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# A TIME-PERFORMANCE IMPROVEMENT MODEL WITH OPTIMAL ERGONOMIC RISK LEVEL USING GENETIC ALGORITHM

**Summary**

The optimization of productivity has received significant attention in the manufacturing field. The majority of operations in the manufacturing business are still performed by workers. The analysis of work efficiency and the avoidance of ergonomic risk levels in the production line of clothing industry is critical. The correlation between a task in production and a reduction in ergonomic risks has been rarely considered in previous studies. This study proposes a time-performance improvement model with an optimal ergonomic risk level using a genetic algorithm; the model is intended to be used in the garment industry and reduce the gap for real-world applications. The results show that by distributing management training and limiting ergonomic risk factors, operator performance of selected operations can be improved, resulting in an optimum solution. The proposed model was implemented through case studies, and the operator performance improved from 73.68% to 92.76%. The significant element of this study is to use ergonomic improvement to increase operator performance through a time-performance improvement model.

*Key words:* *Genetic algorithm, Time-performance improvement model, Ergonomic risk level*

## 1. Introduction

The most important goal in the optimization area is to figure out how to finish processes on time while increasing profit. Moussavi considered ergonomic factors versus productivity and proposed a multi-objective numerical model to achieve ergonomic job rotation in a manufacturing system [1]. Previous studies have found a clear link between weak ergonomics and production losses, as well as quality defects such as assembling faults, which cost industries significantly. As a result, it is critical to maintain suitable ergonomic circumstances for workers while building industries, workstations, and making various decisions that affect ergonomic situations. This reduces the incidence of work-related musculoskeletal disorders (WMSDs), promotes increased productivity and a good-quality product, and lowers the associated costs to companies and society [2]. The complexity of the production environment in today's market forces production managers to attain higher levels of operating performance. Productivity in industrial plants is typically affected by precision [3]. Operators on production line experience stress and face ergonomic challenges as they perform repetitive jobs. As a result, compromises between production line efficiency, ergonomics, and physical demands have to be made. Abdous developed an optimization method for the production line balance problem that takes worker stress into account [4]. Vinel proposed a generic optimized mathematical model for optimizing job rotation based on chances for higher-risk jobs and discovered that job rotation can be effective in dispersing exposure of workers to injury problems; however, it is not always possible to significantly enhance the risk dispersion with job rotation [5]. Previous research has regularly shown the harmful effects of inadequate ergonomic workplace conditions on human health, resulting in the development of workplace health disorders. Managers, on the other hand, lack the instruments to evaluate workplace ergonomic factors, personnel health problems, and financial implications while optimizing system performance. Sobhani presented a hierarchy-modelling approach to incorporating workplace ergonomics into performance optimization techniques [6]. Duraccio provided a model that allows ergonomic improvement by evaluating ergonomic relationships involving manual tasks in the correct settings; the model includes a schematic and a scientific analysis approach to the activities and also determines all relevant ergonomic elements to be examined. Work safety is the most important factor in the efficiency of the management of human resources in every company, and if companies can lower the rate of workplace injuries and unnecessary stress, operator performance will improve. Job rotation has also proven to be effective in increasing efficiency [7]. Mokhtari created a suitable job rotation optimization model system in order to minimize workplace risks in terms of ergonomic factors [8]. Freitas proposed a solution depending on a genetic algorithm that allowed layout optimization with spatial reconstruction based on distances across different regions of the layout. The solution includes the minimization of generalized and operational risks and takes into account the risk assessment results [9]. Sana developed a model that incorporates the model of ergonomic factors, such as loading weights, repetitiveness of activities, and awkward working postures, and job rotation scheduling and planning as a multi-objective technique for preventing the development of musculoskeletal disorders [10]. Barathwaj suggest to increase the rate of production, reduce the cycle time, allocate an equal volume of work load to all workstations, reduce the work process, and eliminate inefficiencies between the stations throughout the assembly operation. Additionally, the author gathered risk posture, which is used to evaluate the ergonomic overall risk of a workstation throughout assembly [11]. The linear programming method was proposed by Botti to find the best scheduling for the activities done by workers exposed to ergonomic risk factors of repetitive tasks and to maximize overall operator productivity while ensuring the workflow and safe ergonomic surroundings [12]. Sunil introduced an objective function to investigate the potential for input reduction. The goal of the lean integration with the Kaizen concept was to locate any gaps or slack in the input variables [13]. An integrated production and maintenance strategy that is both affordable and effective is presented in [14].

