, including objectives, content and sequence of steps to solve the problem with clear descriptions of constraints and performance conditions. The problem statement in a professional manner taking into account factors in the production practice of the garment industry, building input data, and determining the output requirements of the sewing line balancing problem will help to choose effective learning algorithms and be the basis for designing line-balanced software, including designing functional modules, interfaces, database, system security and user manual.

Table 1. Implementation steps of a problem of type 1 given ***P*** or ***R*** (N_{sx}→Min optimum).

No.	Content
1	- Style's basic information: + Section "Detailed style" includes: style name, Product name, Product description. + Section "Operation breakdown " includes: Number, Tasks name, Description, Machine, Time [s], Operation grade. + Section "Constraints sequence" includes: table, diagram, photo showing the binding sequence of tasks sewing products.
2	- Step 1: User assigns total working time in one day T_{sx} [h/day], total production amount in a day **P** [product/day], ΔR=5,10,15,20 [%] - Step 2: From ***P*** => Calculate ***R*** ($R= T_{sx}/P$), and ΔR [R_{min}; R_{max}]. - Step 3: combine tasks into workstations in the sewing line according to the principle of organizing and coordinating workstations as above. Calculate the workstations time and R_j. - Step 4: Draw the load graph of the workstations with the vertical axis being the cycle time R_j of workstations, and the horizontal axis is the ordinal numbers of workstations. - Step 5: Test if ***K*** is optimal + Calculate the number of balance workstations + Calculate the balance efficiency *K*% with the numerator is the number of workstations having their specific cycle time lied within the allowed cycle time interval [R_{min}; R_{max}], and the denominator is the total number of workstations. + If ***K*** ≥ 60%, then conclude the sewing line balancing => Go to step 6. +If ***K*** < 60%, return to step 1, enter other parameters. - Step 6: Correct the sewing line's parameters ***P***, ***R***, R_{min}, R_{max}, ***N***.
3	- The software returns the results in the order of priority: + Level 1: ***K*** = 60%, and N_{min} + Level 2: K_{max} < 60% is not optimal, and N_{min} => Software gives notice "The line has not balanced in terms of load Go back to the previous step to change the parameters"
	=> The software gives calculation results: ***K***, ***H***, T_{sp}, ***P***, ***N***, ***R***, R_{min}, R_{max}

Table 2. Implementation steps of the problem of type 2 given ***N*** (***K*** ≥ 60%, P_{sx}→Max optimum).

No.	Content
1	- Style's basic information: + Section "Detailed style" includes: style name, Product name, Product description. + Section "Operation breakdown " includes: Number, Tasks name, Description, Machine, Time [s], Operation grade. + Section "Constraints sequence" includes: table, diagram, photo showing the binding sequence of tasks sewing products.
2	- Step 1: User assigns total working time in one day T_{sx} [h/day], number of workers ***N***, ΔR = 5, 10,15, 20 [%]. - Step 2: Using the Binary Search algorithm, find **R** in the range of values from T_{min} = 0 to $T_{max} = T_{sp}$ (Normal product processing time according to the operation breakdown table $T_{sp} = \sum t_i$,the case sewn by only one person), calculate ΔR [R_{min}; R_{max}]. + Step 2.1: $T_{mean}=(T_{min} + T_{max})/2$ and $R=T_{mean}$. + Step 2.2: From the operation breakdown and binding the sequence of combining tasks to workstations in the full line according to the principle of organizing and coordinating the operations as the *P* problem. + Step 2.3: The total number of workstations is N_1. If $N_1 = N$ does not exist => Assign $T_{min} = T_{mean}$ => Go back to step 2.1 If exists $N_1 = N$ => Assign $T_{max} = T_{mean}$ => Go back to step 2.1 The algorithm will run until $(T_{min} + \alpha) > T_{max}$ => Go to step 3. - Step 3: Draw the load graph of the workstations with the vertical axis being the cycle time R_j of workstations, and the horizontal axis is the ordinal numbers of workstations. - Step 4: Test if ***K*** is optimal + Calculate the number of balance workstations + Calculate the balance efficiency *K*% with the numerator is the number of workstations having their specific cycle time lied within the allowed cycle time interval [R_{min}; R_{max}], and the denominator is the total number of workstations in full-line. + If ***K*** ≥ *60%*, then conclude that N_1 is the number of workers on the line => Go to step 5. + If ***K*** < *60%*, go back to step 1 and enter another parameter. - Step 5: Correct the sewing line's parameters ***P***, ***R***, R_{min}, R_{max}, ***N***.
3	- The software returns the results in the order of priority: + Level 1: **R**-value at which $N_1 = N$, ***K*** = *60%*, and P_{max} + Level 2: ***R***-value at which $N_1 = N$ and K_{max} < *60%* is not optimal. Give the corresponding ***P***-value result. => Software gives notice "The line has not balanced the load. Return to the previous step to change the parameter".
	=> The software gives calculation results: ***K***, ***H***, T_{sp}, ***P***, ***N***, ***R***, R_{min}, R_{max}.

