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https://doi.org/10.21278/TOF.461032621
ISSN 1333-1124
eISSN 1849-1391

INTEGRATING ERGONOMIC FACTORS WITH WASTE IDENTIFICATION DIAGRAM TO ENHANCE OPERATOR PERFORMANCE AND PRODUCTIVITY IN THE TEXTILE INDUSTRY

Summary

Industries have introduced lean manufacturing systems to outperform their competitors and sustain their growth. The implementation of lean tools results in satisfying the customer needs. Industries focus primarily on technical assistance when implementing lean strategies, but the success and sustainability of a lean strategy largely depend on the skill and cooperation of the workers. Research findings show that most industries have not attached importance to human factors while implementing lean logic. The negligence of human factors affects the quality of life of workers. Hence, this study intends to improve the quality of life and efficiency of workers by integrating ergonomic factors with the implementation of lean strategies in apparel industry. To accomplish this, the waste identification diagram was improved by adding a component to determine operators' performance and analyse human factors. The ergonomic-waste identification diagram has been created to identify tasks related to ergonomic investigations and analyse human factors with lean metrics. The results point to the fact that an egalitarian approach increases the performance of operators and productivity of the organization.

Key words: *Ergonomics, Lean manufacturing, Waste identification diagram, Operators' performance, Textile industry*

1. Introduction

Many companies have successfully adopted lean production methods. Lean methods serve to maximize productivity by using a specific, structured way. As defined by different researchers, lean principles are an efficient way of increasing efficiency by removing or minimizing time-consuming activities that add no value [1]. The benefits of implementing independent or merged lean manufacturing techniques include reduced processing times, removal of non-valued actions, and a tidy and sanitary workstation. Additional benefits include a smooth production flow, higher productivity, reduction in operating cost, participation of employees, and reduced stock [2]. Lean management is a dynamic socio-cultural framework that can continuously incorporate and combine technical and social processes to promote a practice of continuous improvement. Despite the initial operating efficiency gains due to the use of the most successful and well-established lean strategies, the majority of lean manufacturing businesses struggle to produce sustainable results over a long period of time; thus, most businesses return to their conventional business strategy [3]. Practices in lean management are categorized as soft and hard practices. Soft practices include personnel and interrelations, while hard practices include lean scientific and analytical methods. Soft practices are the key to better performance by lean production and long-term performance sustainability, but companies do not always put the same emphasis on soft and hard methods by relying only on lean technical tools. In comparison, effective lean plants use soft practices more widely than ineffective lean plants, although their hard practices do not vary significantly [4]. The lean manufacturing approach introduces the human aspect as a central component in the sustainability of continuous improvement. Thus, lean manufacturing influences the content of individual jobs and the quality of work by increasing opportunities for participation and learning. Lean philosophy must establish and recognise a range of job characteristics to ensure consistency with workplace ergonomics. Human factors and ergonomics have been proposed as a key consideration for continuous improvement and sustainability [5]. Research has shown the negative impact of lean on both the working surroundings and workers' health and safety in physical tasks with low complexity. Due to this negative impact on the workers' quality of life, it is important to move from a straightforward model to a more comprehensive model that realises lean as an open and ambiguous method, which has positive and negative impacts, depending on the actual lean methods used in the workstation [6]. More than half of previous studies on the lean report negative findings for wellness and risk factors in the quality of life [7]. Work-related health issues result in various health conditions of workers and in different levels of their performance in terms of efficiency and the number of defective products produced [8]. On the other hand, in contrast to all lean practices, Value Stream Mapping (VSM) should be used at all stages of implementation of lean. Value stream mapping has been denoted as an appropriate initial method [9]. VSM is integrated into an external module and value stream mapping with sustainability (Sus-VSM) was developed with indicators to measure societal and environmental sustainability and efficiency of a production line [10].

The incorporation of the ergonomic dimensions into the lean rationale tool established a value stream map with an ergonomic element. The ergonomic value stream mapping (Ergo-VSM) method was shown to have fair usefulness for the target group and seemed to have effectively catalysed reform processes, resulting in recommendations for updated value streams that included both ergonomics and waste reduction [11]. In lean environments, VSM is a very common method for describing output flows, mapping the product or product family value streams, and helping to define certain forms of waste. While very common, this tool has some limitations already discussed in several journals, notably in terms of its limitations on the display of most forms of waste and on the ability to portray different production paths. To overcome these limitations, Waste Identification Diagram (WID) has been developed. WID can describe several routes and most forms of waste in a very clearway. The WID overcomes some difficulties of value stream mapping and introduces certain facets of a manufacturing mechanism that could not be depicted by value stream mapping. In addition to all the benefits of WID in terms of quantitative data, there is another important benefit in terms of visual information that can be easily interpreted by production workers [12]. The waste identification diagram encompasses a range of new elements and better graphic abilities, which makes it a viable alternative technique to value stream mapping [13]. The integration of ergonomics, such as operational and physical ergonomics, and psychosocial considerations into the framework of industry has proven to promote competitiveness and efficiency. Several studies have demonstrated the impact of ergonomics on increased productivity [14]. This study, therefore, focuses on creating an enhanced WID. An ergonomic module is used as an integral part of the WID. The WID enhanced with the assessment of ergonomic factors is named ergonomic WID. Besides, this research develops a framework for an ergonomic WID to assess physical (physiological and cognitive) and ergonomic risk factors for companies, including lean criteria in the textile industry. This research explores physical and cognitive considerations for physical activity. Factors for determining the risk of human factors are established across literature and used in the ergonomic WID; the usefulness of ergonomic WID is verified via action research. The garment industry, a labour-concentrated business is selected as a case study. The proportion of manual labour is greater in the assembly operation. Hence, this research was performed in the Indian textile industry. The outcome may affect human factor ergonomic consideration during the effective implementation of lean. If substantial human comforts are integrated with standard WID parameters, the resulting approach will be a valuable tool for enhancing the operator performance at the core zone during the lean implementation.

1.1 Lean Productivity with Soft Lean

Palange and Dhatrak proved a number of studies focused on hard lean strategies that neglect soft methods. Simultaneous use of both hard and soft lean methods guarantees optimal application of lean strategies to enable favourable outcomes in an enterprise. Costa et al. found soft lean methods deal with workers and their interaction with the process. Research has shown that effective lean organizations have compensated for the greater exposure in soft lean methods successfully.

1.2 Quality of Life of Workers in Lean Surrounding

Researches on the adoption of lean strategies and working practices have demonstrated negative and positive impacts on the welfare and comfort of workers. Anyhow, the adverse impacts have been predominant [15]. Negative effects of many lean production organization activities (delegation of roles, problem-solving requirement, standardization, task rotation) on job retention, employee desire to continue the job, and health in the workplace are described and it has been shown that quality control is positively related to health in the workplace. Lean production organization activities, as a whole, have a damaging impact on the behaviours and health in the workplace [16]. It has been proven that lean activities are strongly linked to discomfort and spontaneous non-linear stress reactions. Lean activities with tension ratios are significantly linked to management choices in the design and implementation of lean strategies [17]. Researchers found significant relations between lean system components and task-related loads (identified by workers) which are influenced by the working environment. Staff working in leaner workplaces indicated that they had less control over both the pacing of the task and its methodological facets, higher workload, more competing demands from various aspects of the work, less clarity regarding their role, minimum variety of tasks, and less chance to perform their skills. These work design characteristics have important effects on the work-related pressure and differences in the design of the work [18]. Workers in all lean manufacturing units felt the adverse effect of lean, but those in production lines felt the greatest impact, with poor workplace involvement, low self-efficacy, and increased job stress. Decreasing the quality of work design will increase the degree of job stress among workers [19]. Ergonomic remedies such as proper machine height fixing, inclined work table, anti-fatigue sheets, task rotating, stretching exercises, and small-break method are used to reduce absences and attrition due to body pain and to improve the productivity and quality of the product and operation [20].

