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Optimization Combining with Digital Transformation of the Men's Shirts Processing at Small and Medium-Sized Garment Enterprises in Vietnam

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ABSTRACT

Industry 4.0 has become a hype among the manufacturing industries across the globe. Recent developments require significant capital investments, but these technologies are yet to be established in developing countries such as Vietnam, especially the apparel industry. Based on a survey of the current situation at small and medium-sized enterprises in Vietnam's textile industry, the paper proposes to apply technology, test and evaluate the effectiveness of applying and coordinating digital systems in management and chain supply. Multifaceted applications have been specifically explored including automatic equipment and digital systems, spanning the domains of automation, robotics, artificial intelligence, data analytics, and the Internet of Things (IoT). These technologies are posited as catalysts for transformative improvements in production efficiency and resource utilization. Furthermore, experimental results point out the symbiotic relationship between technology adoption and effective management strategies to achieve holistic operational enhancements. As the Vietnamese textile industry strives for competitive excellence in the global arena, this research offers actionable insights for industry practitioners, policymakers, and researchers.

1. Introduction

The contemporary landscape of industrial practices, marked by internationalization, mass customization, and intricate corporate structures, poses unprecedented challenges to traditional enterprises [1], [2]. This scenario is further intensified by the relentless progress in science and technology on a global scale, which significantly influences the trajectory of industrialization [3]. In response to this dynamic environment, the emergence of Industry 4.0 represents the latest epoch in manufacturing evolution, aspiring to enhance productivity while minimizing resource utilization [4]-[9]. The foundational concept of Industry 4.0, designed to fortify the competitiveness of German companies [10]. This paradigmatic shift encompasses an amalgamation of innovative concepts and technologies, including radio-frequency identification (RFID) [11], big data, cloud computing, intelligent sensors [12], machine learning (ML) [13], [14], robotics [15], additive manufacturing (AM) [16], artificial intelligence (AI) [17], augmented reality (AR) [18], and the internet of things (IoT) [19].

While the industry grapples with the imperative of enhancing productivity and labor efficiency, research projects such as Motion Time-study Measurement (MTM) [20] and General System Description (GSD) [21] have been proposed to establish processing time norms for operations in garment production. These initiatives involve standardizing and encoding data based on the order of movements during operations, contributing to the creation and storage of standardized data for the garment production process. In a bid to apply artificial intelligence to automation within the garment industry, these databases enable the analysis, editing, and processing of information data, facilitating the prediction of potential scenarios or occurrences.

However, the textile and apparel manufacturing sector, particularly prevalent in developing economies with small and medium-sized enterprises (SMEs), confronts unique challenges in the era of intelligent manufacturing [22]-[28]. Paramount among these challenges are issues of product quality and compliance, crucial for the sustained viability of enterprises in the textile and apparel sectors [29]-[32]. The advent of Industry 4.0 in the fourth industrial revolution demands strategic technology adoption for intelligent operations within this sector. Despite modest integration in specific domains, applications of Industry 4.0, such as RFID-tagged intelligent beams and sewbots, demonstrate significant potential for cost savings and increased production efficiency [32]-[36]. Noteworthy advancements in production efficiency are exemplified by a large increase, with robotic counterparts producing T-shirts compared to human sewing lines in an eight-hour shift [11], [36]. Nevertheless, the transformative impact of Industry 4.0 faces impediments due to the unpreparedness of many SMEs in the textile and apparel sector to embrace these technological advancements [22], [23]. Addressing this gap is crucial to ensuring the resilience and competitiveness of the sector. Eurydice et al. introduced digital twin (DT) for garment production line administration, enhancing production line balancing and obstacle identification through virtual simulation models [37]. By analyzing real-time data, DT facilitates the oversight, regulation, and optimization of manufacturing processes, contributing to improved performance and efficiency. Another study by Rundassa et al. assessed data management challenges in Ethiopia's textile sector, proposing a data management model that significantly reduces search time for garment industry data and enhances process and data flow traceability [38].

The Vietnamese textile industry, a linchpin of the nation's economy, stands at the intersection of tradition and modernity. This research aims to strategically integrate high technology into production processes and managerial practices to elevate production efficiency in this critical sector. However, the current scenario presents challenges, with most enterprises struggling to integrate digitization and digital transformation due to equipment system complexities and limited automation deployment plans (Institute for Strategic and Policy Research of the Ministry of Industry and Trade report) [39]. Specifically, the lack of emphasis on online productivity management in existing production management software poses a significant hindrance. In response, the authors propose the implementation of automatic equipment in the men's shirt sewing line (SMS) and the development of software to digitize process data from SMS stitching technology. This initiative is intended to yield cost savings in productivity, quality, energy consumption, and administration and operations. Drawing upon an evaluation of existing garment manufacturing process management software and an analysis of the current state of digitization, automation, and digital transformation in Vietnam [40]-[48], the research endeavors to develop a process management software. The survey results of the enterprise's actual production process utilizing the proposed method are presented in the latter part of this scientific endeavor.

Therefore, the rest of the paper is structured as follows: Section 2 focuses on the application of automated equipment in the men’s shirt production line, Section 3 discusses the design of software for digitizing the data of the men’s shirt sewing technology process, Section 4 includes evaluation and discussion.

2. Research and Design Automatic Equipment in Men's Shirt Sewing Line

2.1. Research Subjects

Fig. 1 is a basic men's shirt with closed button-down collar, collar band separate, long sleeves with cuff flap and cuffs, chest pocket without flap on the left shirt body.

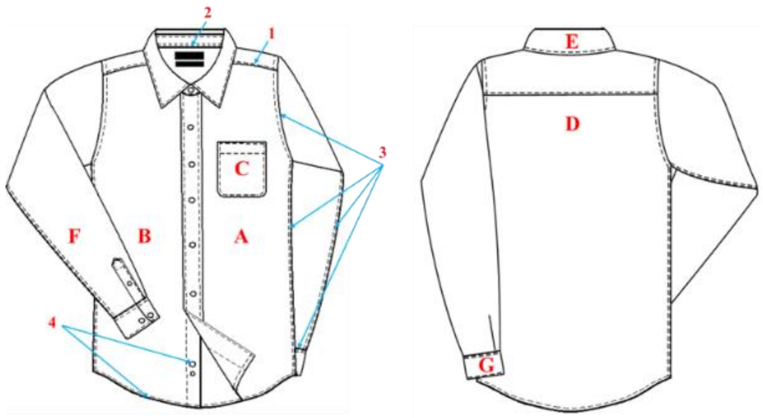


Fig. 1. Basic men's shirt product description

To facilitate the construction of a sewing technology process table for shirt products, we have furnished a rudimentary block diagram of shirt processing, as illustrated in Fig. 2. As illustrated in Fig. 1, the primary detail clusters are designated as A, B, C, and the assembly clusters on the product are labeled 1, 2, 3, etc.

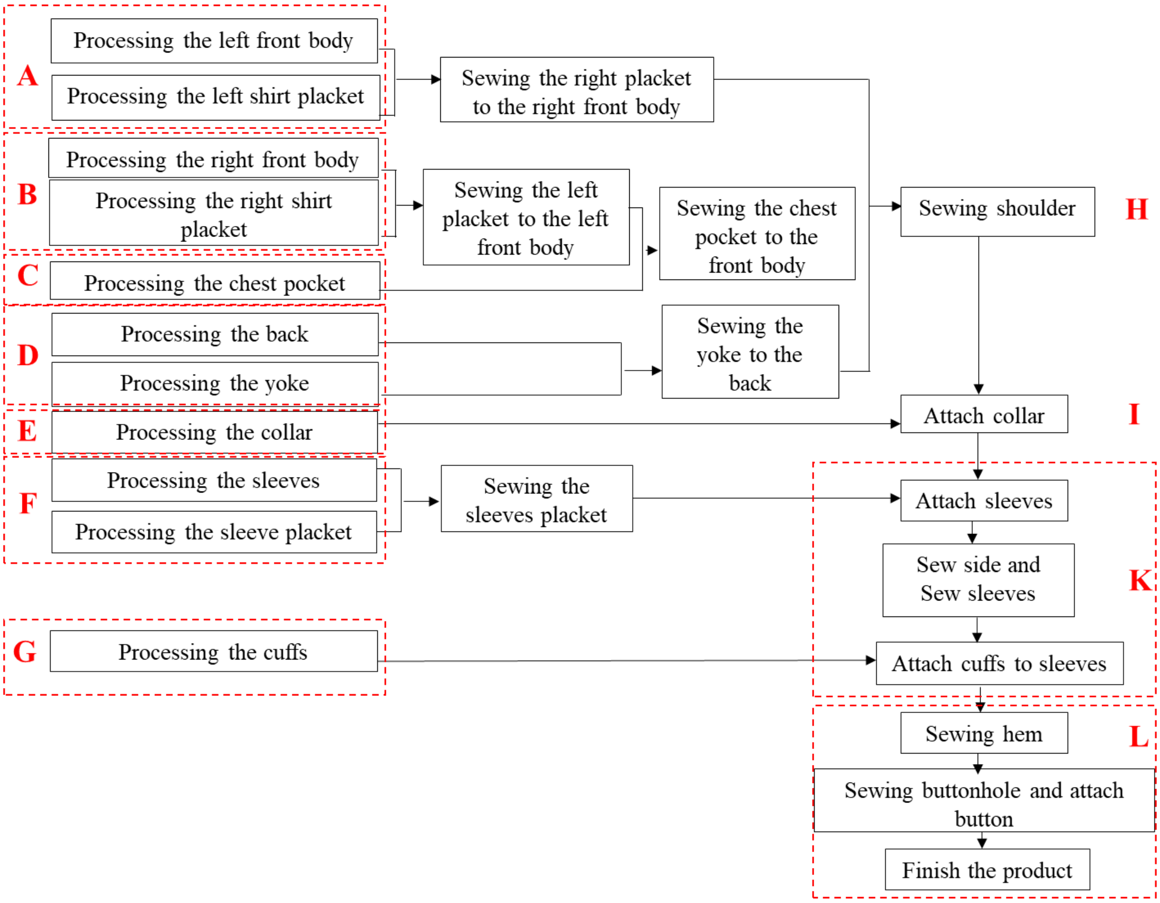


Fig. 2. The block diagram of the basic men's shirt sewing technology process

An issue that is present pertains to the administration of data concerning primary and secondary sewing details, as well as the automated seamless arrangement associated with production line management software and automatic equipment [49], [50]. The vast quantity of data poses challenges in terms of management, process organization, productivity monitoring, and product quality assurance. By utilizing artificial intelligence and digital transformation to manage and partake in the control process of automated equipment, it is possible to reduce costs, improve quality, and increase productivity [51]. Time and production expense at each stage and for the entire manufacturing process.