Various research studies have used several strategies to optimize the time-cost trade-off. Most studies evaluate the direct connection between cost and time while reducing costs within a certain period or compressing schedules to stay within financial constraints. Furthermore, while the current time-performance improvement model has an immediate effect on operator performance, significant parameters like rework and fatigue are also reduced. As a result, the essential elements should be taken into account further in the time-performance improvement model. Earlier research has shown that worker productivity can be increased by management strategies, such as training, continuous improvement, and cash incentives. The purpose of this research is to recommend a time-performance improvement model with an optimal ergonomic risk level that takes into account variable performance concerning the workplace environment and administration. By showing the relationship between labour performance, cycle time, and ergonomic risk factors, the suggested model analyses the effect of varying productivity, lead time, and operator performance. Genetic algorithms are used to find the optimal ergonomic risk level and working conditions. As a result, the concept can minimize the cycle time without causing any adverse effects and thus reduce the ergonomic risk factors without exceeding the standard time. Operators will suffer work-related musculoskeletal disorders (WMSDs) in unchecked, adverse ergonomic workplace conditions. Poor working conditions are caused by a combination of stress and environmental issues. Lifting large objects, uncomfortable postures, sitting or standing for longer timeframes, repeated actions, and vibrations are all fatigue variables [15]. As a result, the reduction in ergonomic risk levels has been a significant topic in recent times and is considered one of the objectives to improve operator performance in this study. The ergonomic risk level score is not incorporated with the lean parameters during the performance evaluation, and ergonomic evaluations were done independently of those in the existing literature. An optimal ergonomic risk level score will convince the management to introduce minor changes in the workplace and to provide training with available resources. To the best of our knowledge, the time-performance improvement model with the ergonomic risk level reduction concern has not been presented in the research conducted so far.

This study provides a case study to evaluate the suggested optimal technique. The remaining part of the paper is structured as follows. Section 2 presents the studies on time-cost trade-offs, cycle time, ergonomic risk factors, and operator performance. Section 3 explains how to formulate the proposed model, while section 4 describes a real-world scenario. Section 5 gives the ergonomic risk evaluation, while section 6 presents and discusses the analytic results. Conclusions and suggestions for future research are presented in the concluding section.

## 2. Literature review

The literature for this study is collected from the science citation index database, Scopus, and scientific information databases.

### 2.1 Optimization method

Various project optimization strategies have been developed in earlier studies. In this study, a time-performance improvement model is developed to be implemented in the production process of the garment industry. The techniques mentioned in the previous section mostly included the mathematical models for job rotation, job scheduling, and layout planning. Previous studies have shown that cycle time reduction and ergonomic rick level reduction were two objectives in job scheduling changes, but not in the direct changes in workers' fatigue in workstation surroundings. The time-performance improvement model links the cycle time and operator performance with the ergonomic risk level score at the workstation. Pea-Mora developed a feedback model based on system dynamics for fast-track infrastructure projects and changed the worker productivity assumptions, which were used in earlier analyses as a constant. In the active system, the functions of delivery time target, process knowledge, fatigue impact, and regular productivity influence production and eventually affect cycle time and cost [16]. Management has been highlighted as a major factor influencing labour productivity in earlier studies. Improving the work environment and management training can effectively minimize the time needed to increase labour productivity [17]. A mixed objective function can find the best possible combination of process parameters by giving both objectives equal importance [18]. The current workers' output can be increased. It is possible to shorten cycle time without raising expenditures or to cut project costs while keeping the delivery on schedule. Thus, through management activities, such as workstation improvement, waste reduction, and ergonomic training, this study proposes an integrated technique to directly improve the labour productivity of existing resources and minimize cycle time. Hence, this study tends to reduce the ergonomic risk factor through the improvement of the work environment and management training to reduce cycle time and increase operator performance.