1.3 Integration of Lean Manufacturing and Ergonomics

Human aspects of a lean environment have been considered only in a small number of studies. For example, Botti, Mora, and Regattieri have introduced a novel mathematical model for the implementation of lean activities in hybrid production lines to offer an effective, efficient production line design method that satisfies the lean standards and ergonomic criteria of secure assembly work. Workplace ergonomics is a crucial parameter in the assembly production line, the same as other lean manufacturing metrics, e.g. tact time, cycle time, and work in progress [21]. Aqlan, Boldrin, Ramakrishnan, and Lam used the ergonomic considerations and lean concepts for the redesign of internal transportation in a high-end server production surrounding in order to reduce the waiting time, while the carts have been redesigned to eliminate ergonomic hazards [22]. Tortorella, Ferreira, and Vergara have formed a structure to integrate the socio-technical and ergonomic elements of lean launch in the automotive sector. A combined strategy, focused on human factors, is intended for minimizing the detrimental results of lean by experimental design in order to improve the perceived work autonomy, job quality, and organizational success. Fraser, Harris, and Luong developed a model to explore the significance of technological and ergonomic factors of cellular production. A collaborative path to technological and ergonomic factors helps to interpret the different stages of the development process. This model helps employees to be effective in the process quality development [23]. Jarebrant et al. created a value stream map with ergonomic factors to evaluate manufacturing units and nursing homes. Yusuff and Abdullah proved that ergonomics can support lean production by identifying the hazard to reduce the risk associated with the work station [24].

1.4 Lean Manufacturing in Textile Industries

Small and medium-sized companies are under pressure from a tough financial environment and must become more profitable to remain competitive. However, many small and medium-sized textile businesses have not implemented new concepts of quality control for efficiency; this reflects an interesting study void [25]. Bashar and Hasin found that only 52% of businesses in garment industry used lean resources and strategies to a certain degree. However, the degree of implementation of lean is not high enough. More than one third, of the garments, i.e. 35.7% to be more precise, have been produced without the implementation of lean. Among lean textile businesses, 24% had very limited and low degrees of implementation, while 14% of the textile businesses stated that their degree of implementation was high. Finally, only 5% of lean textile businesses had a high degree of implementation [26]. Kumar, Mohan, and Mohanasundaram have proven that the key problems in the textile industry are the lead time, production volume, very poor line handling, and tissue loss. Improved efficiency is accomplished by introducing different lean techniques in the company, such as 5S, value stream mapping, and line balancing in the sewing portion. Research findings on the implementation of lean practices in the textile industry show a decrease in the work-in-progress product, an improvement in the manufacturing process, and an increase in the line quality [27]. Implementation of lean manufacturing in the textile industry results in a reduced number of defective products and incomplete orders, in production time and penalties, which leads to an increase in profit [28]. Different kinds of waste-related issues and various deficiencies of the textile sewing section have been assessed by using particular lean manufacturing techniques as well as by assessing the sewing success in terms of efficiency, time, and consistency [29]. The established layouts from the textile business located in Tamilnadu, India, have been analysed for this study, and then lean manufacturing parameters have been integrated with ergonomic factors in order to improve the production process.

2. Literature Review Findings

A review of the literature shows that important studies have been conducted in the context of work conditions and the lean while studies combining the lean and ergonomics have been rarely conducted. In the aforementioned few studies, minimal shares of ergonomics are considered in the sectors such as nursing homes and automobiles. Besides, measurement systems were not flexible to measure the ergonomic parameters in the manufacturing industries. As mentioned above, the garment industry is a labour-concentrated field in which ergonomic factors play a major role in the implementation of lean methods. To the best of our knowledge, no attempt has been made so far to integrate the waste identification diagram with the human factors in the garment industry. The aim of this research is to establish an approach combining ergonomics and lean parameters. The objectives of the research are:

1. Evaluate factors to calculate the risk levels in human factors
2. Develop an ergonomic WID by enhancing the conventional WID with the addition of human factor parameters
3. Implement the developed ergonomic WID in the garment industry processes.

3. Materials and Methods

The aim of the analysis was achieved in five stages, as shown in Figure 1. A systematic literature review was undertaken and evaluation parameters were established. After that, the items to be measured for the defined parameters were developed and verified to determine the risk level of human factors. In the third stage, the WID was upgraded to create an ergonomic WID by incorporating human factors. The next stage illustrates the ergonomic WID in the textile industry sector. The results of the analysis are explored in the fifth stage. This research needs to recognize essential behaviours with higher risk levels for human factors and to identify the necessary ergonomic measures to be implemented. Also, we need to analyse the results of the approaches and draw conclusions. Thus, we undertook research using an action research method, as shown in Figure 2. Action research included repeated mechanisms, such as the evaluation of the present situation, preparation of actions, performance of the action, estimation of effects, and the concept of learning [30]. The studies listed in our reference list were used in this approach to make modifications to the system. In our research, we conducted interviews to collect data, which were analysed using document analysis and the Gemba walk observation. The outputs were reported directly to the management.

3.1 Choosing of Lean Parameters

Parameters, such as takt time, Throughput Yield (TPY), changeover time, and work in progress, were selected and additional parameters, such as operation time and standard time, were chosen [12]. The lean metrics can be calculated as follows: Takt Time (TT) is computed from Equation (1).

Takt time = Operating time per day / Customer demand per day.

$$TT = OT_i / CD_i \tag{1}$$

The operating time per day is the time required for the referred station to work in a day. For one working day, average values vary from 460 to 500 minutes. The customer demand per day here denotes the quantity of goods needed by the next station. Cycle Time (CT) is the amount of time required for the operation conducted in the station on a single product. Several observations (P_i) for every process in the same unit were recorded, and a total average time should be allocated to a process. Cycle time is computed from Equation (2).

$$CT_i = P_{1i} + P_{2i} + \ldots + P_{ni} / \text{Total number of readings} \tag{2}$$