Table 3. Implementation steps of type 3 problem (*K* ≥ *60%* optimization).

No.	Content
1	- Style's basic information: + Section "Detailed style" includes: style name, Product name, Product description. + Section "Operation breakdown" includes: Number, Tasks name, Description, Machine, Time(s), Operation grade. + Section "Constraints sequence" includes: table, diagram, photo showing the binding sequence of tasks sewing products.
2	- User assigns total working time in one day Tsx [h/day] - Select line type: + Conjugate line. + Group conjugation line.

3	Conjugate line: => Draw the norm time chart of the whole line tasks.	Group conjugate line: => The staff chooses the tasks in the assembly group from the full-line operation breakdown table. => Draw the norm time chart of the assembly group's tasks.
4	In full-line, the processing time of tasks runs from [T_{min}; T_{max}]. Corresponding to this period, the power domain of the line will be [P_{Tmax}; P_{Tmin}]	The assembly group's tasks rated time runs from [T_{lrmin}; T_{lrmax}]. Corresponding to this period, the power domain of the assembly group will be [P_{Tlrmax}; P_{Tlrmin}].
5	Method 1: - Step 1: In the range [P_{Tmax}; P_{Tmin}], choose one **P** value (usually in the middle of this range determined by the user) => Calculate ***R***, and cycle time interval [R_{min}; R_{max}] (Δ=*5*, 10, 15, 20% - asked and assigned the value by the user). - Step 2: combine tasks into workstations in the sewing line according to the principle of organizing and coordinating workstations as the ***N*** or ***P*** problem. Calculate the rated time of workstations and R_j. - Step 3: Draw the load graph of the workstations with the vertical axis being the cycle time R_j of workstations, and the horizontal axis is the ordinal numbers of workstations. - Step 4: Test if ***P*** is the optimal capacity + Calculate the number of balance workstations + Calculate the balance efficiency ***K%*** with the numerator is the number of workstations having their specific cycle time lied within the allowed cycle time interval [R_{min}; R_{max}], and the denominator is the total number of workstations in full-line. + If ***K*** ≥ *60%*, then the conclusion ***P*** is the optimal capacity => Go to step 5. + If ***K*** < *60%*, then choose ***P*** again (greater or smaller value) => Return to step 1. - Step 5: Correct the sewing line's parameters ***P, R***, R_{min}, R_{max}, ***N***.	Method 1: - Step 1: In the range [P_{Tlrmax}; P_{Tlrmin}], choose one ***P*** value (usually in the middle of this range determined by the user) => Calculate *R*, and cycle time interval [R_{min}; R_{max}] (Δ=5, 10, 15, 20% - asked and assigned the value by the user). - Step 2: combine tasks into workstations in the sewing line's assembly group according to the principle of organizing and coordinating workstations as the ***N*** or ***P*** problem. Calculate the rated time of workstations in the assembly group and R_j. - Step 3: Draw the load graph of the assembly group's workstations with the vertical axis being the cycle time R_j of workstations, and the horizontal axis is the ordinal numbers of workstations. - Step 4: Test if *P* is the optimal capacity of the assembly group. + Calculate the number of balance workstations in the assembly group. + Calculate the balance efficiency of the assembly group. $E\ [\%] = \frac{e_1}{e_2} \times 100\ [\%]$ with numerator e_1 is the number of workstations lied within the allowed cycle time interval [R_{min}; R_{max}], and denominator e_2 is the total number of workstations in the assembly group. + If ***e*** ≥ *60%*, then the conclusion *P* is the optimal capacity of the assembly group => Go to step 5. + If ***e*** < *60%*, then choose ***P*** again (greater or smaller value) => Return to step 1. - Step 5: Correct the assembly group's parameters ***P, R***, R_{min}, R_{max}, ***N*** of the assembly group => Go to step 6.
6	Method 2: The algorithm runs to find ***P*** in the range of ***P*** values so that ***K*** ≥ *60%*	Method 2: The algorithm runs to find ***P*** in the range of ***P*** values so that ***e*** ≥ *60%*.
7		- Step 6: combine tasks into workstations in the sewing line's detail group according to the principle of organizing and coordinating workstations as the ***N*** or ***P*** problem. Calculate the rated time of workstations in the detail group and R_j. - Step 7: Draw the load chart of the detail group's workstations. - Step 8: Test if *P* is the optimal capacity of the whole line. + Calculate the number of workstations lied within the allowed cycle time interval [R_{min}; R_{max}] in the detail group. + Calculate the balance efficiency of the detail group $f\ [\%] = \frac{f1}{f2} \times 100\ [\%]$ with numerator f_1 is the number of workstations lied within the allowed cycle time interval [R_{min}; R_{max}], and denominator f_2 is the total number of workstations in the detail group. + Calculate $K\ [\%] = \frac{k1}{k} \times 100\ [\%]$ $= \frac{e1+f1}{e2+f2} \times 100\ [\%]$ + Simultaneous test ***K*** and ***f*** values: If ***K*** ≥ *60%* and ***f*** ≥ *60* (level 1), then ***P*** is the optimal => Go to step 9. If ***K*** ≥ *60%* and ***f*** < *60%* (level 2) => Temporarily save the result. If ***K*** < *60%*, then choose ***P*** again (greater or smaller value) => Return to step 1. - Step 9: Correct the detail group's parameters (***N*** of detail group). (It is essentially a given problem ***P***)
8		Full line - Step 10: Draw the load chart of the full line - Step 12: Accurate parameters of the full line ***P, R***, R_{min}, R_{max}, ***N*** of the full line.
9		Note: algorithm priority + Level 1: ***K*** ≥ *60%*; ***e*** ≥ *60%* and ***f*** ≥ *60%* + Level 2: ***K*** ≥ *60%*; ***e*** > *60%* and ***f*** < *60%*
	=> The software gives calculation results: ***K, H***, T_{sp}, ***P, N, R***, R_{min}, R_{max}.	