### 2.2 Cycle time and ergonomic risk factors

When demand is unpredictable, reducing cycle time is important, especially since a longer cycle time puts the company at risk of being out of stock at the time the orders are placed [19]. Lack of management commitment and lack of employee training are the main barriers to the minimization of cycle time [20]. In the manufacturing industry, workers still do the work in most production processes. In the textile sector, the reduction of cycle time and ergonomic risks are significant components. The aims of an effective job and a reduction in ergonomic risks are rarely correlated. Furthermore, research into multi-objective techniques in the earlier studies is scarce [21]. Safety factors are considered and used to reduce the production time and the setup time [22]. Workers will get work-related musculoskeletal disorders (WMSDs) as a result of ignored ergonomic risks in adverse workplace conditions. Poor working circumstances are caused by environmental and workload factors. The Quick Exposure Check (QEC) is a tool for finding workplace risk factors and screening participants for the risk of musculoskeletal disorders at work. QEC can be used as a particular risk assessment method in a variety of occupational scenarios [23]. QEC was used to measure the severity of musculoskeletal disorders and their levels in human body regions. The QEC results were associated with a substantial risk of musculoskeletal problems with the spine and neck [24]. The QEC method acts as an analysis tool that will not help measure working postures. Improving the work environment should include posture measurement with bending and twisting positions of the body. Rapid Upper Limb Assessment (RULA) is a technique developed in the field of ergonomics to evaluate and analyse work postures adopted by the upper body. RULA does not require the use of any special tools to assess the posture of the back, neck, and arms. RULA takes the minimum time to evaluate and conduct an overall score of the sequence of tasks suggested to reduce operator risk [25]. RULA employs a systematic procedure to assess the body's postural and musculoskeletal disorders and the risks associated with repetitive job tasks. A one-page spreadsheet has been used to assess the necessary or chosen posture, body movement, action type, and repetition. A researcher can assign a score to every one of the following body regions using the RULA worksheet: wrists, forearms, shoulders, neck, trunk, and back [26]. Earlier research has found that when operational improvements are combined with risk evaluations, overall business performance improves [27].

According to the authors' knowledge, there seems to be no prior research concentrating on a time-performance improvement model with the optimum ergonomic risk level score to improve operator performance and cycle time. Practical manufacturing issues frequently necessitate a combination of cycle time and ergonomic risk score considerations. Managers want to improve production efficiency by shortening cycle times, but workers are more concerned with their health and avoiding ergonomic hazards. Cycle times and ergonomic risk reduction are frequently at odds, but it is critical to think about these two goals at the same time. As a result, current research aims to increase operator performance and reduce cycle time by optimizing the ergonomic risk level score.

## 3. Model description

When making multi-objective decisions with a time-performance improvement model, decision-makers will choose the more efficient variant with a shorter process time. As a result, the proposed model aids decision-makers in finding the required ergonomic risk score improvement that maximizes operator performance while reducing cycle time. This section describes the proposed generic formulation and objective function of the model, as well as an optimal improvement strategy to improve operator performance and cycle time.

The operator performance is computed as

$$OP_i = \sum_{i=1}^{n} \left( {AP_i}^{S_t C_t} \right) \qquad (1)$$

To improve operator performance, the objective function is

$$OP_j = \sum_{j=1}^{n}(AP_j{}^{S_tC_t{}'}) \quad (2)$$

subject to ≤ 100,

where $AP_i{}^{S_tC_t}$ is the actual performance of operator (i) with standard time$(S_t)$ and cycle time $(C_t)$. Following optimization, a new $AP$ of the same activities is created with reduced cycle time, where improvement in operator performance $(j)$ is combined with reduced cycle time $(C_t{}')$. In general, reduced cycle time $(C_t{}')$ is better than cycle time $(C_t)$ before improvement. The cycle time is expressed as

$$C_t = O_t * P_r * A_t * ERL = f(M, \overline{W}, \overline{S}, E_r), \quad (3)$$

where $O_t$ is the observed time of the process, $P_r$ stands for the performance rating given by westing house system, $A_t$ is the allowance time, and $ERL$ is the score of ergonomic risk level. Cycle time depends on S that stands for the skill needed to complete the job, and W represents the job content. Er is the ergonomic design condition of working environment. Assumed S and W are constants in this study because the operator is capable of doing the job and the job content is provided as a necessity. The value considering cycle time after improvement $(C_t{}')$ is the optimal cycle time,

$$C_t{}' = O_t * P_r * A_t * ERL' \quad (4)$$

The operator performance is calculated as,

$$OP = S_t/C_t, \quad (5)$$

where standard time $(S_t)$ is constant and suggested by the company from the previous experience. $OP$ will increase if cycle time $(C_t)$ decreases.