2.2. Integrating Automated Equipment into the Men's Shirt Production Line

Based on data regarding the system of smart sewing equipment currently used in production lines, the authoring team studied the labor organization for two sewing lines: one using traditional sewing equipment, referred to as the Traditional Sewing Line (TSL), and the other incorporating additional automated sewing equipment, referred to as the Modern Sewing Line (MSL).

The problem addressed in this study is the labor organization for two sewing lines: TSL and MSL for basic men's shirt products in the form of group conjugate chains. Subsequently, a comparison and evaluation of various economic and technical indicators of these two sewing lines are conducted to provide specific evidence on the increased efficiency when applying smart equipment to industrial sewing production lines. For the convenience of comparison and evaluation, we will organize the design of two medium-sized production lines with average capacity, both initially designed with a production capacity of 1000 products per shift. In this study, the Motion Time-study Measurement (MTM) [20] and the General System Discription (GSD) [21] were applied to analyze the sewing operation processes and determine the actual time required for sewing operations on traditional sewing machines. Meanwhile, the video recording and timing method was utilized to analyze the activities of workers on automated machines. Table 1 illustrates the specific analysis of activities, their frequency, and the time required in the original operation as a prelude. Table 2 presents the timed results for each operation of the EPA-205 collar shaping machine. Similar approaches were applied to other stages. Application of the MTM and GSD has determined the execution time of each stage of two lines: TSL and MSL as shown in Table 3.

Table 1. Analysis of the process of pressing and creating the front placket

No	Description of Operation	Code	TMU	Frequence
1	Get the right front body with 2 hands	GP2H	33	1
2	Place part to table	PPL2	47	1
3	Get the front placket pattern	GP1E	14	1
4	Put the front placket pattern on right front body	PPL1	27	1
5	Fold the edge of the front placket according to the pattern	FFLD	43	3
6	Complete the fold line of the front placket	FCRS	28	3
7	Get the iron	GP1H	20	1
8	Put the iron on the fold line	PPAL	10	1
9	Apply pressure to part	A	14	24
10	Place the iron to table	PPAL	10	1
11	Fold the edge of the front placket for the second time	FFLD	43	3
12	Complete and shape the right front placket	FCRS	28	3
13	Get the iron	GP1H	20	1
14	Put the iron on the fold line	PPAL	10	1
15	Apply pressure to part	A	14	24
16	Place the iron to table	PPAL	10	1
17	Take the pattern out of the front placket	FUNF	23	1
18	Place the pattern to table.	PPAL	10	1
Total		**1332 TMU = 48s**		

After calculating the standard time for each operation on the MSL and TSL, the functioning of both production lines will be synchronized and balanced in accordance with line balancing principles. When considering an initial capacity of P = 1000 products per shift, the individual cadence of the embroidery line is computed to be R = 28.8s. The manufacturing process is composed of three production groups, which are differentiated by the characteristics of the work divisions within them:

Table 2. The operation steps of the automatic front plain pressing and creasing machine EPA-205

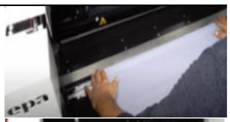
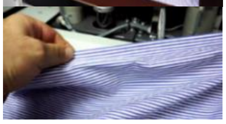
No	Description of the Process	Illustration
1	Place the part in a device with a fixed threshold to fold the part into the correct folding position.	
2	The device will automatically fold the edge of the part 2 times	
3	The pressing unit moves to receive the part and then press the fold line to create front placket	
4	After the pressing is completed, the part is transferred to the back of the device	
5	Semi-finished products are brought to the table below for easier retrieval by workers.	
6	Semi-finished product when out of the device	
	Total of steps	**16s**

Table 3. Technological process of basic men's shirt sewing according to TSL and MSL

No	The operation step	TSL		MSL	
		Machine	**Time (s)**	**Machine**	**Time (s)**
A1	Pressing and creating the right front placket	BSP-300	48	EPA- 205	16
A2	Topstitch right front placket	DDL-5550N-7	18.5	Automatic Front Plain Sewing Machine	13
A3	Mark the position of the front planket on the left front body	Working table	6		
A4	Press and fold left front edge	BSP-300	32	Automatic Front Placket Sewing and Pressing Machine	40
A5	Fuse fusible lining on front placket and press and fold 2 edges of the left front placket	BSP-300	62.7		
A6	Sew front placket to left front	DDL-5550N-7	25		
A7	Sew 2 parallel top stitches on the front placket	DDL-5550N-7	29.7		
A8	Mark the position where the pocket mouth is folded	Working table	4		
A9	Press and fold pocket mouth	BSP-300	28.2	Automatic Pocket Pasting Machine WS-8700	20
A10	Topstitch pocket mouth	DDL-5550N-7	6		
A11	Press pocket	BSP-300	46.1		
A12	Mark the position of the pocket on the left front	Working table	6		
A13	Sew pocket on left front	DDL-5550N-7	30.3		
B1	Sew brand lable to under yoke	DDL-5550N-7	23	JUKI AMS-221EN-2516	18
B2	Sew 2 yokes to back	DDL-5550N-7	21.1		21.1
B3	Counter stitch yoke	DDL-5550N	13	DDL-5550N-7	13
C2	Press and fold under sleeve placket	BSP-300	53	BSP-300	53
C3	Sew under sleeve placket to sleeve	DDL-5550N-7	19.6	DDL-5550N-7	19.6
C1	Press and fold upper sleeve placket	BSP-300	78.3	U-3506-D/PS	36
C4	Sew upper sleeve placket to sleeve and topstitch sleeve placket	DDL-5550N-7	53.3		
C5	Press and fold sleeve edge	BSP-300	61.3	BSP-300	61.3

No	The operation step	TSL		MSL	
		Machine	Time (s)	Machine	Time (s)
D1	Fuse fusible lining on upper cuff and press and fold upper cuff edge	BSP-300	31.6	BSP-300	31.6
D2	Fell upper cuff bottom	DDL-5550N-7	15.2	DDL-5550N-7	15.2
D3	Run stitch cuff	DDL-5550N-7	41.7	971-825 Dürkopp Adler	30
D4	Cut and turn cuff	Working table	11.6		
D5	Press and form cuff	BSP-300	24.7	NS-85P	4
D6	Topstitch cuff	DDL-5550N	31	DDL-5550N	31
E1	Fuse fusible lining on upper collar	BSP-300	19		
E2	Run stitch collar	DDL-5550N-7	37.8	UAM-03	31
E3	Cut and turn collar	Working table	8		
E4	Press and form collar	BSP-300	22.4	NS-81P-1 & NS-6050J	42
E5	Topstitch collar	DDL-5550N-7	20.5		
E6	Sew closed collar bottom	DDL-5550N-7	10.7	DDL-5550N-7	10.7
E7	Mark the center point on the collar	Working table	4	Working table	4
E8	Fuse fusible lining on upper collar band and press and fold collar band bottom edge	BSP-300	46.6	BSP-300	46.6
E9	Fell collar band bottom	DDL-5550N-7	12	DDL-5550N-7	12
E10	Mark 3 points on the collar band	Working table	31.2	Working table	31.2
E11	Sew collar band to collar	DDL-5550N-7	27.6	DDL-5550N-7	27.6
E12	Cut and turn collar band	Working table	5	Working table	5
E13	Press and form collar band	BSP-300	24.5	BSP-300	24.5
E14	Topstitch collar band	DDL-5550N-7	15.8	DDL-5550N-7	15.8
E15	Cut collar band bottom	Working table	5.3	Working table	5.3
E16	Mark 3 points on the collar band bottom	Working table	4.3	Working table	4.3
F1	Sew shoulder	DDL-5550N-7	36	DDL-5550N-7	36
F2	Counter stitch shoulder	DDL-5550N-7	20.7	DDL-5550N-7	20.7
F3	Sew collar to body	DDL-5550N-7	20.8	DDL-5550N-7	20.8
F4	Counter stitch collar	DDL-5550N-7	26	DDL-5550N-7	26
F5	Sew sleeve to body	DDL-5550N-7	63.2	DDL-5550N-7	63.2
F6	Press the sleeve sewn seam towards the body	BSP-300	59	BSP-300	59
F7	Counter stitch sleeve	DDL-5550N-7	32.6	DDL-5550N-7	32.6
F8	Sew side and under sleeve	MS-1190	67.8	MS-1190	67.8
F9	Sew pleat on sleeve	DDL-5550N-7	17.2	DDL-5550N-7	17.2
F10	Sew cuff to sleeve	DDL-5550N-7	34.7	DDL-5550N-7	34.7
F11	Press and fold the hem	BSP-300	84.4	BSP-300	84.4
F12	Topstitch hem	DDL-5550N-7	31.6	DDL-5550N-7	31.6
F13	Sew buttonhole to front placket, cuff and sleeve placket	LHB-780	48.8	LHB-780	48.8
F14	Sew button to front placket, cuff and sleeve placket	MB-373	84.5	MB-373	84.5
Total time			1742.9		1310.1

- Group 1: Processing group of front body, back body, fly with buttonhole, pocket and sleeve.
- Group 2: Processing group of cuff and collar.
- Group 3: Assembly group.

Table 3's division of the shirt manufacturing process's stage count into three processing groups facilitates the maintenance of a steady product flow along the assembly line. This contributes to the autonomous line's performance optimization, resulting in labor, energy, and production cost savings. The subsequent outcomes will illustrate the aforementioned modifications and tasks.

2.2.1. Results of Labor Organization for TSL

After balancing the line for each production group, the coordinated results of technological operations across the entire production line will be represented in the load chart as shown in Fig. 3. The number of operations with the individual cadencefalls within the permissible tolerance range, which is 26/34, accounting for 76.47% > 60%, while the number of under-load and overload operations is 8/34, accounting for 23.53%. This indicates that coordinating such operations is reasonable. Therefore, the parameters for the traditional sewing line are as follows: Individual cadence

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of the production line (R) ≈ 28.8s. Production capacity of the line (P) = 1000 products/shift. Total manufacturing time for a product (Tctsp) = 1742.9s. Total number of workers directly involved in production (N) = 60 people. Productivity per worker (Q) = 16 products/person/shift. Total number of machines used on the line: 66 machines.