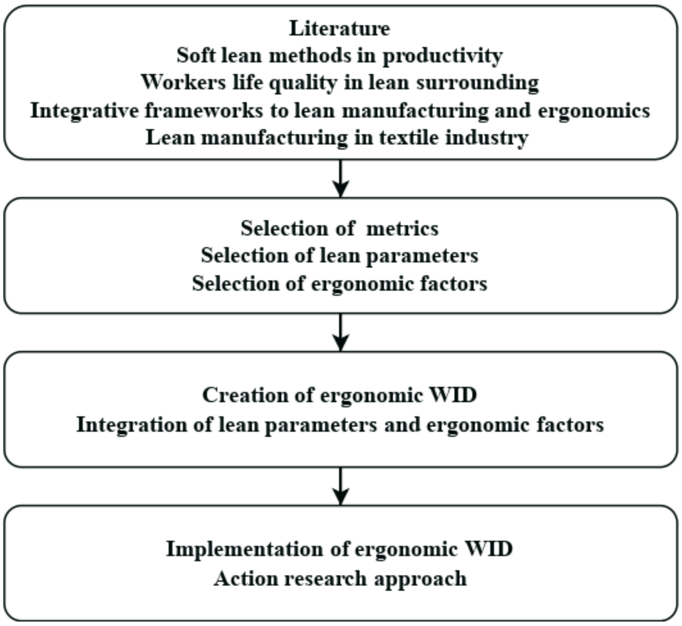


Fig. 1 Methodology

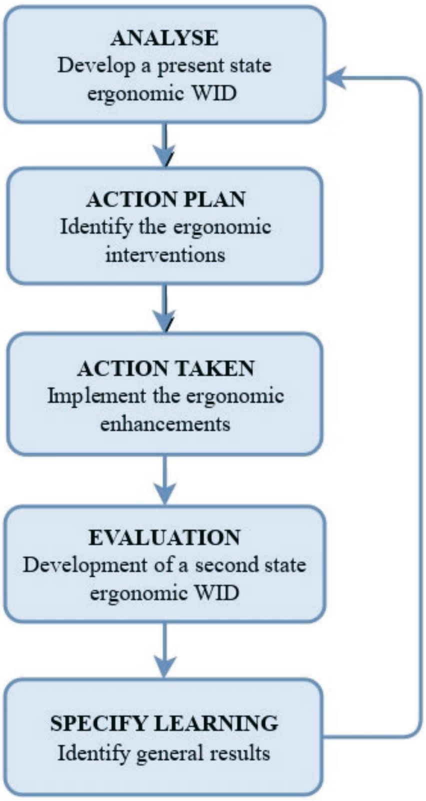


Fig. 2 Action Research

Throughput yield is integrated to show the reliability of workers. The throughput yield is derived from Equation (3).

$$\text{Throughput Yield (TPY)} = (\text{Inputs} - \text{defects}) / \text{Inputs} \cdot 100\ \% \tag{3}$$

Changeover time is measured by the stop watch time study method for every unit. The transport effort is calculated by multiplying the number of products shipped from one station to another and the distance between the stations. Transport effort is calculated in the following manner:

$$\text{Transport effort (TEi)} = \text{Quantity (Qi)} \cdot \text{Distance (Di)} \quad (4)$$

In addition, operator performance is calculated because of the relation with the quality of life of workers. The operator performance is expressed by Equation (5).

$$\text{OPI} = [\text{Standard Time (STi)} \times \text{Cycle time (CTi)}] \times 100\% \quad (5)$$

3.2 Gathering Ergonomic Factors to Be Measured

Physical factors were assessed by awkward working posture. Work design factor and administrative factors were assessed by job clarity and supervisor support. Physical aspect includes the uncomfortable working posture. Ergonomic factors are shown in Table 1.

Table 1 Metrics for measuring ergonomics risks taken from the listed literature sources

No.	Ergonomic factors	Human factors	Literature sources
1	Physical factor	Awkward working posture	Jarebrant, Winkel, Johansson Hanse, et al
2	Psychosocial factor	Job stress	T.Koukoulaki
3	Work design factor	Job clarity	Sprigg and Jackson
4	Managerial factor	Supervisor support	T.Koukoulaki
5		Communication system	Brown, Collins and McCombs [31]

3.3 Evaluation of Factors to Calculate the Risk Levels in Human Factors

The Quick Exposure Check (QEC) method is used for assessing the physical factors with risk exposure; it takes into account physical, organizational, and psychosocial elements. The method is used to evaluate the posture and motions of four major body parts: the spine, wrists/arms, neck, and shoulder/hand. The observed worker provides the following information: amount of load carried, time to accomplish the task, level of arm force exertion, visual requirements, vibration, operating vehicles, work intensity, and level of stress [32]. The risk profile is classified as a very low score (42-46), low score (46-84), medium score (106-138), high score (168-198), and extremely high score (187-242) based on the total score obtained from the investigator and labour scores with a range of 42 to 269. The conversion from QEC points to the five-point Likert scale is shown in Table 2.

Table 2 Metrics for measuring the ergonomics risks

No.	QEC points	Level of risk	Five-point Likert scale
1	42 to 46	Very low	1
2	46 to 84	Low	2
3	106 to 138	Medium	3
4	168 to 198	High	4
5	187 to 242	Very high	5

Questionnaires have been created to assess the ergonomic level of risk in the five-point Likert scale for psychosocial factors, work design factors, and managerial factors. The five-point Likert scale was used to determine the level of risk for human variables [33, 34]. The measured variables are shown in Table 3. In order to validate the measurement object, face validation was carried out by expertise (academic and industrial) as well as the sample analysis [35]. The sample analysis was performed on a sample of five industrial engineers for a specific operation. In addition, a test was carried out to assess the accuracy among the observers by Krippendorff's alpha [36].

Table 3 Measured modules for measuring the ergonomic risk level

Categorization	Criterion	Scale of modules	Measured modules
Physical factor	Awkward working posture	Very low – 1 Low – 2 Medium – 3 High – 4 Very high - 5	• The bent and twisted pose of work • Unbalanced sitting and standing • Time of standing in the same position • Stretch of arm from chest horizontally / vertically
Psychosocial factor	Job stress	Very low – 1 Low – 2 Medium – 3 High – 4 Very high - 5	• Staff believes that their work adversely impacts on their physical or mental health. • Staffs have much more work to do and too many unnecessary targets.
Work design factor	Job clarity	Very high – 1 High – 2 Medium – 3 Low – 4 Very low - 5	• Employees have clearly planned priorities and objectives for their work • Understanding of one's own duties • Strong understanding of what needs to be done • Awareness of what is required of the employee
Managerial factor	Supervisor support	Very high – 1 High – 2 Medium – 3 Low – 4 Very low - 5	• The probability of a supervisor addressing the needs of staff • Transparency of modifications in the system • Supervisor supports the staff even in tough conditions
	Communication system	Very high – 1 High – 2 Medium – 3 Low – 4 Very low - 5	• Communication board availability • The conducting of daily meetings • Local language knowledge • Availability for standard operating procedures (SOP)

3.4 Creation of Ergonomic WID

3.4.1 Waste Identification Diagram (WID)

In the form shown in Figure 3, WID diagrams consist of blocks, arrows and a pie chart. The blocks show the stations (benches, computers, and machinery), the arrow indicates the transport effort required to transfer parts from one unit to another, and the pie chart shows the tasks and the respective shares of the workforce, i.e. the way employees spend most of their time. Four principal data types are included in block dimensions:

1. The block length is the sum of work-in-progress (WIP) that waits processing. It can be calculated in units, kg, meters, cubic meters, or any other units in terms of monetary units.
2. Total block height is the Takt Time (TT).
3. The lower part of the block height reflects the time of the Cycle Time (CT). The contrast between the CT and the TT gives a feeling of idleness.
4. The depth of the block reflects the phase transfer time or Change Over Time (C/O). The arrows are simply transport effort and are considered as a loss because transport does not add value to the commodity.