### 3.1 Methodology

The Genetic algorithm (GA) is a familiar technique that is inspired by the genetic progression process. GA mirrors the Darwinian idea of survival of the fittest. The fundamental components of GA are fitness selection, chromosome representation, and biologically inspired operators. A novel concept, inversion, is commonly utilized in GA implementations. Selection, mutation, and crossover are biologically inspired operators. In selection, chromosomes are chosen for further processing based on their fitness value. In the crossover operator, a randomized locus is selected, and the sub-sequences within chromosomes are changed to produce an offspring. Some chromosome bits will be randomly switched based on the likelihood of mutation. The new populations are created by iteratively applying genetic operators to individuals already present in the population. The fundamental components of GA include the selection, representation, mutation, and crossover of chromosomes, as well as the fitness function computation. GA dynamically changes the search method based on crossover and mutation probability to find the best answer, it can change the encoded genes, can evaluate numerous people, and generate multiple best solutions. As a result, GA offers superior worldwide search capabilities. This method gradually replaces the most unfavourable variables in a suboptimal response with newly generated random variables. The physical desire to perfect can also be a source of extreme optimal solution inspiration [28]. The following steps are involved in the time-performance improvement model with optimal ergonomic risk level: (1) evaluate the operator performance improvement based on the amount of time required for each activity improvement; (2) allocate the optimal ergonomic risk level score in a specific circumstance for each process; and (3) find an optimal strategy from alternatives as an optimal solution benchmark for batch processing. The MATLAB GA module is one of the most widely used applications for analysing genetic algorithms. This study makes use of the MATLAB GA module, which allows for the application of a broad range of variables as well as sophisticated and iterative calculations. The researcher may simply change variables and evaluate and analyse the findings while using Microsoft Excel as a GA platform [29]. The method of the genetic algorithm is shown in Figure 1.

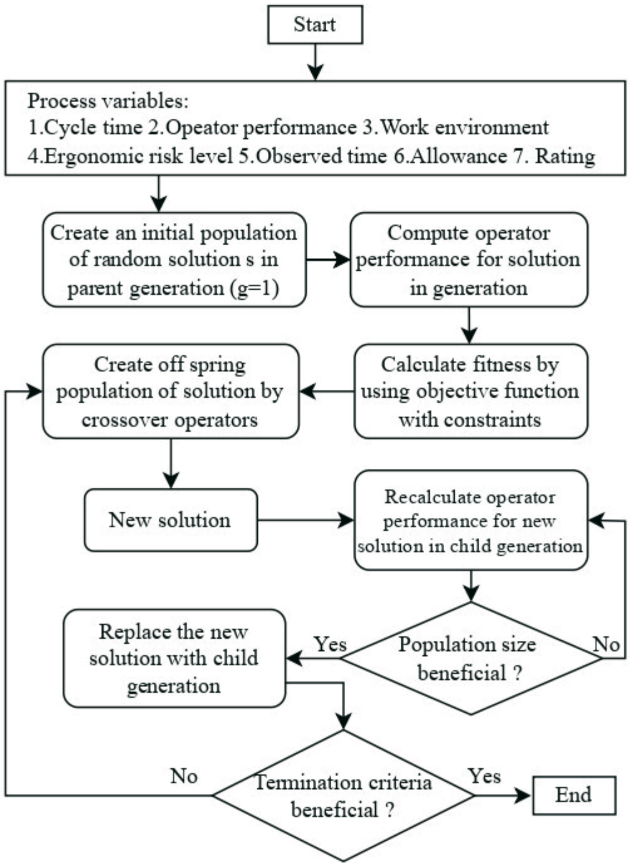


**Fig. 1** Methodology

3.2 Calculation of risk level score

The ergonomic risks of the worker allocated to the workstation are represented using the ergonomic risk level, ERL, and the quick exposure check method, QEC, is used to calculate them. The ergonomics risk score of body parts is calculated using the QEC method. The back of the body, shoulder, wrist, neck, work tempo, and stress are the evaluated modules. The ERL score is calculated as