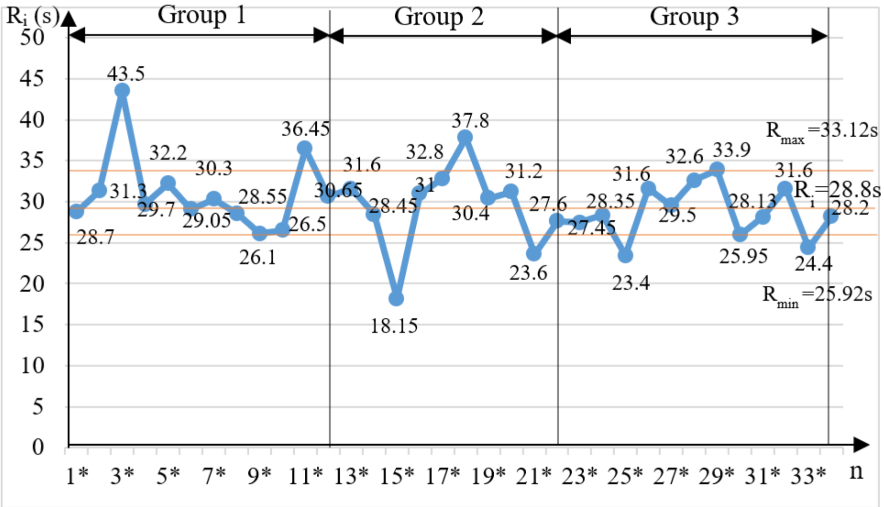


Fig. 3. Overall load chart of the traditional sewing line (TSL)

2.2.2. Labor Organization for MSL

Similarly to the labor organization with TSL, we have the load chart after coordinating the operations as shown in Fig. 4. The load chart indicates that the number of operations with individual cadence falls within the permissible tolerance range, which is 19/27, accounting for 70.37% > 60%. Meanwhile, the number of under-load and overload operations is 8/27, accounting for 29.63%. Coordinating such operations in MSL is deemed reasonable.

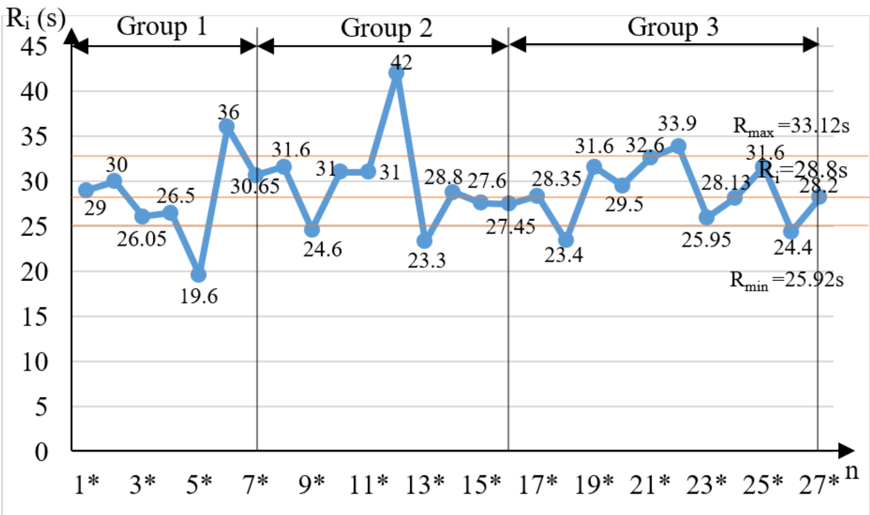


Fig. 4. Overall load chart of the modern sewing line (MSL)

The following technical parameters have been recalculated for MSL: The individual production line cadence (R) is 28.8 seconds. The line's production capacity (P) is one thousand items per shift. The product's total manufacturing time (Tctsp) is 1310.1 seconds. The total number of individuals directly engaged in production (N) is 46. 21 products per individual per shift is the labor productivity per employee (Q). There were 49 devices utilized in total along the line. On the basis of the parameters determined for the two lines, the following comparison charts have been generated for each parameter:

- Total manufacturing time for a product Tctsp (s).
- Total number of workers directly involved in production N (people).
- Total number of machines on the line.
- Labor productivity/worker Q (products/person/shift).

Based on the chart in Fig. 5, we can see that the use of semi-automatic equipment in the production of basic men's shirts has reduced the total product manufacturing time from 1742.9s to 1310.1s, which has saved 24,83% of total manufacturing time for a product. In Fig. 6 illustrates the initial selection capacity P remains constant at 1000 products per shift. However, the workforce engaged in production on the MSL has reduced from 60 to 46 individuals, resulting in a 23.33% reduction in direct labour on the production line.

As depicted in Fig. 7, the number of machines in the queue decreased by 25.76%, or 14 machines, from 65 machines using conventional stitching equipment to 51 machines using semi-automatic equipment. As shown in Fig. 8, the labour productivity of each worker on the sewing line equipped with semi-automatic machinery has increased by 23.8% to 21 products per person per shift, whereas the line employing conventional sewing equipment yields only 16 products per person per shift.

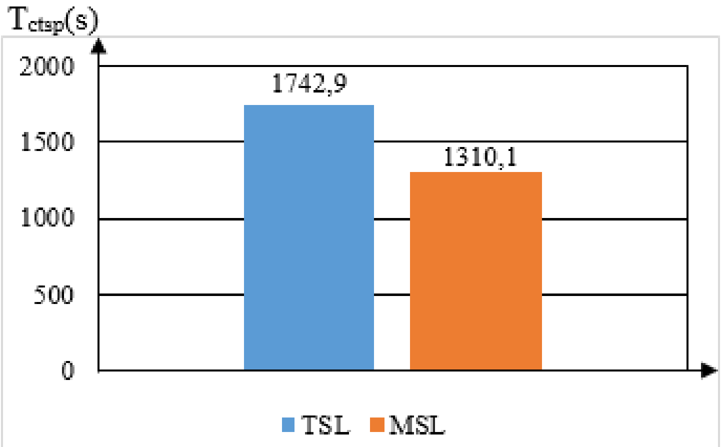


Fig. 5. Compare total product manufacturing time between TSL and MSL

Fig. 6. Compare the number of workers directly involved in the sewing line N (people)

In the comparison with TSL (Fig. 9a), the stages are continuously optimized, helping to improve the efficiency and productivity of the entire line, in Fig. 9b. The production lines are improved by using MSL, in Fig. 9b. Besides, data management is also optimized, contributing to improving the management quality of the entire system.

Fig. 7. Compare the total number of machines used on the line between TSL and MSL

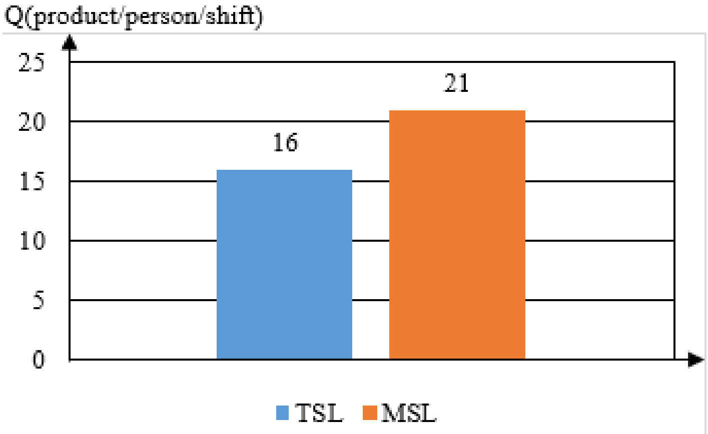


Fig. 8. Compare labor productivity per worker between TSL and MSL (products/ person/ shift)

(a) (b)

Fig. 9. The actual product line with (a) TSL and (b) MSL

3. Designing Software for Digitizing the Data of the Men's Shirt Production Process

The organization of the production deployment for men's shirts involves labor force, apparatus, and product processing technology. Conversely, men's shirts exhibit a wide array of fashionable designs and varieties; the machinery system comprises manual, automatic, and semi-automatic components; and the workforce comprises individuals with varying degrees of expertise and proficiency. A very large and interconnected data system is the result. Moreover, clothing products are subject to extremely stringent quality standards and export delivery and production schedules.

Hence, the development of software aimed at digitizing the data within the system will serve to enhance the efficiency of the production deployment procedure within the textile and garment sector [52].

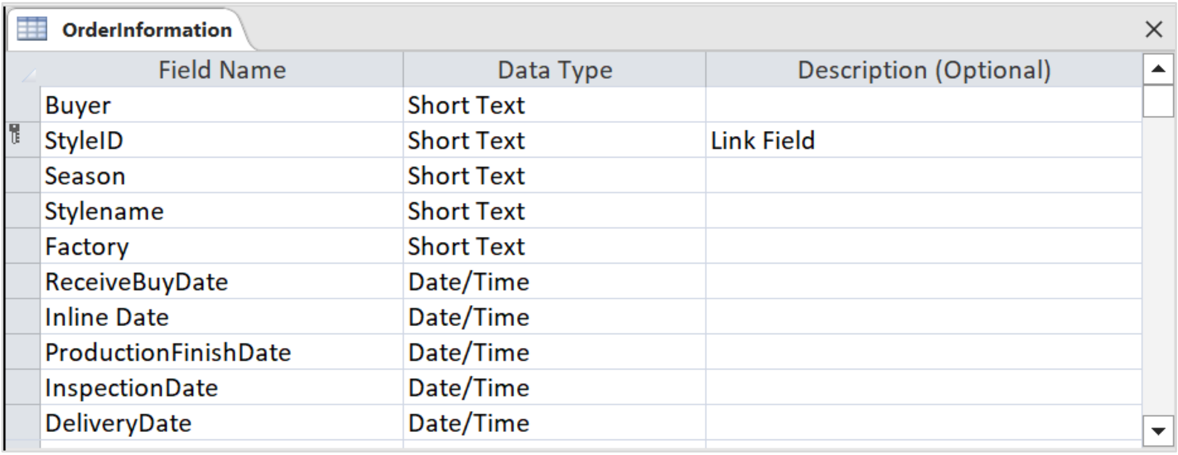
MS Access is relational database management software that provides a collection of tools for developing applications rapidly and simply. MS Access facilitates the organization, management, and exploitation of data on a computer through the development of non-programmatically executable applications [53]. As a result, Access software was selected by the author's team to design and develop the database for the men's shirt processing procedure digitization software. It comprises the subsequent procedures: The process involves the following stages: constructing the software structure, designing software features, finalizing the interface, establishing relationships between data fields, running tests, and conducting evaluations. The software design process will consist of the subsequent phases:

3.1. Building a Database System

The database system must be constructed as the initial phase of software design, and it must then progress through the subsequent stages: Gathering and structuring essential data; Partitioning data into tables; Configuring table data fields and assigning primary keys; Relationship establishment among database entities. The development of the software requires the creation of the subsequent nine database tables: Information regarding orders; A list of processing clusters; A classification of processing clusters; A sewing technology process for processing clusters; Configure the processing method for each cluster. Coordination of elemental processes; Equipment profile; Worker profile; and Elements of process coordination in detail.

3.1.1. Order Information

The database table "Order Information" comprises 10 data fields with data types configured as depicted in Fig. 10. Among them, a primary data field is the "Style ID" which also serves as a linking field. Users will update data and information about products when receiving orders in this database table.