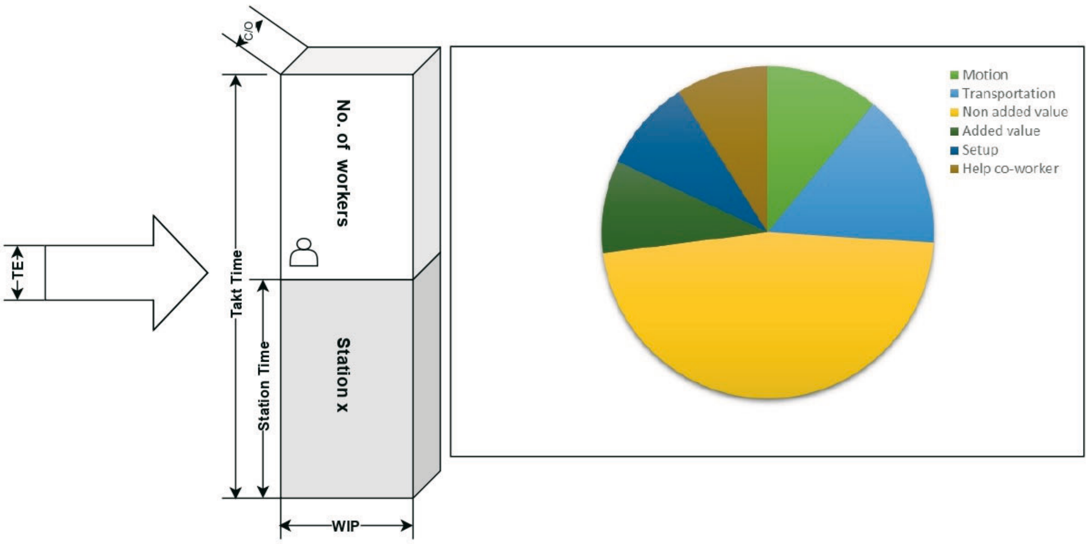


Fig. 3 Main icons of a waste identification diagram

The denser the arrow, the larger the amount of waste involved in the task. The transport effort is measured by multiplying the quantity of products to be moved per unit of time by the distance between stations. The pie chart illustrates how time is used for various tasks; it also shows value added activities and various wastes, such as waiting, motion, and transport [12, 13].

3.4.2 Incorporation of the human factor elements in the waste identification diagram

The conventional WID method was intended for the quantitative analysis of value-added and non-value-added activities. For the enhancement purpose, the station time is replaced by the cycle time. An additional block was included in the standard WID to show the standard time, operator performance, or team performance, and the human factor risk score for the respective processes. Another block was added to the WID block, to show the risk level of human factors, such as psychosocial, physical, job design and managerial variables. The mean values for the whole phase (Figure 4) have been calculated.

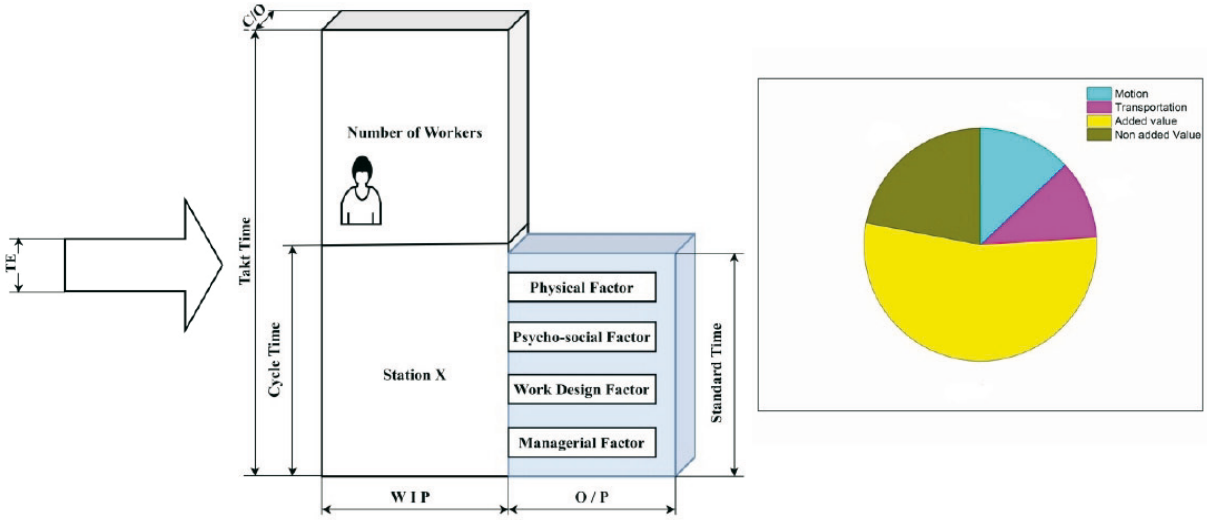


Fig. 4 Main icons of ergonomic WID

3.5 Rating of the Standard Time Block and Human Factor Elements

Many enterprises use the standard time from General Sewing Data, while some enterprises obtain the standard time value from their own experience and observation of processes [37]. Grades (Rx) were assigned on the Likert scale. The mean of the scores (My) is the risk level of independent ergonomic measures. Finally, the mean of the independent ergonomic measures (MCz) reflects the risk level of the ergonomic factor category. An ergonomic WID tool is shown in Figure 4. Ergonomic risk is determined as follows:

$$My = (R1i + R2i + \ldots + Rn) / \text{total number of modules measured for one factor} \quad (6)$$

$$MCz = (M1 + M2 + \ldots + Mn) / \text{total number of considered factors} \quad (7)$$

where,

Rx is the rating of the x^{th} module (x = 1,2,…., n)

My is the average of the y^{th} considered factor (y = 1,2….., n)

3.6 Implementation of Ergonomic WID Tool in the Textile Industry

The research was performed on a garment manufacturer located in Tamilnadu, India; the business combines all operations, from fabric to wearable clothes. The selected business had started practicing a few lean methodologies: Kanban, total productive maintenance, and 5S to minimize the changeover time, lean waste, WIP, and to increase flexibility. This case study was done by a team that consists of three engineers from the industry, two industrial engineering managers, and a team leader. In the selected garment industry, manufacturing processes are both automated and manual. Most of the processes were performed manually for the selected garment. There was also a greater demand for human labour because of the sewing process difficulty. Instructions on the apparel types based on consumer preferences are issued by the Technical Product Development Department. The product type covers children's clothing. The flow of the sewing process is shown in Figure 5. The processes were classified as Skilled Processes (SP) and Low-skilled Processes (LSP). The selected station has a line layout with fifteen operators including supervisors. The age of the workers varies from 19 to37 and their body mass from 17.9 to 29.4 kg/m with a mean (standard deviation) of 30.13 (5.2) and 24.0 (2.9), respectively.