Table 4. Algorithms for sewing line balancing problems

No.	Sewing line balancing problem		Algorithm
	Input	***Optimal Priority Order***	
1	Given ***P*** or ***R***	***K*** ≥ *60%*, and $\boldsymbol{N_{min}}$	SA
2	Given ***N***	***N*** *found=**N** input*, ***K*** ≥ *60%*, and $\boldsymbol{P_{max}}$	Binary Search and SA
3	***R*** value optimization problem	***K*** ≥ *60%*, N_{min}	SA

RESULTS AND DISCUSSION

Objectives of the sewing line balancing problem

The purpose of the study is to optimize the sewing line balance in industrial production in real conditions with three groups of input data:

Type 1: the capacity of the line given is determined as the total production amount in a shift from which the cycle time is figured. Objective: Minimum number of workers, Nsx→Min.

The problem assumes that the worker's capacity and ability to work are the same, regardless of the influence of the operation grade.

Type 2: Having the total number of workers from which to calculate the cycle time. Objective: Maximize total production amount in a day, P_{sx}→Max.

Type 3: Balancing the sewing line according to the characteristic's product regardless of the number of workers N or total production amount in a day. Objective: Optimizing the cycle time R to ensure the line is balanced (K maximum and ≥60%) and effectively using the number of workers on the line N_{sx}→Min as well as total production amount in one day is the largest P_{sx}→Max.

The results of the statement of the sewing line balancing problem

Not only do base on the method of designing and balancing the sewing line being researched and taught at the Department of Garment & Fashion Technology, School of Textile – Leather & Fashion, Hanoi University of Science and Technology [4], [5], [6], but it also establishes the requirements of the sewing line balancing problem presented in section 2 above, the team has conducted to demonstrate their problems include the contents and process of performing steps to solve three types of statements of balancing the sewing line of industrial knitted products. The results are displayed in Tables 1, 2 and 3.