$$ERL = (B_{rl} + S_{rl} + W_{rl} + N_{rl} + W_p + S)/number\ of\ modules\ measured, \quad (6)$$

where $B_{rl}$ is the risk level score in the back of the body, $S_{rl}$ stands for the risk level score on the shoulder, $W_{rl}$ and $N_{rl}$ are the wrist risk level scores of the wrist and neck, respectively, and $W_p$ and $S$ stand for the work pace and stress. The Ergofellow software is used to evaluate the risk scores. The questionnaires for observer and operator were circulated and the scores were plotted. In the quick exposure check method, scores vary from 8 to 56 for the back of the body, 10 to 56 for the shoulder and arm, 10 to 46 for the wrist and hand, 4 to 18 for the neck, 1 to 9 for work pace, and 1 to 16 for stress. The higher the score, the higher the risk level. The existing maximum score is taken as the starting point for ergonomic improvement. In this study, a genetic algorithm is used to find the optimal ergonomic risk level, which helps to design the workstation with a minimal level of alteration instead of altering the entire workstation. By using the formula, the existing ergonomic risk level is measured, but the required ergonomic risk level is obtained with the help of a genetic algorithm.

$$B_{rl} = (B_{rl_1} + B_{rl_2} + \cdots + B_{rl_n})/Total\ number\ of\ observed\ samples \tag{7}$$

$$S_{rl} = (S_{rl_1} + S_{rl_2} + \cdots + S_{rl_n})/Total\ number\ of\ observed\ samples \tag{8}$$

$$W_{rl} = (W_{rl_1} + W_{rl_2} + \cdots + W_{rl_n})/Total\ number\ of\ observed\ samples \tag{9}$$

$$N_{rl} = (N_{rl_1} + N_{rl_2} + \cdots + N_{rl_n})/Total\ number\ of\ observed\ samples \tag{10}$$

$$W_p = (W_{p_1} + W_{p_2} + \cdots + W_{p_n})/Total\ number\ of\ observed\ samples \tag{11}$$

$$S = (S_1 + S_2 + \cdots + S_n)/Total\ number\ of\ observed\ samples \tag{12}$$

Workers and operators from all the workstations, two production managers, supervisors, and an industrial engineer are involved in plotting the risk level score and analysing the possibility of improvement in the production line. Three different case studies were evaluated for this study. Children's T-shirt production is case study 1, which includes 11 activities and 46 workers. Tablecloth production is case study 2, which includes 8 activities with 32 workers. In case study 3, kitchen glove production was evaluated with six activities and 46 workers. The working posture varies with each activity. Sitting posture plays a major role in cut pattern formation, machine setting, and sewing activities. The standing posture includes the visual check, cutting process, labelling, quality check, and ironing activities. Worker movements are necessary during activities 2, 5, 9, and 11. The maximum existing score for each module is considered equal to improvement level 1. The risk level scores of all activities in case studies 1, 2, and 3 for the basic work conditions are shown in Tables 1, 2 and 3, respectively.