Table 4 Data collected on lean parameters in the sewing operations

Lean parameters	Set the machine (Tension)	Receive cut cakes	Sew the shoulder	Sew the left side portion with label	Sew the sleeves	Sew the right side portion	Tack the sleeves	Tack the bottom	Remove the stickers	Check sewing and check for the needle	Bundling the piece	Move to the storage
CT(min)	1	1.83	0.75	0.98	1.16	0.83	0.91	0.83	0.28	1.95	1.66	2.83
ST(min)	0.5	1.25	0.58	0.75	1	0.66	0.83	0.66	0.08	1.25	0.83	1.5
OP %	50.00	68.31	77.33	76.53	86.21	79.52	91.21	79.52	28.57	64.10	50.00	53.00
Product count	0	1260	1260	1260	1259	1257	1257	1256	1255	1255	1255	1255
Damage	0	0	0	1	2	0	1	1	0	0	0	0
TT (min)	21	21	21	21	21	21	21	21	21	21	21	21
Rework	0	0	0	9	17	8	6	4	0	84	0	0
TPY %	0	100	100	99	97.6	97	96.5	96.1	96.1	89.4	89.4	89.4
WIP	0	150	20	15	20	10	8	8	5	25	30	30

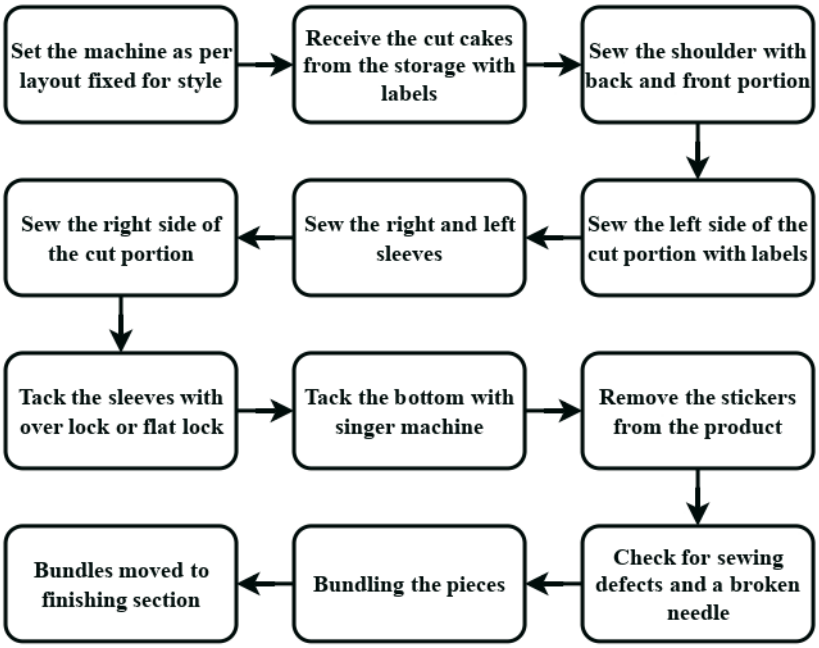


Fig. 5 Detailed sewing process and flow of the product

Table 5 Risk levels of ergonomic factors for the sewing process

Human factors	Set the machine (Tension)	Receive cut cakes	Sew the shoulder	Sew the left side portion with label	Sew the sleeves	Sew the right side portion	Tack the sleeves	Tack the bottom	Remove the stickers	Check sewing and check for the needle	Bundling the piece	Move to storage
Physical factor	3.7	4.1	3	3.3	3.9	3.3	3.2	3	4.6	4.6	4.5	3.8
Psychosocial factor	3.9	3.5	1.5	3	2	2	1.8	1.5	3.9	4	3.8	3.6
Work design factor	2.0	1.5	1.6	2.0	2.2	1.2	2.1	2.2	1.8	0.8	1.5	0.5
Managerial factor	1.0	0.5	2.5	2.6	2.5	1.5	2	2.5	1.5	1.4	1.0	0.6

3.7 Data Collection for the First-stage Ergonomic WID

Data has been collected in the pilot module through document analysis, observation of the Gemba walk, and interviews [38]. As shown in Table 4, the number of operators, customer demand, cycle time, standard time and change over time, and throughput yield for each process, was collected. The document analysis was carried out through production reports. The first-stage ergonomic WID was developed using the collected data. The values of Takt time, cycle time, throughput yield, transport effort, and operator performance of each operation were calculated by using the equations (1), (2), (3), (4), and (5), respectively. Based on the Gemba walk and interviews used for data observation, the research team quantified the human factor risk level. The team was divided into two separate groups. Every operation was tested for 20 minutes. Ten sets of data were collected for every process and the mode (Rx) was graded. Sewing operations and the handling of materials were rated. The ergonomic score was found by using equations (6) and (7), as shown in Table 5.

3.8 Analysis of the First-stage Ergonomic WID and Ergonomic Measures

Table 6 The first-stage ergonomic WID metrics

Lean parameters	
Cycle time (min.)	15.01
Standard time(min.)	9.89
Team performance (ST/CT) (%)	66
Reworks	128
Damages	5
Throughput yield (TPY) (%)	87.54
Change over time (min.)	4
Transport effort (kg・m)	112.5
Lead time (min.)	115

Table 6 shows the first-stage lean parameters. The team performance is poor with 66%, which is due to 5.12 minutes over standard time used to finish a garment. The allowance for thread removal was provided where appropriate. Except for receiving cut cakes and sewing checking, all activities were value-added activities, while the cut cake receiving and quality inspecting were considered as non-value-added activities. Human factor risk levels varied from 0 to 5 and were categorized as: 0 – 1 = very low (VL), 1 – 2 = low (L), 2 – 3 = medium (M), 3 – 4 = high (H), and 4 – 5 = very high (VH), as shown in Table 7.

Table 7 Categorization of human risk levels for the sewing process

Human factors	Set the machine (Tension) (SP)	Receive cut cakes (LSP)	Sew the shoulder (SP)	Sew the left side portion with label (SP)	Sew the sleeves (SP)	Sew the right side portion (SP)	Tack the sleeves (SP)	Tack the bottom (SP)	Remove the stickers (LSP)	Check sewing and check for the needle (SP)	Bundling the piece (LSP)	Move to storage (LSP)
Physical factor	H	VH	H	H	H	H	H	H	H	H	VH	H
Psychosocial factor	H	H	L	H	L	L	L	L	H	H	H	H
Work design factor	L	M	L	L	VL	VL	VL	VL	L	VL	L	VL
Managerial factor	M	M	VL	VL	VL	L	L	L	M	M	M	M

SP- Skilled Process, LSP- Low Skilled Process

Critical operations were the operations above the medium risk level. Some processes were at high and very high risk levels based on physical factors, and even the LSPs did have a very high risk level. In particular, the bundling of the bits and obtaining cut cakes are at very high levels of risk. In psychosocial factors, machine setting, receiving cut cakes, side portion sewing, removing the stickers, bundling, and checking are at high risk levels. The remaining processes are in the low level risk category. For all activities, two ergonomic problems were generally noticed: uncomfortable posture and job pressure. To reduce these problems, anti-fatigue pads for staff to maximize comfort in standing and ergonomically designed pallets for the handling of materials, together with psychological preparation have been proposed. The management recommended ergonomically built chairs, tables, pallets, and trolleys.

Table 8 Causes of risk and ergonomic innovations for processes at risk

Categorization of factors	Processes	Observed risks	Ergonomic enhancement
Physical factors	Setting of the machine, Sewing processes	• Unbalanced and uncomfortable sitting	• Ergonomically designed chairs
	Receiving of cut cakes, Moving to the storage	• Carrying the bundles with awkward posture • Repeatable walk to the storage	• A trolley provided to move the bundles from the storage to the station
	Removing the stickers, Checking the sewing, Bundling the pieces	• Continuous standing in the same spot	• Anti-fatigue mats and short breaks for the workers
	Checking the sewing and checking for the needles	• The worker stretching hands and bending the trunk while grabbing the cloth	• Ergonomically designed table • Doing stretching exercises
Psychosocial factors	Machine setting	• Mental workload due to poor knowledge about maintenance	• Training provided by the maintenance people
	Receiving inputs	• Work pressure due to receiving different job orders at the same time	• Ergonomically designed pallets for the categorisation of job orders
	Remove stickers	• Difficulty with identifying the sticker	• Suggested use of contrast colour stickers for easy identification
	Check for broken needles	• Unnecessary task. This task is done by metal detectors	• Suggest to minimise the importance of needle check during the sew check
	Check the sewing	• Quality checking failures	• Proper training provided by quality supervisors
Work design factors	Sew the shoulder	• No clarity with the pairing of front and back due to different job orders at the same time	• Jobs are categorised by ergonomically designed pallets
Managerial factors	Process flow	• Poor communication about the process flow and operations	• Standard operating procedures disseminated through notice boards and banners in the shop floor
		• Communication difficulty between workers and supervisors	• Suggest the management to consider the known language criteria for the best communication

3.9 Plotting the Second Stage Ergonomic WID after the Ergonomic Enhancements

The previously mentioned ergonomic enhancements were applied. Ergonomic improvement practices were adopted, controlled, and monitored and data was gathered to establish the second stage ergonomic WID. Ergonomic risk levels after enhancements are shown in Table 11. Figure 6 shows the established second state ergonomic WID and Table 10 shows its lean metrics.