OrderInformation

Field Name	Data Type	Description (Optional)
Buyer	Short Text	
StyleID	Short Text	Link Field
Season	Short Text	
Stylename	Short Text	
Factory	Short Text	
ReceiveBuyDate	Date/Time	
Inline Date	Date/Time	
ProductionFinishDate	Date/Time	
InspectionDate	Date/Time	
DeliveryDate	Date/Time	

Fig. 10. Design view for the "order information" database table

3.1.2. List of Processing Clusters

As illustrated in Fig. 11, the "List of processing clusters" database table is a data table that enumerates assembly and primary clusters for the men's shirt product. It consists of three data fields, each of which is formatted with a distinct data type. As the linkage field of the primary table, the "Processing Clusters ID" data field serves as the primary key. The codes for the listed main clusters and assembly clusters have been designated by the author in the primary key field of this table, in accordance with the guidelines outlined in the "Setting Primary Key" section. The data in this database table is author-prescribed with default values as shown in Fig. 12.

ListProcessingCluster

Field Name	Data Type	Description (Optional)
Order of Processing Clusters	Short Text	
Processing Clusters Name	Short Text	
Processing Clusters ID	Short Text	Link Field

Fig. 11. Design view for the "list of processing clusters" database table

ListProcessingCluster

Order of Processing Clusters	Processing Clusters Name	Processing Clusters ID
1	Processing the left shirt placket	A-LP
2	Processing the right shirt placket	B-RP
3	Processing the chest pocket	C-CP
4	Processing the back body	D-BB
5	Processing the collar	E-CO
6	Processing the sleeves	F-SL
7	Processing the bottom sleeves	G-BS
8	Processing the sewing shoulder	H-SS
9	Processing to attach collar on the body	I-AC
10	Processing to attach sleeves on the body	K-AS
11	Processing to finish the product	L-FP

Fig. 12. The data stored in the "list of processing clusters" database table

3.1.3. Processing Clusters Classification

The "Processing Group Classification" database table is used to store various structures for classifying main clusters and assembly clusters on the men's shirt product. This table comprises 3 data fields, and their respective data types are presented as shown in Fig. 13. The primary key, simultaneously the linking field of this data table, is the "Processing Method ID".

ProcessingClustersClassification

Field Name	Data Type	Description (Optional)
ProcessingClusterID	Short Text	
ProcessingMethodofDetailCluster	Short Text	
ProcessingMethodID	Short Text	Link Field

Fig. 13. Design view for "processing clusters classification" database table

3.1.4. Sewing Technology Process for Processing Clusters

The database table titled "Sewing technology process for processing clusters" contains information pertaining to the sewing technology process utilized in every classified main cluster and assembly cluster. As shown in Fig. 14, this database table contains seven data fields. The primary key of this database table is the "Elemental Process ID" while the "Processing Method ID" serves as the linking data field.

SewingTechnologyProcess

Field Name	Data Type	Description (Optional)
Elemental ProcessID	Short Text	
Elemental Process Name	Short Text	
Work Characteristics	Yes/No	
Tyle of Equipment	Short Text	
Worker Level	Short Text	
Time	Number	
Processing MethodID	Short Text	Link Field

Fig. 14. Design view for "sewing technology process for processing clusters" database table

3.1.5. Set up the Processing Method of Each Cluster

The "Set up the processing method of each cluster" database table is a descriptive table outlining the specific structure of main clusters and assembly clusters for a specific product. It comprises 3 key information fields as shown in Fig. 15, including: "Style ID" - data linked to a specific product code, "Processing Cluster ID" - data representing the main clusters and assembly clusters on that particular product, and "Processing Method ID" - data representing the specific structure or processing method of those main clusters and assembly clusters.

SetuptheProcessingMethodforeachCluster

Field Name	Data Type	Description (Optional)
StyleID	Short Text	
ProcessingCluterID	Short Text	
ProcessingMethodID	Short Text	

Fig. 15. Design view for "set up the processing method of each cluster" database table

3.1.6. Coordination of Elemental Processes

The primary objective of the database table titled "Coordination of Elemental Processes" is to retain a comprehensive coordination chart for the elemental processes across an entire product production line. This chart comprises concise summaries of data pertaining to the overall workforce and equipment, worker hierarchies, and equipment variants. It functions as the fundamental basis for the automated organization of personnel and machinery. As illustrated in Fig. 16, this database table is populated with eight crucial data fields that encompass all the essential storage information required for an elemental process chart. In addition to functioning as the linkage field, the "Elemental Process Coordination ID" is the primary key of this database table. Users are responsible for updating the elemental process chart for a particular product with all pertinent information and data.

3.1.7. Worker Profile

The purpose of the "Worker Profile" database table is to maintain fundamental worker information in order to facilitate the software development procedure for worker assignment automation. The database table in question is structured to contain nine essential data elements, which comprise the most fundamental personal details of an employee. The database table will be updated and stored by users through manual means.

CoordinationofElementalProcesses

Field Name	Data Type	Description (Optional)
Style ID	Short Text	Link Field
Sequence	Number	
Elemental Process Coordination ID	Short Text	Link Field
Coordination Process Step	Short Text	
Total Standard Time (s)	Currency	
Individual Cadence (s)	Currency	
Worker Level	Number	
Total number of workers	Number	
Tyle of Equipment	Short Text	
Total number of equipment	Number	

Fig. 16. Design view for "'coordination of elemental processes" database table

WorkerProfile

Field Name	Data Type	Description (Optional)
WorkerID	AutoNumber	Link Field
Full name of the worker	Short Text	
Gender	Yes/No	
Birthday	Date/Time	
Address	Short Text	
Place of origin	Short Text	
Worker Level	Number	
Date of employment	Date/Time	
Status	Yes/No	

Fig. 17. Design view for "worker profile" database table

3.1.8. Equipment Profile

Similar to the "Worker Profile", "Equipment Profile" database table is used to store basic information about equipment, in Fig. 17. It integrates with the "Worker Profile" table to support the software design process for automatically arranging equipment. The database table comprises 16 data fields, with 1 primary key field, which is also the linking field as shown in Fig. 18.

EquipmentProfile

Field Name	Data Type	Description (Optional)
Equipment ID	Short Text	Link Field
Equipment name	Short Text	
Equipment category	Short Text	
Manufacturing country	Short Text	
Manufacturing year	Date/Time	
Supplier	Short Text	
Unit Price	Currency	
Purchase date	Date/Time	
Start date of production	Date/Time	
Liquidation price	Currency	

Fig. 18. Design view for "equipment profile" database table

3.1.9. Details of Elemental Process Coordination

"Details of elemental process coordination" is a holding table within the database. It compiles information from the database tables mentioned earlier in order to store comprehensive coordination data for a particular product. As shown in Fig. 19, this data table comprises seven key data fields and three linking fields. The author designates this database table as a "waiting table" due to the fact that neither the author nor the user pre-populates or updates its data. Until the user selects the "Assign" button, the table data will remain in a pending state until the "Assignment" module is executed. Subsequently, the software will be executed, inserting all the information into the table in an automated fashion.

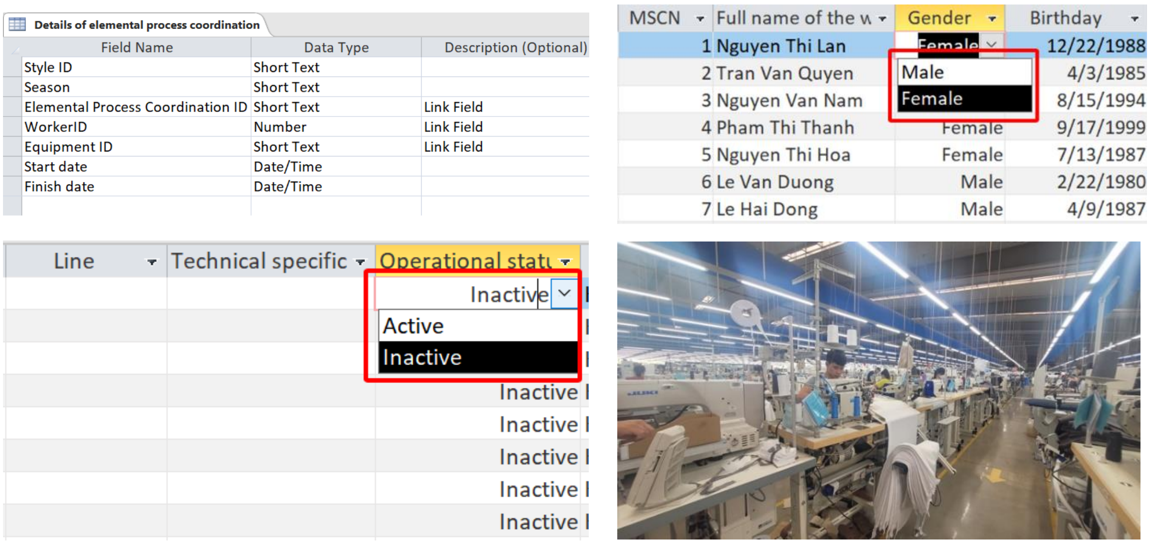


Fig. 19. Design view for "details of elemental process coordination" database table

3.2. Relationships Between Database Tables

The objective of the shirt-specific digital data software for the garment manufacturing technology process is to produce comprehensive coordination outcomes utilizing a compilation of foundational data, such as apparatus profiles, worker profiles, and the garment manufacturing technology process table. Therefore, the database table labelled "Details of elemental process coordination" functions as the primary data table for the entire database infrastructure. It facilitates the development of modules that execute data automatically. Three data tables inlude "Coordination of elemental processes", "Worker Profile", and "Equipment Profile". The "Order Information" table serves as the ancestor for the "Coordination of elemental processes" table. The interrelationships that ensue among the tables are visually represented in Fig. 20.