**Table 1** Basic risk level score of case study 1

| Activity | $B_{rl}$ | $S_{rl}$ | $W_{rl}$ | $N_{rl}$ | $W_p$ | $S$ | $ERL$ |
|---|---|---|---|---|---|---|---|
| 1 | 0.8265 | 0.8942 | 0.89471 | 1 | 1 | 1 | 0.935901667 |
| 2 | 0.9212 | 0.9367 | 0.89471 | 1 | 1 | 1 | 0.958768333 |
| 3 | 0.82612 | 0.9135 | 0.926 | 1 | 1 | 1 | 0.94427 |
| 4 | 0.82612 | 0.9135 | 0.926 | 1 | 1 | 1 | 0.94427 |
| 5 | 0.926 | 1 | 0.92 | 0.999 | 1 | 1 | 0.974166667 |
| 6 | 0.89471 | 0.8459 | 0.92304 | 0.84612 | 1 | 1 | 0.918295 |
| 7 | 0.9997 | 0.9135 | 0.926 | 1 | 1 | 1 | 0.9732 |
| 8 | 0.92 | 0.9135 | 0.926 | 1 | 1 | 1 | 0.959916667 |
| 9 | 0.92 | 0.8942 | 0.89471 | 0.8 | 1 | 1 | 0.918151667 |
| 10 | 0.90592 | 0.9135 | 0.926 | 1 | 1 | 1 | 0.95757 |
| 11 | 0.93554 | 0.9315 | 0.96875 | 1 | 1 | 1 | 0.972631667 |

**Table 2** Basic risk level score of case study 2

| Activity | $B_{rl}$ | $S_{rl}$ | $W_{rl}$ | $N_{rl}$ | $W_p$ | $S$ | $ERL$ |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 0.9135 | 0.9135 | 0.86667 | 1 | 1 | 0.948945 |
| 2 | 1 | 0.9135 | 0.9135 | 0.86667 | 1 | 1 | 0.948945 |
| 3 | 0.82612 | 0.9135 | 0.926 | 1 | 1 | 1 | 0.944270 |
| 4 | 0.926 | 1 | 0.92 | 0.999 | 1 | 1 | 0.974167 |
| 5 | 0.89471 | 0.8459 | 0.92304 | 0.84612 | 1 | 1 | 0.918295 |
| 6 | 0.9997 | 0.9135 | 0.926 | 1 | 1 | 1 | 0.973200 |
| 7 | 0.92 | 0.9135 | 0.926 | 1 | 1 | 1 | 0.959917 |
| 8 | 0.926 | 1 | 0.84375 | 0.86667 | 1 | 1 | 0.939403 |

**Table 3** Basic risk level score of case study 3

| Activity | $B_{rl}$ | $S_{rl}$ | $W_{rl}$ | $N_{rl}$ | $W_p$ | $S$ | $ERL$ |
|---|---|---|---|---|---|---|---|
| 1 | 0.82612 | 0.9135 | 0.926 | 1 | 1 | 1 | 0.944270 |
| 2 | 0.926 | 1 | 0.92 | 0.999 | 1 | 1 | 0.974167 |
| 3 | 0.89471 | 0.8459 | 0.92304 | 0.84612 | 1 | 1 | 0.918295 |
| 4 | 0.9997 | 0.9135 | 0.926 | 1 | 1 | 1 | 0.973200 |
| 5 | 0.82612 | 0.9135 | 0.926 | 1 | 1 | 1 | 0.944270 |
| 6 | 0.926 | 1 | 0.84375 | 0.86667 | 1 | 1 | 0.939403 |

## 4. Discussion of the cases

Three products are evaluated in a garment industry located in Tamilnadu, India. Examined products are T-shirts, kitchen gloves, and tablecloths. The chosen industry has implemented a few lean manufacturing tools. Major processes are done manually in the industry, which increases the targets for the workers. Ergonomic risk level factors are analysed, and the workstation design is improved to reduce cycle time and improve operator performance.

### 4.1 Process information for the case studies

The case studies in this section are garment projects that include sewing activities. The aim is to understand the nature of the proposed method. As stated above, the children's t-shirt is the first case study. The width of the shirt in the chest area is 31 centimetres, the length of the shirt is 41 centimetres, the bottom width is 31 centimetres, and the sleeve size is 10.5 centimetres. The tablecloth manufacturing processes are the subject of the second case study. The length of the tablecloth is 304.8 centimetres and its width is 203.2 centimetres. Kitchen glove production processes are considered in the third case study. The length and breadth of the kitchen gloves are 33 centimetres and 19 centimetres, respectively. Initial cycle time and operator performance are calculated with observed time, performance rating, constant standard time, and constant labour usage. Real-time observation is conducted through the Gemba walk method, and practical time is calculated with a stopwatch (observed time) handled by industrial engineers. The ergonomic risk level for all the processes in the case studies is analysed by the quick exposure check method (QEC). Quantity $(Q)$is measured before and after the improvement. The basic information and steps of case studies 1, 2, and 3 are shown in Table 4, 5, and 6, respectively. Basic time is formulated as