4. Results and Discussion

Significant improvements were identified in the ergonomic conditions.

Table 9 Data gathered after ergonomic enhancements and the implementation of ergonomic WID

Lean metrics	Set the machine (Tension)	Receive cut cakes	Sew the shoulder	Sew the left side portion with label	Sew the sleeves	Sew the right side portion	Tack the sleeves	Tack the bottom	Remove the stickers	Check sewing and check for the needle	Bundling the piece	Move to storage
CT(min)	0.53	1.33	0.58	0.76	1	0.66	0.83	0.66	0.1	1.33	1	1.6
ST(min)	0.5	1.25	0.58	0.75	1	0.66	0.83	0.66	0.08	1.25	0.83	1.5
OP %	94.34	93.98	100	98.68	100	100	100	100	80.00	93.98	83.00	93.75
Product count	0	1260	1260	1260	1260	1259	1259	1259	1258	1258	1258	1258
Damage	0	0	0	0	1	0	0	1	0	0	0	0
TT (min)	21	21	21	21	21	21	21	21	21	21	21	21
Rework	0	0	0	2	4	1	1	2	0	49	0	0
TPY %	0	100	100	99.84	99.60	99.84	99.84	99.68	99.84	95.95	99.84	99.84
WIP	0	150	15	5	10	5	6	5	2	10	30	2

Table 10 Metrics of the second stage ergonomic WID

Lean parameters	
Cycle time (min.)	10.38
Standard time(min.)	9.89
Team performance (ST/CT) (%)	95.27
Reworks	59
Damages	2
Throughput yield (TPY) (%)	91.19
Change over time (min.)	2
Transport effort (kg・m)	37.5
Lead time (min.)	86

The scale of the diagram shown in Figure 6 is as follows: 1 min = 0.5cm; team performance of 20% = 1cm; transport effort of 15kg・m = 1cm; work in process of 10 = 1cm; the larger the blocks, the bigger the values. In Figure 6, the whole sewing section is considered. For bigger products, this methodology can be used for each individual process. From the diagram in Figure 6, one can see that the physical factor risk level, psychosocial risk level, work design risk level, and the managerial risk levels are below the medium risk level.

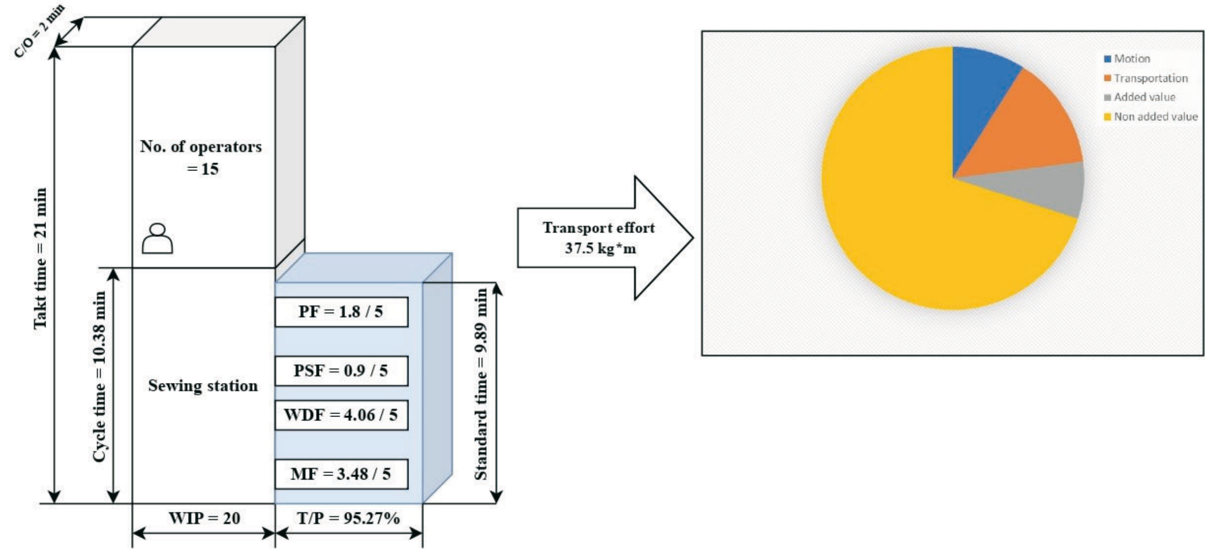


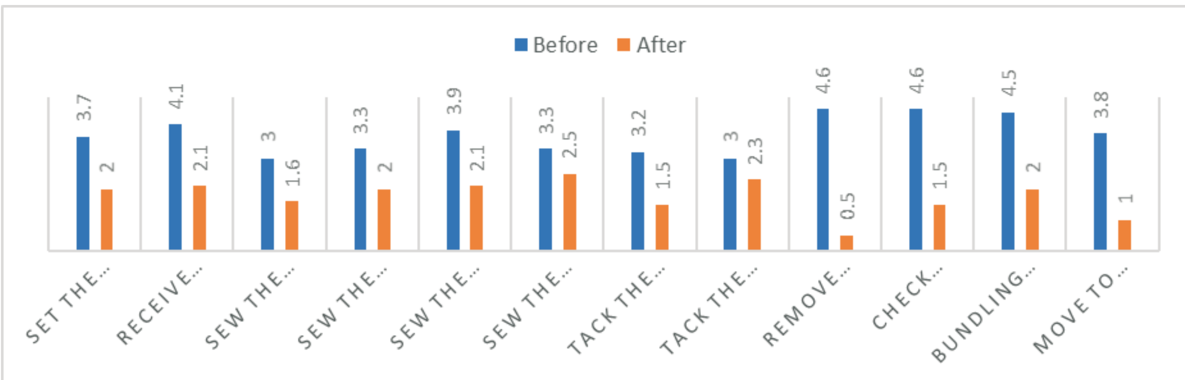
Fig. 6 The established second stage ergonomic WID