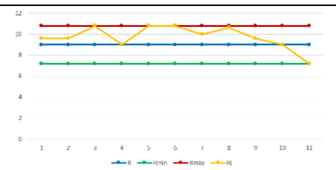
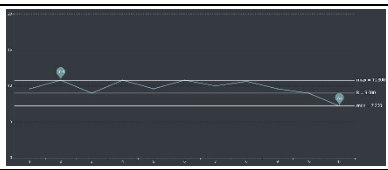
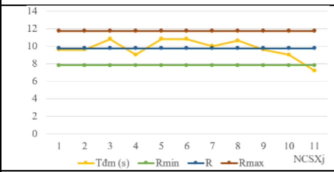
Algorithms

This paper proposes to specifically apply the algorithm in the Meta-Heuristic group corresponding to the three problems of balancing the knitted product line in the gar-ment industry, see Table 4.

We have applied the line balancing software for 14 knitting production lines, and the actual set of data for T-Shirt and Polo-Shirt at 03 factories were collected and analyzed. The Vietnamese factories are Ha Nam - HANOSIMEX Company Limited, Star Fashion Company Limited, and Regent Garment Factory Limited. The collected results of balancing the sewing line for T-Shirt and Polo-Shirt products using the software BSL-HUST-1, 2, 3 were compared with the method invented by Hanoi University of Science and Technology, and the conventional sewing line balancing method from the factories. In the following Figure 1, we represent a T-Shirt code T08 balancing process presented on our software.

The methods to balance the production line according to the principles from Hanoi University of Science and Technology and using BSL-HUST-1 software are calculated independently but given the same results. All three methods present good results with K ≥ 60%, but the first two methods are better than the company's one. Similarly, parameters P, and H calculated by the method of Hanoi University of Science and Technology are larger than those of the company. Looking at the load chart of the whole line generated by the software, there are no under-loaded or overloaded production steps, whereas the company's method has an under-loaded step. The same number of workers are required for production among all methods, the R parameter decreases leading to the H parameter increases.

Table 5. Comparing the load chart of the sewing line code T08.

	Hust balancing method	BSL-HUST-1 Software	Regent Garment Factory Limited's method
Load chart of the sewing line T08			
Comment	From the load graph, all manufacturing steps have their own spans in the range ***ΔR***.		From the load chart, there is 1 manufacturing step underload.