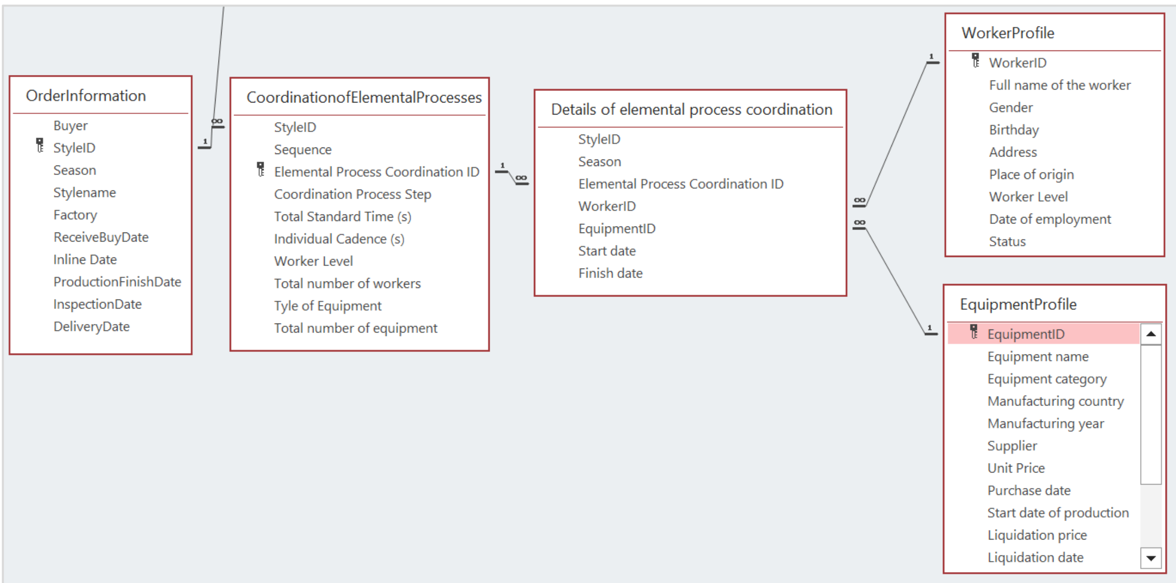


Fig. 20. Manegement tables for worker assignment and automatic equipment arrangement

3.3. Designing the Interface for the Digital Software of the Sewing Process

The digital software for automating the creation of the technology process table for men's shirt manufacturing is defined with a structure consisting of 2 modules: Building the sewing technology process and assigning workers and arranging equipment to serve the design of the sewing line.

3.3.1. Module "Building the Sewing Technology Process"

Comprises 3 Tasks with Features and Interfaces Presented Sequentially as follows.

- Task 1: Order Information

Users can update, store, and edit information directly on the "Order Information" interface (Fig. 21) by entering data into text boxes and utilising buttons located in the upper-right quadrant of the screen, including the data update button, save button, navigation buttons, and so forth. The interface and functionalities designed for this task have satisfactorily met the author's functional requirements, as indicated by the results of this test run. The software must facilitate direct updates, storage, and edits of information, in addition to the submission of data related to orders, as indicated in Fig. 22. In subsequent procedures, the data that is retained will be applied.

- Task 2: Setting up the processing method of each cluster on the production

Once the fundamental order information has been stored, users will proceed to this task in order to establish the appropriate structure or processing method for each primary cluster and assembly cluster associated with the product. The cluster "Processing the left shirt planket" is illustrated in this section with the structure "Soft Front Placket" (Table 4 and Fig. 23). The data set on the interface of this task will be immediately automatically stored in the original database table. Then, the system will perform all the functions that the author has designed and build a complete sewing technology process table for the order, as presented below.

- Task 3: The sewing technology process of the product

"The sewing technology process of the product" depicts the outcome of the sewing technology process for the 78J6178 product, including the sewing stages for clusters established in task 2, in Fig. 24. Upon examining the interface's representation of the sewing technology process, one can discern that the elemental processes or processing steps have been automatically arranged in the proper sequence for each cluster, with the requisite conditions for moving forward with the allocation of personnel and configuration of equipment along the production line.

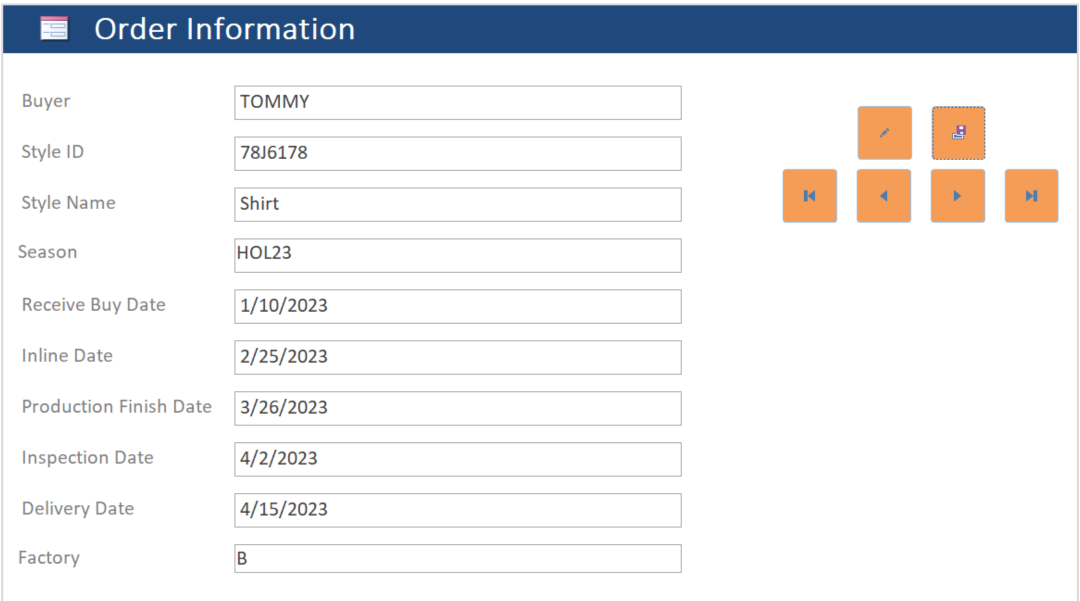
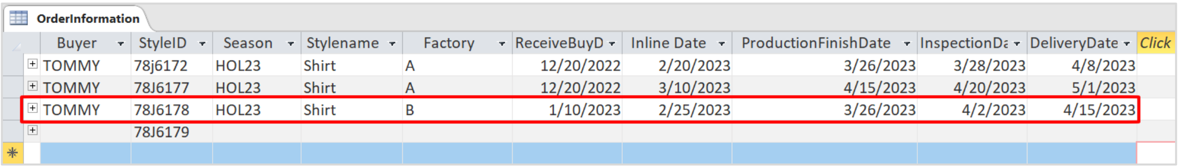


Fig. 21. The test run result of updating information on the main interface of the "order information" task



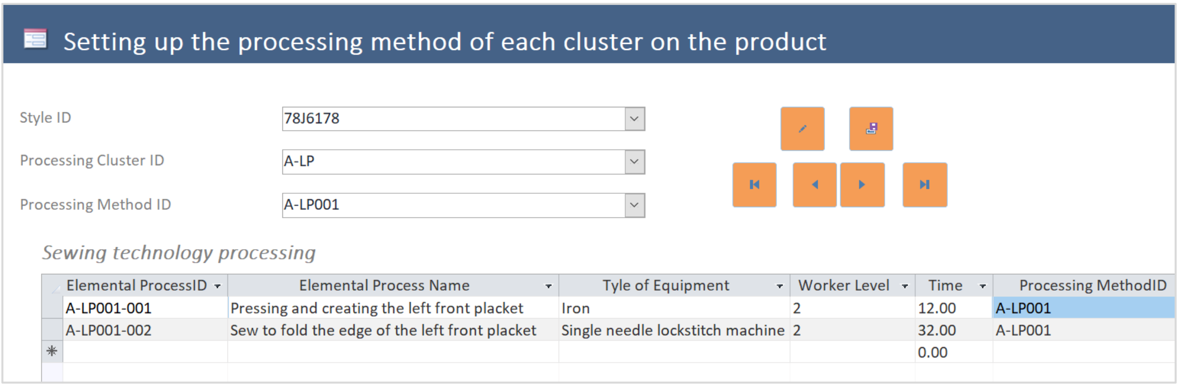
OrderInformation

Buyer	StyleID	Season	Stylename	Factory	ReceiveBuyD	Inline Date	ProductionFinishDate	InspectionD	DeliveryDate	Click
TOMMY	78j6172	HOL23	Shirt	A	12/20/2022	2/20/2023	3/26/2023	3/28/2023	4/8/2023	
TOMMY	78J6177	HOL23	Shirt	A	12/20/2022	3/10/2023	4/15/2023	4/20/2023	5/1/2023	
TOMMY	78J6178	HOL23	Shirt	B	1/10/2023	2/25/2023	3/26/2023	4/2/2023	4/15/2023	
	78J6179									

Fig. 22. The updated data results on the main interface are stored in the “order information” database table

Table 4. The data for “processing cluster ID” and “processing method ID” respectively exist on the product code 78J6178 men's shirt

Style ID	Processing Cluster	Processing	Processing Method of	Processing
78J6178	Processing the left shirt	A-LP	Soft Front Placket	A-LP001
78J6178	Processing the right shirt	B-RP	Covered Placket	B-RP002
78J6178	Processing the chest pocket	C-CP	Chest pocket with visible seam	C-CP001
78J6178	Processing the back body	D-BB	The back body with 2 layer yoke	D-BB002



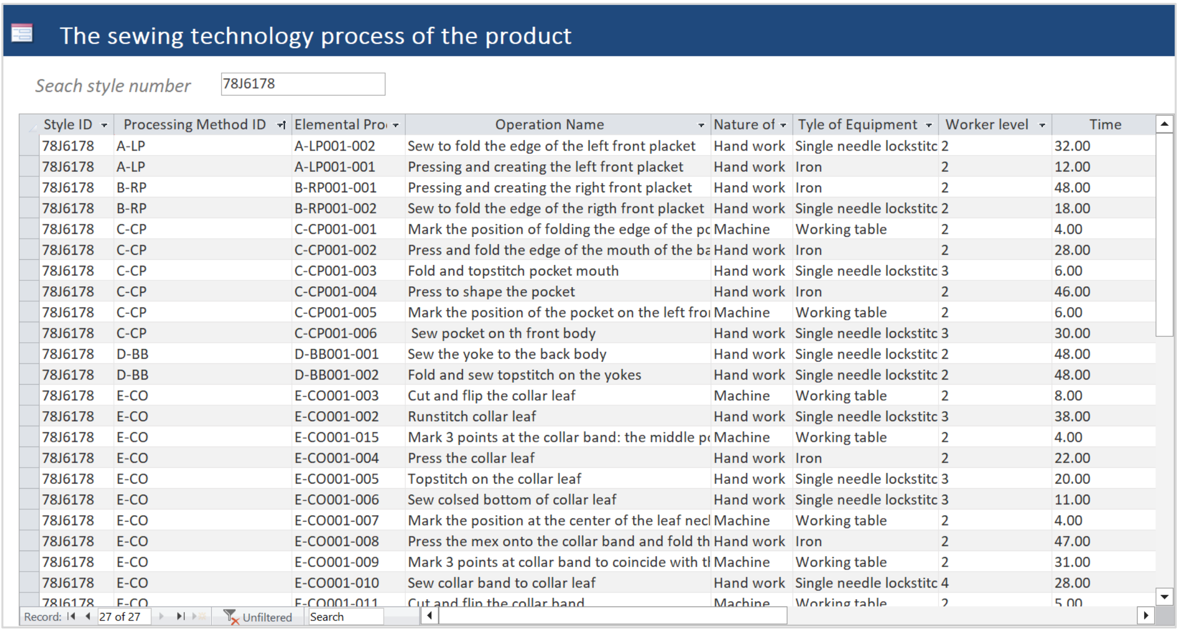
Setting up the processing method of each cluster on the product