$$B_t = O_t * P_r \tag{13}$$

**Table 4** Process information of case study 1

| Activity | $S_t$ in minutes | $Q$ in numbers | Basic time in minutes | $ERL$ score | $C_t$ in minutes per $Q$ | $OP$ in % |
|---|---|---|---|---|---|---|
| 1 | 51.0 | 7 | 60.1 | 0.935901667 | 61.8 | 82.48 |
| 2 | 130.0 | 5 | 154.3 | 0.958768333 | 177.5 | 73.23 |
| 3 | 4.5 | 262 | 5.7 | 0.94427 | 6.4 | 70.15 |
| 4 | 2.0 | 541 | 2.7 | 0.94427 | 3.1 | 64.38 |
| 5 | 3.0 | 17 | 3.8 | 0.974166667 | 4.1 | 73.52 |
| 6 | 5.0 | 10 | 6.2 | 0.918295 | 6.8 | 73.13 |
| 7 | 7.5 | 533 | 8.8 | 0.9732 | 10.2 | 73.24 |
| 8 | 4.5 | 572 | 5.6 | 0.959916667 | 5.9 | 76.61 |
| 9 | 3.2 | 17 | 4.1 | 0.918151667 | 4.1 | 77.59 |
| 10 | 2.0 | 529 | 2.8 | 0.95757 | 3.2 | 62.97 |
| 11 | 1.2 | 409 | 1.8 | 0.972631667 | 2.1 | 58.45 |

**Table 5** Process information of case study 2

| Activity | $S_t$ in minutes | $Q$ in numbers | Basic time in minutes | $ERL$ score | $C_t$ in minutes per $Q$ | $OP$ in % |
|---|---|---|---|---|---|---|
| 1 | 143 | 7 | 160.11 | 0.948945 | 176.12 | 81.20 |
| 2 | 415 | 2 | 463.46 | 0.948945 | 509.81 | 81.40 |
| 3 | 80 | 8 | 91.08 | 0.94427 | 109.30 | 73.19 |
| 4 | 3 | 29 | 4.43 | 0.974166667 | 4.88 | 61.52 |
| 5 | 5 | 11 | 5.70 | 0.918295 | 6.27 | 79.77 |
| 6 | 4.5 | 810 | 5.62 | 0.9732 | 6.74 | 66.76 |
| 7 | 1 | 1838 | 1.25 | 0.959916667 | 1.37 | 72.92 |
| 8 | 3.5 | 174 | 4.38 | 0.939403333 | 4.82 | 72.65 |

**Table 6** Process information of case study 3

| Activity | $S_t$ in minutes | $Q$ in numbers | Basic time in minutes | $ERL$ score | $C_t$ in minutes per $Q$ | $OP$ in % |
|---|---|---|---|---|---|---|
| 1 | 0.6 | 979 | 0.74 | 0.94427 | 0.86 | 69.96 |
| 2 | 3.5 | 47 | 3.83 | 0.974166667 | 4.15 | 84.32 |
| 3 | 4 | 17 | 4.45 | 0.918295 | 5.18 | 77.20 |
| 4 | 3 | 2023 | 3.60 | 0.9732 | 4.15 | 72.25 |
| 5 | 1 | 5191 | 1.40 | 0.94427 | 1.62 | 61.80 |
| 6 | 3.5 | 168 | 4.31 | 0.939403333 | 4.99 | 70.09 |

## 5. Improvement in ergonomic conditions

The ergonomic conditions of the workstation have been improved to reduce the ergonomic risk level. Physical factors considered to measure the risk level are unbalanced sitting and standing, bent and twisted posture of the worker, prolonged time of standing in the same position, and angle of the upper and lower arms from the body. The observed physical risk factors are shown in Table 7.