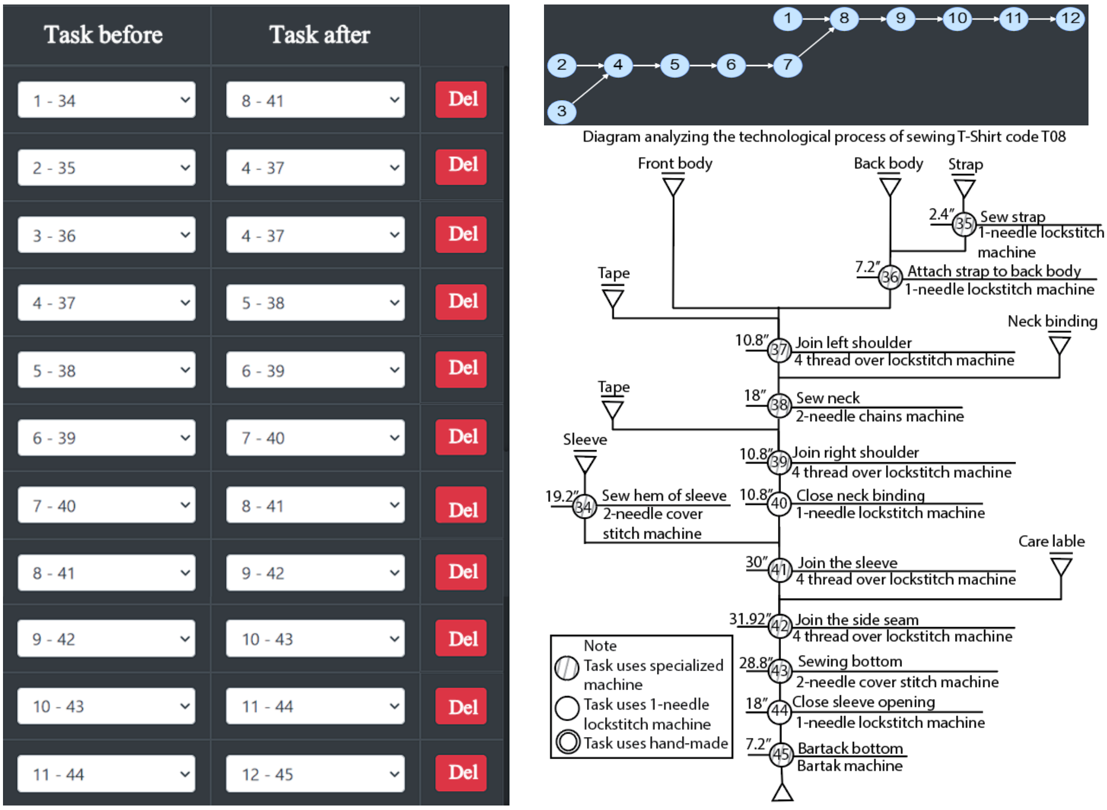


Figure 1. Representative photo of the BSL-HUST software balancing for production line code T08.

Table 6. Comparing the layout diagram of the sewing line T08 between varied methods.

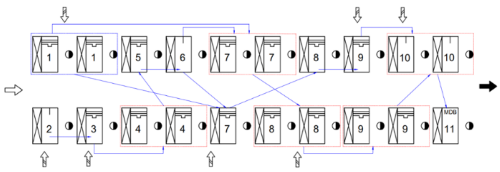
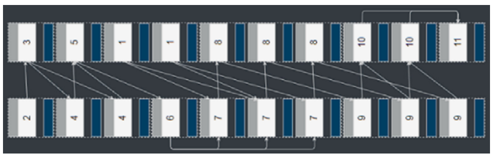
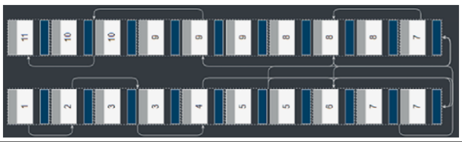
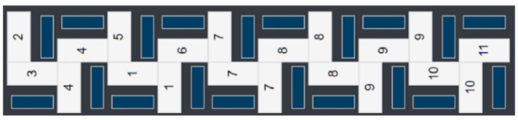
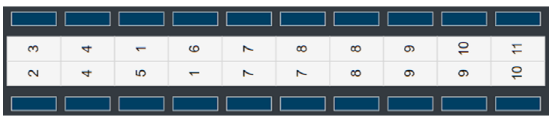
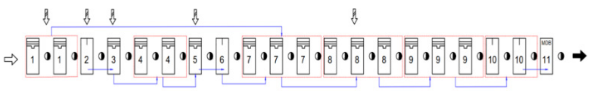
	The layout diagram of the T08 sewing line	Layout form
HUST balancing method		Horizontal arrangement, semi-finished products moved with zigzag routes using container.
BSL-HUST-1 software		Zigzag lines
		U lines
		'Cell' line (perpendicular sitting position)
		'Cell' line (opposite sitting position)
Line balancing design of Regent Garment Factory Limited.		Horizontal layout, semi-finished products transported in a straight line, with semi-automatic hanging lines

Table 7. Comparing sewing line parameters for T08 production line.

	K%	P [product/shift]	N [person]	R [s]	H%
HUST balancing method	**100**	3200	20	9	108.4
BSL-HUST-1 software	**100**	3200	20	9	108.4
Line balancing results from Regent Garment Factory Limited's methods.	**90.909**	2952	20	9.756	100

The layout of the sewing lines in three relatively similar ways is all horizontal. However, there is a difference: the company's line is a line with a series of machines, in reality, the production of T-Shirt products at Regent Garment Factory Limited paired two lines to run the same product, using the line for transporting semi-finished products to preserve production area and improve labor productivity. The software BSL-HUST-1 supports more U-shaped line layouts and cell lines. From here, it can be seen that the determination of a reasonable capacity to effectively ensure the balance of the sewing line by BSL-HUST-1 software is completely reasonable and can be applied to actual production.

CONCLUSION

Based on the actual requirements of garment industry production and the process of line balancing according to the method of Hanoi University of Science and Technology, this study has stated the sewing line balancing problem of knitted products through concrete, explicit and coherent steps whereas giving suggestions for choosing suitable algorithms for each problem. It is one of the initial steps contributing to developing sewing line balancing software applied to solve the sewing line balancing problem in industrial production.

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