Style ID: 78J6178
Processing Cluster ID: A-LP
Processing Method ID: A-LP001

Sewing technology processing

Elemental ProcessID	Elemental Process Name	Tyle of Equipment	Worker Level	Time	Processing MethodID
A-LP001-001	Pressing and creating the left front placket	Iron	2	12.00	A-LP001
A-LP001-002	Sew to fold the edge of the left front placket	Single needle lockstitch machine	2	32.00	A-LP001
				0.00	

Fig. 23. The result of setting up the processing method for the cluster “processing the left shirt placket” as “soft front placket” on the interface of the task “setting up the processing method of each cluster on the product”



The sewing technology process of the product

Seach style number: 78J6178

Style ID	Processing Method ID	Elemental Pro	Operation Name	Nature of	Tyle of Equipment	Worker level	Time
78J6178	A-LP	A-LP001-002	Sew to fold the edge of the left front placket	Hand work	Single needle lockstitc	2	32.00
78J6178	A-LP	A-LP001-001	Pressing and creating the left front placket	Hand work	Iron	2	12.00
78J6178	B-RP	B-RP001-001	Pressing and creating the right front placket	Hand work	Iron	2	48.00
78J6178	B-RP	B-RP001-002	Sew to fold the edge of the rigth front placket	Hand work	Single needle lockstitc	2	18.00
78J6178	C-CP	C-CP001-001	Mark the position of folding the edge of the pc	Machine	Working table	2	4.00
78J6178	C-CP	C-CP001-002	Press and fold the edge of the mouth of the ba	Hand work	Iron	2	28.00
78J6178	C-CP	C-CP001-003	Fold and topstitch pocket mouth	Hand work	Single needle lockstitc	3	6.00
78J6178	C-CP	C-CP001-004	Press to shape the pocket	Hand work	Iron	2	46.00
78J6178	C-CP	C-CP001-005	Mark the position of the pocket on the left fro	Machine	Working table	2	6.00
78J6178	C-CP	C-CP001-006	Sew pocket on th front body	Hand work	Single needle lockstitc	3	30.00
78J6178	D-BB	D-BB001-001	Sew the yoke to the back body	Hand work	Single needle lockstitc	2	48.00
78J6178	D-BB	D-BB001-002	Fold and sew topstitch on the yokes	Hand work	Single needle lockstitc	2	48.00
78J6178	E-CO	E-CO001-003	Cut and flip the collar leaf	Machine	Working table	2	8.00
78J6178	E-CO	E-CO001-002	Runstitch collar leaf	Hand work	Single needle lockstitc	3	38.00
78J6178	E-CO	E-CO001-015	Mark 3 points at the collar band: the middle pc	Machine	Working table	2	4.00
78J6178	E-CO	E-CO001-004	Press the collar leaf	Hand work	Iron	2	22.00
78J6178	E-CO	E-CO001-005	Topstitch on the collar leaf	Hand work	Single needle lockstitc	3	20.00
78J6178	E-CO	E-CO001-006	Sew colsed bottom of collar leaf	Hand work	Single needle lockstitc	3	11.00
78J6178	E-CO	E-CO001-007	Mark the position at the center of the leaf necl	Machine	Working table	2	4.00
78J6178	E-CO	E-CO001-008	Press the mex onto the collar band and fold th	Hand work	Iron	2	47.00
78J6178	E-CO	E-CO001-009	Mark 3 points at collar band to coincide with tl	Machine	Working table	2	31.00
78J6178	E-CO	E-CO001-010	Sew collar band to collar leaf	Hand work	Single needle lockstitc	4	28.00
78J6178	E-CO	E-CO001-011	Cut and flip the collar band	Machine	Working table	2	5.00

Record: 27 of 27 Unfiltered Search

Fig. 24. Search results for the sewing technology process of a specific product

3.3.2. Module "Worker Assignment and Equipment Arrangement"

Once the author has acquired adequate information and data from the stitching technology process chart in the preceding task, they will examine and assess the automated results during a test run by carrying out the subsequent procedures in the task of worker assignment and equipment arrangement. The following actions constitute the precise procedures that users will undertake while performing the task: software testing:

- Step 1: Select data for "Style ID" (see Fig. 25).
- Step 2: Selecting data for "Season" within the "Style ID" data (see Fig. 26).
- Step 3: Click the "Assignment" button to assign workers and equipment to the production line for product style 78J6178. Immediately, the software displays a notification indicating the number of machines assigned and the remaining quantity as shown in Fig. 27. Upon clicking "OK" a detailed form shows the quantity of equipment types needed and used, accompanied by a Messenger Box stating "Success" as in Fig. 28.
- Step 4: After selecting "OK" in the Messenger Box, the data will be displayed in the supplementary form "Details of elemental process coordination". At this point, user will see that the software has assigned suitable workers and corresponding equipment to the workflow steps, as shown in Fig. 29.
- Step 5: Prior to selecting the "Finish" button, users ascertain when each workflow phase concludes by monitoring the actual production environment. The "Details of elemental process coordination" sub-form will update with the "Production Finish Date" data as soon as this button is pressed. This signifies the completion of the corresponding work phase and resets the status of the worker and equipment. The illustration of the outcome is presented in Fig. 30.

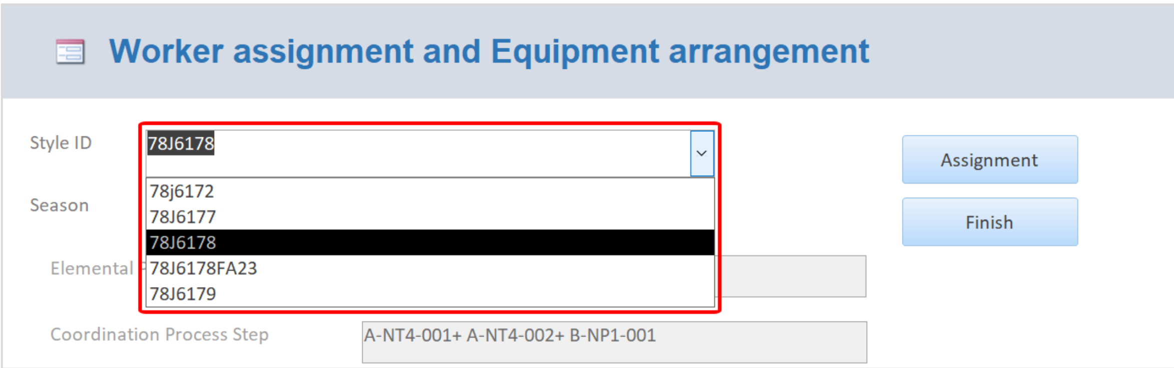


Fig. 25. The displayed result of selecting data for "Style ID" on the interface

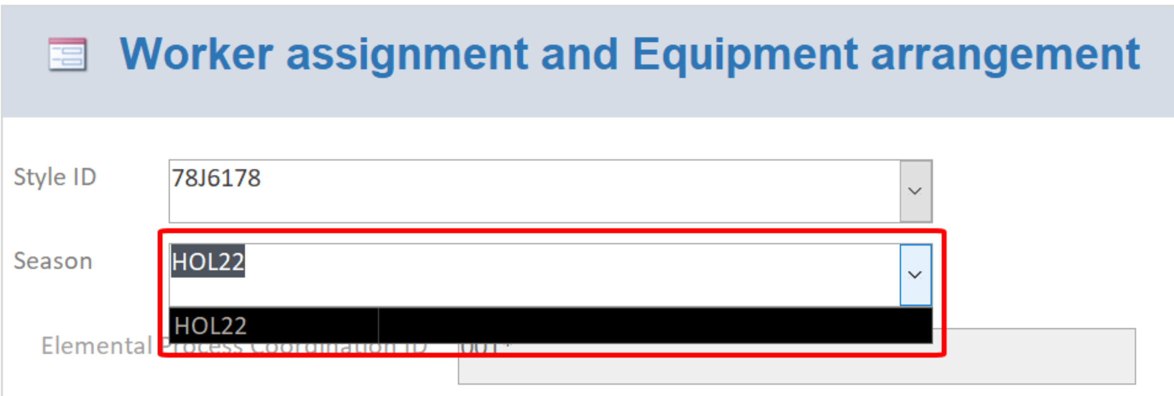


Fig. 26. The displayed results of selecting data for "season" on the interface

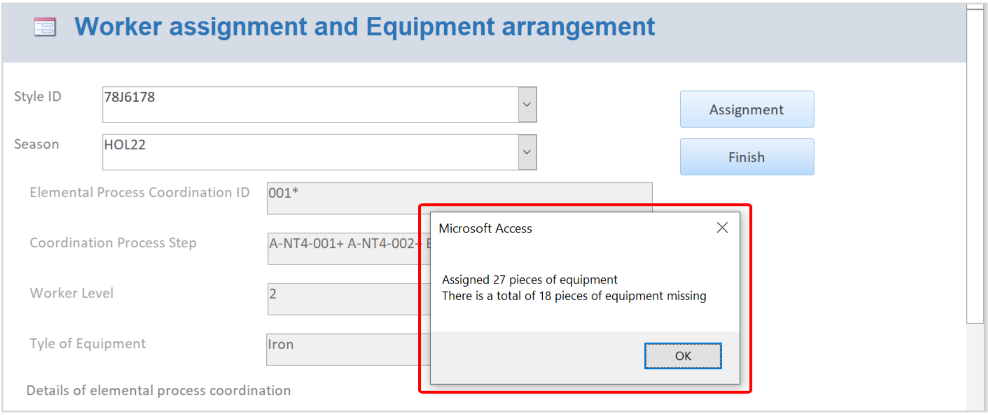
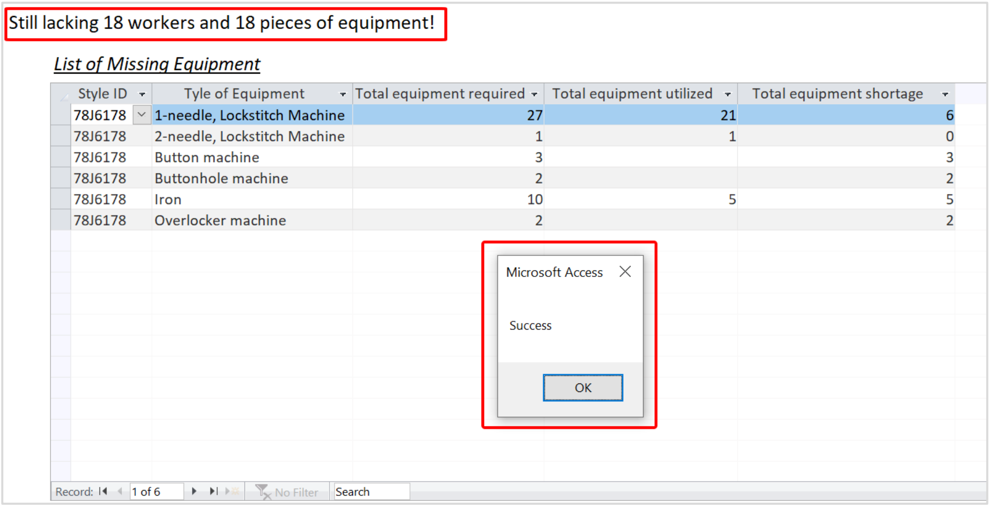
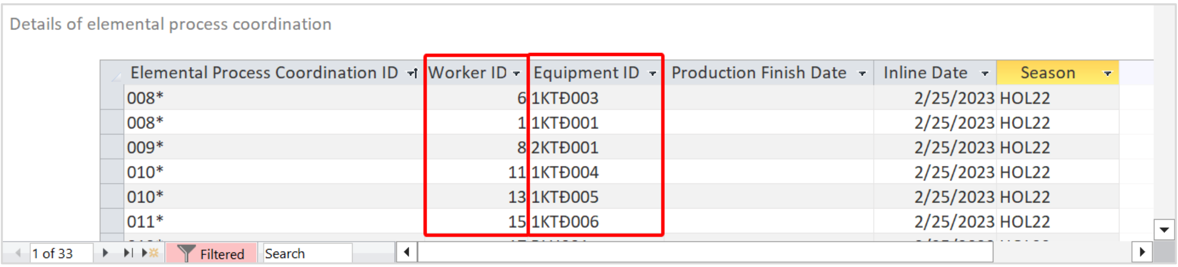