Table 11 Grades of ergonomic factors after the enhancement

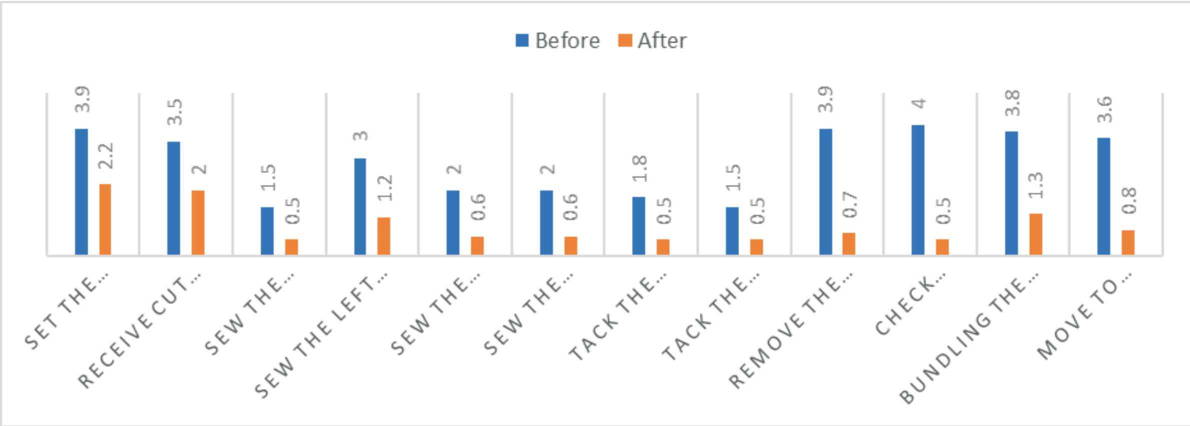
Human factors	Set the machine (Tension)	Receive cut cakes	Sew the shoulder	Sew the left side portion with label	Sew the sleeves	Sew the right side portion	Tack the sleeves	Tack the bottom	Remove the stickers	Check sewing and check for the needle	Bundling the piece	Move to storage
Physical factor (PF)	2.0	2.1	1.6	2.0	2.1	2.5	1.5	2.3	0.5	1.5	2.0	1.0
Psychosocial factor (PSF)	2.2	2.0	0.5	1.2	0.6	0.6	0.5	0.5	0.7	0.5	1.3	0.8
Work design factor (WDF)	3.9	2.8	4	3.9	4.3	4.1	4.6	4.5	4	4.3	4	4.3
Managerial factor (MF)	2.5	3	4.3	4.3	4.2	3.9	4	4	3	2.9	3	2.7

It is noted that there is a substantial decrease in the level of risk of the human factor, which shows improvements in the quality of life of employees, as seen in Figure 7. Improvement in the quality of worker life led to improved organizational efficiency in the cycle time and the improvement in operator performance and quality, as shown in Figure 8. In addition to maintaining lean practices in an enterprise, lean efficiency can be improved by providing a safe atmosphere and technology. This agrees with [37], where the authors state that a systematic model could assist organizations struggling to achieve efficient and sustainable implementation of lean strategies.

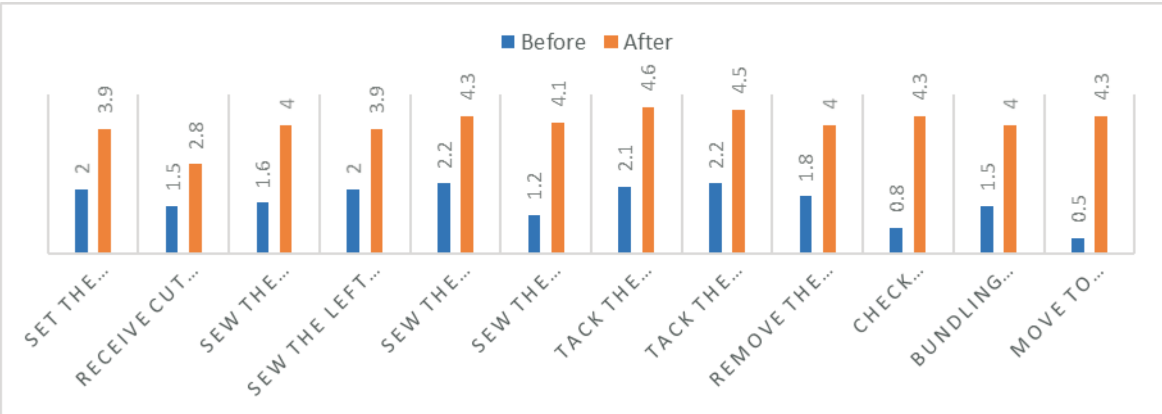
1 Physical Factors (PF)



2 Psychosocial Factors (PSF)



3 Work Design Factors (WDF)



4 Managerial Factors

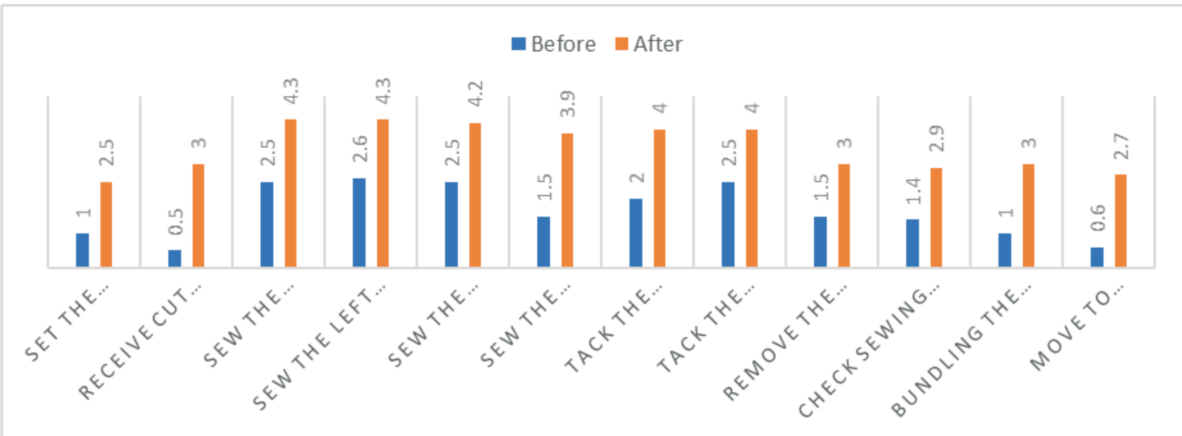
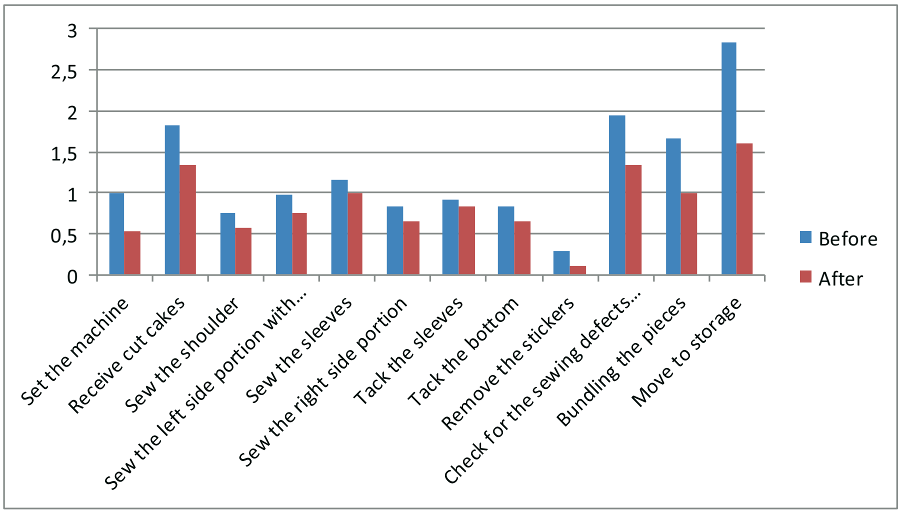