Fig. 27. The result of the software notifying the quantity of assigned equipment and the remaining quantity



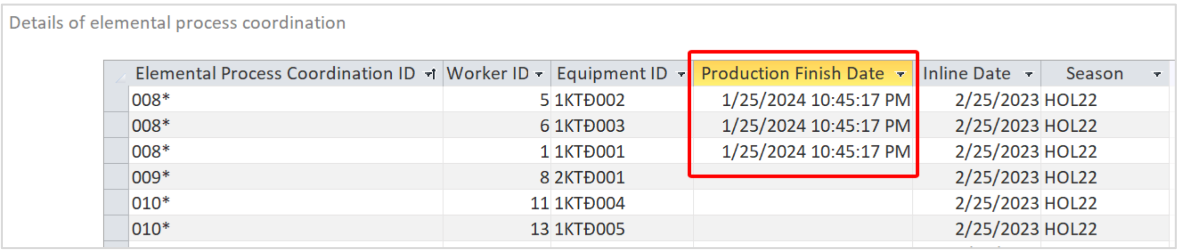
Style ID	Tyle of Equipment	Total equipment required	Total equipment utilized	Total equipment shortage
78J6178	1-needle, Lockstitch Machine	27	21	6
78J6178	2-needle, Lockstitch Machine	1	1	0
78J6178	Button machine	3		3
78J6178	Buttonhole machine	2		2
78J6178	Iron	10	5	5
78J6178	Overlocker machine	2		2

Fig. 28. The interface displays a detailed form showing the quantity of required and missing types of equipment, accompanied by a messenger box notification stating "success"



Elemental Process Coordination ID	Worker ID	Equipment ID	Production Finish Date	Inline Date	Season
008*	6	1KTĐ003		2/25/2023	HOL22
008*	1	1KTĐ001		2/25/2023	HOL22
009*	8	2KTĐ001		2/25/2023	HOL22
010*	11	1KTĐ004		2/25/2023	HOL22
010*	13	1KTĐ005		2/25/2023	HOL22
011*	15	1KTĐ006		2/25/2023	HOL22

Fig. 29. The result of arranging workers and equipment for each workflow step is displayed in the sub-form "details of elemental process coordination"



Elemental Process Coordination ID	Worker ID	Equipment ID	Production Finish Date	Inline Date	Season
008*	5	1KTĐ002	1/25/2024 10:45:17 PM	2/25/2023	HOL22
008*	6	1KTĐ003	1/25/2024 10:45:17 PM	2/25/2023	HOL22
008*	1	1KTĐ001	1/25/2024 10:45:17 PM	2/25/2023	HOL22
009*	8	2KTĐ001		2/25/2023	HOL22
010*	11	1KTĐ004		2/25/2023	HOL22
010*	13	1KTĐ005		2/25/2023	HOL22

Fig. 30. The result showing the date and time of completion for each workflow step in the "details of elemental process coordination" sub-form

Based on the test run of the "Worker assignment and equipment arrangement", module was executed in accordance with the steps and outcomes detailed above. An absence of complications or errors was noted throughout the testing phase, as the software effectively and seamlessly allocated personnel and equipment. Consequently, the software is designed to be user-friendly, with well-defined functions that enable navigation and comprehension without the need for detailed instructions.

4. Conclusion

In the digital age, achieving sustainability through the implementation of digital transformation has become a prerequisite for business expansion. Utilizing this approach to establish trust with critical stakeholders is even more crucial in the context of business-to-business commerce. Implementing such strategies may contribute to the manufacturing sector's environmental sustainability, societal well-being, and financial gains. In the comparison between TSL and MSL, using digital software for administrative and production management in conjunction with intelligent control systems and automation systems has helped reduce the amount of time, energy, and money wasted on the production of garments. wear. Moreover, the implementation of a market economy has substantially enhanced the competitiveness of small and medium-sized textile and garment enterprises, enabling them to penetrate and dominate the domestic market as well as expand their international presence.

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References

[1] M. A. Iqbal, J. Su, "Apparel professionals' perception of sustainability-related technology: a structural equation modeling approach," *Research Journal of Textile and Apparel*, 2023, https://doi.org/10.1108/RJTA-04-2023-0040.

[2] B. Deepthi, and V. Bansal, "Industry 4.0 in Textile and Apparel Industry: A Systematic Literature Review and Bibliometric Analysis of Global Research Trends," *Vision the Journal of Business Perspective*, vol. 28, no. pp. 157-170, 2020, https://doi.org/10.1177/09722629221130233.

[3] D. C. P. Jayasuriya, G. D. N. Perera, and A. Padukkage, "Developing a Practical Nomological Framework on Cyber loafing and Job performance for the Global Apparel Manufacturing Sector by Identifying Research Gaps," *International Journal of Research and Innovation in Social Science*, vol. 7, no. 10, pp. 1422-1442, 2023, https://dx.doi.org/10.47772/IJRISS.2023.701110.

[4] I. Castelo-Branco, F. Cruz-Jesus, and T. Oliveira, "Assessing Industry 4.0 readiness in manufacturing: Evidence for the European Union," *Computers in Industry*, vol. 107, pp. 22-32, 2019, https://doi.org/10.1016/j.compind.2019.01.007.

[5] H. Fatorachian, and H. Kazemi, "A critical investigation of Industry 4.0 in manufacturing: Theoretical operationalization framework," *Production Planning & Control*, vol. 29, no. 8, pp. 633-644, 2018, https://doi.org/10.1080/09537287.2018.1424960.

[6] H. Fatorachian, and H. Kazemi, "Impact of Industry 4.0 on supply chain performance," *Production Planning & Control*, vol. 32, no. 1, pp. 63-81, 2021, https://doi.org/10.1080/09537287.2020.1712487.

[7] O. Bongomin, E. O. Nganyi, M. R. Abswaidi, E. Hitiyise, and G. Tumusiime, "Sustainable and dynamic competitiveness towards technological leadership of Industry 4.0: Implications for East African community," *Journal of Engineering*, pp. 1-22, 2020, https://doi.org/10.20944/preprints202004.0187.v1.

[8] A. Majumdar, H. Garg, and R. Jain, "Managing the barriers of Industry 4.0 adoption and implementation in textile and clothing industry: Interpretive structural model and triple helix framework," *Computers in Industry*, vol. 125, p. 103372, 2021, https://doi.org/10.1016/j.compind.2020.103372.

[9] M. Ghobakhloo, "The future of manufacturing industry: a strategic roadmap toward Industry 4.0," *Journal of Manufacturing Technology Management*, vol. 29, no. 6, pp. 910-936, 2018, https://doi.org/10.1108/JMTM-02-2018-0057.

[10] D. Küsters, N. Praß, and Y.S. Gloy, "Textile learning factory 4.0–preparing Germany's textile industry for the digital future," *Procedia Manufacturing*, vol. 9, pp. 214-221, 2017, https://doi.org/10.1016/j.promfg.2017.04.035.

[11] A. Ali, and M. Haseeb, "Radio frequency identification (RFID) technology is a strategic tool towards higher performance of supply chain operations in textile and apparel industry of Malaysia," *Uncertain Supply Chain Management*, vol. 7, no. 2, pp. 215-226, 2019, https://doi.org/10.5267/j.uscm.2018.10.004.

[12] T. V. Dang, D. M. C. Tran, and P. X. Tan, "IRDC-Net: Lightweight Semantic Segmentation Network Based on Monocular Camera for Mobile Robot Navigation," *Sensors*, vol 23, no. 15, p. 6907, 2023, https://doi.org/10.3390/s23156907.

[13] T. V. Dang, N. T. Bui, "Multi-Scale Fully Convolutional Network-Based Semantic Segmentation for Mobile Robot Navigation," *Electronics*, vol. 12, no. 3, p. 533, 2023, https://doi.org/10.3390/electronics12030533.

[14] T. V. Dang, N. T. Bui, "Obstacle Avoidance Strategy for Mobile Robot Based on Monocular Camera," *Electronics*, vol. 12, no. 8, p. 1932, 2023, https://doi.org/10.3390/electronics12081932.

[15] H. L. Tran, T. V. Dang, "An Ultra Fast Semantic Segmentation Model for AMR's Path Planning," *Journal of Robotics and Control*, vol. 4, no. 3, pp. 424-430, 2023, https://doi.org/10.18196/jrc.v4i3.18758.

[16] T. N. A. La, T. D. Vu, T. T. Le, and T. D. Bui, "Research MS Access software for apllication in smart garment factory machine management," *MM Science Journal*, pp. 6561-6567, 2023, http://doi.org/10.17973/MMSJ.2023_06_2023042.

[17] R. S. Peres, X. Jia, J. Lee, K. Sun, A. W. Colombo and J. Barata, "Industrial Artificial Intelligence in Industry 4.0 - Systematic Review, Challenges and Outlook," *IEEE Access*, vol. 8, pp. 220121-220139, 2020, https://doi.org/10.1109/ACCESS.2020.3042874.

[18] F. Baytar, T. Chung, and E. Shin, "Evaluating garments in augmented reality when shopping online," *Journal of Fashion Marketing and Management*, vol. 24, no. 4, pp. 667-683, 2020, https://doi.org/10.1108/JFMM-05-2018-0077.

[19] L. Corchia *et al*., "Radio-frequency Identification Based on Textile, Wearable, Chipless Tags for IoT Applications," *2019 II Workshop on Metrology for Industry 4.0 and IoT (MetroInd4.0&IoT)*, pp. 1-5, 2019, https://doi.org/10.1109/METROI4.2019.8792919.

[20] P. J. O'Connor, A. Hill, M. Kaya, B. Martin, "The measurement of emotional intelligence: A critical review of the literature and recommendations for researchers and practitioners," *Frontiers in psychology*, vol. 10, p. 1116, 2019, https://doi.org/10.3389/fpsyg.2019.01116.

[21] J. Xie *et al*, "A new description model for enabling more general manufacturing systems representation in digital twin," *Journal of Manufacturing Systems*, vol. 72, pp. 475-491, 2024, https://doi.org/10.1016/j.jmsy.2023.12.009.

[22] C. Chen, "Value creation by SMEs participating in global value chains under Industry 4.0 trend: Case study of textile industry in Taiwan," *Journal of Global Information Technology Management*, vol. 22, no. 2, pp. 120-145, 2019, https://doi.org/10.1080/1097198X.2019.1603512.

[23] C. L. Chen, "Cross-disciplinary innovations by Taiwanese manufacturing SMEs in the context of Industry 4.0," *Journal of Manufacturing Technology Management*, vol. 31, no. 6, pp. 1145-1168, 2020, https://doi.org/10.1108/JMTM-08-2019-0301.

[24] D.T. Matt, V. Modrák, and H. Zsifkovits, "Industry 4.0 for SMEs: Challenges, opportunities and requirements," *Palgrave Macmillan*, 2020, https://doi.org/10.1007/978-3-030-25425-4.

[25] F. Norman, "Key factors to promote Industry 4.0 readiness at Indonesian textile and clothing firm. Engineering, Mathematics and Computer," *Engineering, MAthematics and Computer Science (EMACS) Journal*, vol. 2, no. 2, pp. 73-83, 2020, https://doi.org/10.21512/emacsjournal.v2i2.6448.

[26] D. Horváth, and R. Z. Szabó, “Driving forces and barriers of Industry 4.0: Do multinational and small and medium-sized companies have equal opportunities?,” *Technological Forecasting and Social Change*, vol. 146, pp. 119-132, 2019, https://doi.org/10.1016/j.techfore.2019.05.021.

[27] M. Imran, W.U. Hameed, and A.U. Haque, “Influence of Industry 4.0 on the production and service sectors in Pakistan: Evidence from textile and logistics industries,” *Social Sciences*, vol. 7, no. 12, p. 246, 2018, https://doi.org/10.3390/socsci7120246.

[28] E. Rauch, P. Dallasega and M. Unterhofer, "Requirements and Barriers for Introducing Smart Manufacturing in Small and Medium-Sized Enterprises," *IEEE Engineering Management Review*, vol. 47, no. 3, pp. 87-94, 2019, https://doi.org/10.1109/EMR.2019.2931564.

[29] L. Li, “China’s manufacturing locus in 2025: With a comparison of Made-in-China 2025 and Industry 4.0,” *Technological Forecasting and Social Change*, vol. 135, pp. 66-74, 2018, https://doi.org/10.1016/j.techfore.2017.05.028.

[30] A. Lis, A. Sudolska, and M. Tomanek, “Mapping research on sustainable supply-chain management,” *Sustainability*, vol. 12, no. 10, p. 3987, 2020, https://doi.org/10.3390/su12103987.

[31] A. Happonen, and M. Ghoreishi, “A mapping study of the current literature on digitalization and Industry 4.0 technologies utilization for sustainability and circular economy in textile industries,” *Proceedings of Sixth International Congress on Information and Communication, Technology*, pp. 697-711, 2022, https://doi.org/10.1007/978-981-16-2102-4.

[32] X. Zhou, C. Gao, and D. Zhang, “Product service supply chain network competition: an equilibrium with multiple tiers and members,” *International Journal of Production Research*, pp. 1-18, 2022, https://doi.org/10.1080/00207543.2022.2060771.

[33] B. Lalic, S. Rakic, and U. Marjanovic, “Use of Industry 4.0 and organizational innovation concepts in the Serbian textile and apparel industry,” *Fibres & Textiles in Eastern Europe*, vol. 27, no. 3, pp. 10-18, 2019, https://doi.org/10.5604/01.3001.0013.0737.

[34] M. Ghobakhloo, “Industry 4.0, digitization, and opportunities for sustainability,” *Journal of Cleaner Production*, vol. 252, p. 119869, 2020, https://doi.org/10.1016/j.jclepro.2019.119869.

[35] M. Ghoreishi, and A. Happonen, “The case of fabric and textile industry: The emerging role of digitalization, internet-of-things and Industry 4.0 for circularity,” *Proceedings of Sixth International Congress on Information and Communication, Technology*, pp. 189-200, 2022, https://doi.org/10.1007/978-981-16-1781-2_18.

[36] A. A. A. Hakeem, D. Solyali, M. Asmael, and Q. Zeeshan, “Smart manufacturing for Industry 4.0 using radio frequency identification (RFID) technology,” *Jurnal Kejuruteraan*, vol. 32, no. 1, pp. 31-38, 2020, https://doi.org/10.17576/jkukm-2020-32(1)-05.

[37] E. Eurydice, P. Despoina, K. Despoina, and V. Pissas, “A methodological framework for the integration of 3D virtual prototyping into the design development of laser-cut garments,” *Journal of Engineered Fibers and Fabrics*, vol. 18, 2023, https://doi.org/10.1177/15589250231194621.

[38] M.W. Rundassa, D. Kitaw, and E. Berhan, “Comparative advantage of Ethiopian textile and apparel industry,” *Research Journal of Textile and Apparel*, vol. 23, no. 3, pp. 244-256, 2019, https://doi.org/10.1108/RJTA-08-2018-0049.

[39] N. T. Oanh, P. T. M. Hanh, N. T. Dung, “The Effectiveness of Industrial Revolution 4.0 on Labours in Industry Enterprises in Thai Nguyen Province, Viet Nam,” *European Journal of Business and Management Research*, vol. 6, no. 3, pp. 129-132, 2021, https://doi.org/10.24018/ejbmr.2021.6.3.840.

[40] V. Belvedere, A. Grando, and P. Bielli, “A quantitative investigation of the role of information and communication technologies in the implementation of a product-service system,” *International Journal of Production Research*, vol. 51, no. 2, pp. 410-426, 2013, https://doi.org/10.1080/00207543.2011.648278.

[41] M. Ardolino, M. Rapaccini, N. Saccani, P. Gaiardelli, G. Crespi and C. Ruggeri, “The role of digital technologies for the service transformation of industrial companies,” *International Journal of Production Research*, vol. 56, no. 6, pp. 2116-2132, 2018, https://doi.org/10.1080/00207543.2017.1324224.

[42] M.M. Hohn, and C.F. Durach, “Additive manufacturing in the apparel supply chain - impact on supply chain governance and social sustainability,” *International Journal of Operations & Production Management*, vol. 41, no. 7, pp. 1035-1059, 2021, https://doi.org/10.1108/IJOPM-09-2020-0654.

[43] P. Bertola, and J. Teunissen, “Fashion 4.0. Innovating fashion industry through digital transformation,” *Research Journal of Textile and Apparel*, vol. 22, no. 4, pp. 352-369, 2018, https://doi.org/10.1108/RJTA-03-2018-0023.

[44] S. Kusi-Sarpong, H. Gupta, S. A. Khan, C. J. C. Jabbour, S. T., Rehman, and H. Kusi-Sarpong, “Sustainable supplier selection based on Industry 4.0 initiatives within the context of circular economy implementation in supply chain operations,” *Production Planning & Control*, vol. 34, no. 10, pp. 1-21, 2021, https://doi.org/10.1080/09537287.2021.1980906.

[45] R. I. Chang, C. Y. Lee, and Y. H. Hung, “Cloud-based analytics module for predictive maintenance of the textile manufacturing process,” *Applied Sciences*, vol. 11, no. 21, p. 9945, 2021, https://doi.org/10.3390/app11219945.

[46] T. N. A. La, T. H. Nguyen, T. T. Hoang, and K. O. Nguyen, “Research the digital transformation model of material management in Vietnam Garment companies,” *MM Science Journal*, pp. 6753-6762, 2023, http://doi.org/10.17973/MMSJ.2023_10_2023058.

[47] M.C. Elemmi, B.S. Anami, and N.N. Malvade, “Defective and nondefective classification of fabric images using shallow and deep networks,” *International Journal of Intelligent Systems*, vol. 37, no. 3, pp. 2293-2318, 2022, https://doi.org/10.1002/int.22774.

[48] M. Rath, A. Gannouni, D. Luetticke and T. Gries, "Digitizing a Distributed Textile Production Process using Industrial Internet of Things: A Use-Case," *2021 4th IEEE International Conference on Industrial Cyber-Physical Systems (ICPS)*, pp. 315-320, 2021, https://doi.org/10.1109/ICPS49255.2021.9468203.

[49] T. V. Dang, D. S. Nguyen, “Optimal Navigation based on Improved A* Algorithm for Mobile Robot,” *The International Conference on Intelligent Systems & Networks*, pp. 574-580, 2023, https://doi.org/10.1007/978-981-99-4725-6_68.

[50] T. V. Dang, “Autonomous mobile robot path planning based on enhanced A* algorithm integrating with time elastic band,” *MM Science Journal*, pp. 6717-6722, 2023, http://doi.org/10.17973/MMSJ.2023_10_2023052.

[51] N. Yuldoshev, B. Tursunov, and S. Qozoqov, “Use of artificial intelligence methods in operational planning of textile production,” *Journal of Process Management, New Technologies*, vol. 6, no. 2, pp. 41-51, 2018, https://doi.org/10.5937/jouproman1802041Y.

[52] T. V. Dang, “Research and design of a path planning using an improved RRT * algorithm for an autonomous mobile robot,” *MM Science Journal*, pp. 6712-6716, 2023, http://doi.org/10.17973/MMSJ.2023_10_2023051.

[53] F. Aqlan, J. C. Nwokeji and A. Shamsan, "Teaching an Introductory Data Analytics Course Using Microsoft Access® and Excel®," *2020 IEEE Frontiers in Education Conference (FIE)*, pp. 1-10, 2020, https://doi.org/10.1109/FIE44824.2020.9274247.