Fig. 7 Improvements in ergonomic factors

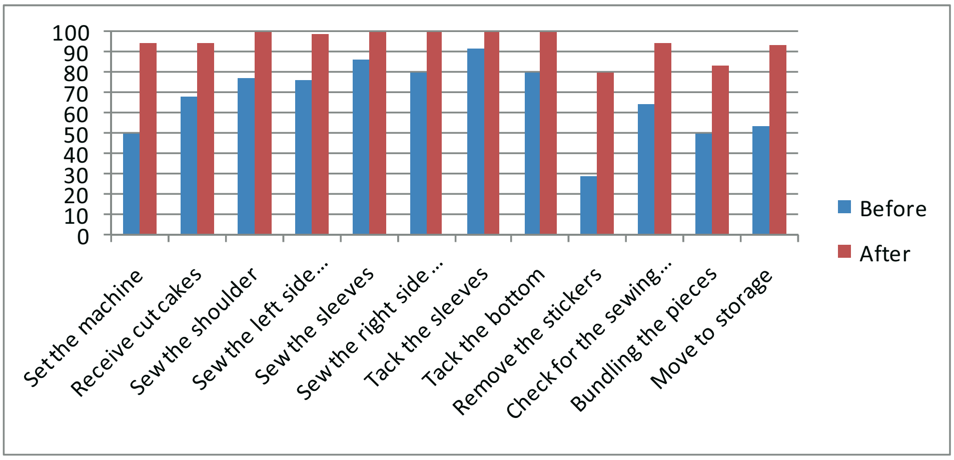
The results confirmed that an integrated strategy minimised the risk levels of the human factor and improved lean efficiency. These findings are in agreement with the results of previous research, which show that human factors help organizations boost their efficiency and reduce the negative effect of lean implementation [5]. In the present analysis, three industrial engineers and two industrial engineering executives were used to collect data and to ensure that the workers were not interrupted while adopting the suggested ergonomic improvement practices and improved data accuracy.

After the enhancement of ergonomic factors, the lean parameter outputs are improved as follows: cycle time is reduced from 15.01 minutes to 10.38 minutes; team performance is improved from 66% to 95.27%; reworks and transport effort are also reduced significantly. Figure 8 shows the improvement in operator efficiency, cycle time, and product quality in the observed sewing process. Processes recommended for the ergonomic reform have made major changes in the ergonomic WID.

1 Cycle Time



2 Operator Performances



3 Throughput Yield (TPY)

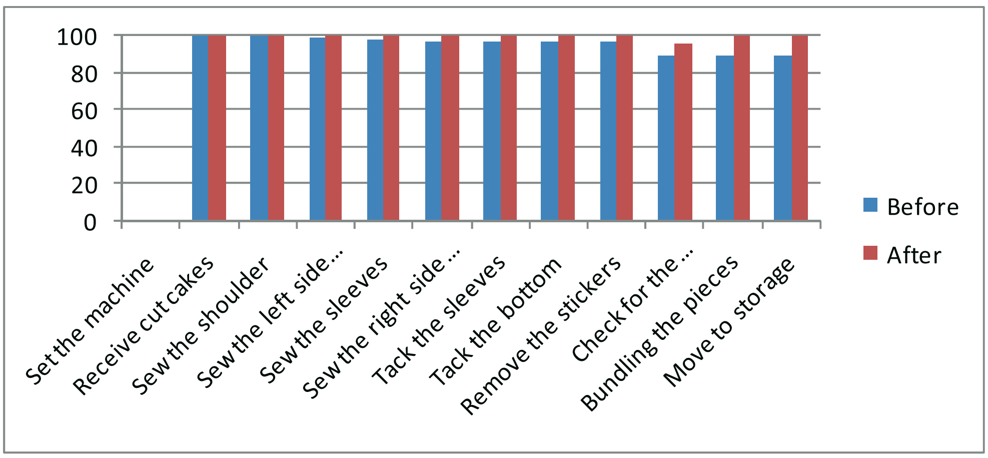


Fig. 8 Improvements in lean factors

The current research is focused on the sewing process only. Individual worker physical differences are not considered. Table 12 shows a comparison between a conventional WID and the ergonomic WID based on quality aspects.

Table 12 Comparison of the current ergonomic WID and a standard WID

No.	Measures	WID	Ergonomic WID
1	Lean parameters	Takt time, WIP, C/O time, Throughput time (TPY), System efficiency	Standard time, Operator performance, Takt time, Cycle time, WIP, C/O time, Throughput yield, Lead time
2	Ergonomic parameters	-	Ergonomic parameters (managerial factors, physical factors, design factors, psychosocial factors)
3	Ergonomic enhancement	-	Time breaks, anti-fatigue mates, training, minimum targets, ergonomic workplace

Interpretation of the study showed that operators are involved in adopting lean practices with ease that helps retain the lean practices. Based on this analysis, the following lessons can be learned and appreciated by managers:

1. A combined system of lean and ergonomic practices improves the sustainability and adaptation of the enterprise.
2. A combined strategy positively affects the quality of life of employees and the organizational efficiency.

Transportation waste, motion waste, and processing have been reduced by ergonomic enhancements. In the process of movement to the storage, an ergonomically designed trolley was provided to reduce the amount of transport effort. Before the provision of the trolley, the worker had to walk three times to the storage, which is at a distance of 15 meters, but after the provision of the trolley, the worker completed the task within a one-time walk to the storage. This change reduces the transport effort from 112.5 kg·m to 37.5 kg·m. In the process of sewing and needle check, over-processing was found. Checking for broken needles in the cloth piece had been done by a metal detector before the packing, but workers were doing that process manually. The manual check process was removed and the cycle time was reduced from 1.95 minutes to 1.33 minutes for the checking process. Motion waste was identified in the sticker removing process. Workers had a hard time finding the sticker in the cloth piece because of the low contrast. For an easy identification, sticker colours were changed to contrast with the cloth colours. The reduction in arm motions on the cloth piece reduced the cycle time from 0.28 minutes to 0.1 minutes.

5. Conclusions

The research shows how an ergonomic WID has been used in the textile industry to successfully combine human factors and lean practices. The current research proves that the combined approach to ergonomic and lean improves the consistency of productivity and the quality of life of workers in the textile industry. The results from this research show that this combined approach reduces the negative effects of lean practices on the quality of life of workers and maximises the performance of workers with the reduction in cycle time and defects. In addition, the ergonomic WID model is able to classify crucial behaviours related to ergonomic risk. Moreover, the results of this analysis agree with the previous research.

Finally, this research concludes that the Ergo-Lean method ensures a secure work zone, strengthening the flexibility and maintenance of lean in organizations.

This study has some limitations with respect to sample size. Only the sewing layout containing 12 operations was measured for the study. To validate the outcomes, a larger sample is desirable. The second disadvantage of the study is that the case study sector had 2 years of experience with lean environment; thus, the outcome differs depending on experience. During the initial lean transition from a conventional process, the Ergo-Lean method offers a better outcome. The third drawback of the study is that ecological and protection considerations were overlooked due to time constraints. Yet, there is potential for the implementation of ergonomic WID in various sectors.

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Submitted: 28.7.2021
Accepted: 30.11.2021

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