The angles of the working posture are measured through the image. With the help of analysed images, the RULA score sheet is used to measure the risk level score during the sitting postures. The basic score measured by the RULA score sheet of sitting and standing postures is 5, which requires investigation and rapid changes. Work station design and training methods are improved to reduce the RULA risk level score to 3. The angle measurement of the neck and trunk is shown in Figures 2 and 3.

**Table 7** Observed physical factors

| Activities | Observed physical risk factors |
|---|---|
| Cut pattern formation | • Sitting continuously in the same position<br>• Eye strain |
| Spreading and visual check | • Standing continuously in the same position<br>• Lifting heavy lot<br>• Continuous staring |
| Cutting process | • Standing continuously in the same position |
| Labelling and stickering | • Standing continuously in the same position |
| Move to input storage | • Walking with the bundles in an uncomfortable posture<br>• Multiple walk times to the storage |
| Machine setting | • Uncomfortable sitting position |
| Sewing process | • Back trunk posture<br>• Upper and lower arm positions |

| Activities | Observed physical risk factors |
|---|---|
| Quality check | • Standing continuously in the same position<br>• Stretching hands away from the body position<br>• Eye strain |
| Move to finish storage | • Walking with the bundles in an uncomfortable posture<br>• Multiple walk times to the storage |
| Ironing process | • Standing continuously in the same position<br>• Stretching hands away from the body position |
| Move to metal detection storage and packing | • Walking with the bundles in an uncomfortable posture<br>• Multiple walk times to the storage |

## 5.1 Ergonomic improvements

In the selected industry, eleven activities were listed for the analysis, including all three case studies. Every activity has a different work environment. Processes depend on the nature of the job. Different kinds of jobs result in different work postures and ergonomic risk levels. The variety of ergonomic risks cannot be measured precisely by one common tool. To achieve an effective ergonomic evaluation, four different kinds of tools were used. To assess ergonomic risks in the listed activities, the National Institute of Occupational Safety and Health (NIOSH) lifting equation, rapid upper limb assessment (RULA), quick exposure check method (QEC), and Ovako working posture analysis system (OWAS) are used. In a few activities, two measurement tools were used to measure the ergonomic risks at different stages of the process. Measurement tools used for the activities are listed in Table 8.

**Table 8** Selection of measurement tool

| Activities | Measurement tool | Reason for the selection of tool |
|---|---|---|
| Cut pattern formation | QEC | Working posture is static most of the time. Job stress was observed in the activity. |
| Spreading and visual check | NIOSH, RULA | NIOSH was used to measure the lifting posture included in this process, and RULA was used during the checking. |
| Cutting process | QEC | Working posture is static. The major problem is job stress. |
| Labelling and stickering | RULA | A major working posture was observed in the upper body. |
| Move to input storage | OWAS | Load-carrying posture is observed in the activity. |
| Machine setting | RULA | Awkward working postures were observed for the entire setting time. |
| Sewing process | RULA | Working posture is static, and the upper body is involved in complete activities. |
| Quality check | QEC | Psychosocial factors are observed in the activity. |
| Move to finish storage | OWAS | Load-carrying posture is observed in the activity. |
| Ironing process | QEC | Working posture is static most of the time. Job stress was observed in the activity. |
| Move to metal detection storage and packing | OWAS, QEC | Load-carrying posture is observed in the activity. |

The Ergofellow software trail version was used to evaluate the ergonomic risk scores with several measurement tools.

#### 5.1.1 Role of the quick exposure check method (QEC)

Questionnaires based on the QEC were used to finalize the risk scores before and after the ergonomic improvements. Other than QEC scores, the remaining ergonomic assessment tool results were used to improve ergonomic conditions. Finalized scores from the QEC were converted to a 0 to 1 scale for optimization purposes, and the same was done in the $ERL$ score.

#### 5.1.2 Evaluation by the NIOSH lifting equation

In this study, several ranges of the lifting index (LI) variants were developed and regarded as markers of the degree of exposure to the risks connected to the strenuous physical requirements of manual lifting tasks. The substantial correlation between both the LI metrics and different low back health problems served as the foundation for the assessment of the values of the LI variants as risk information. Table 9 shows the recommendations at various LI levels. We used data from studies that were, on average, assessed as good to consider the LI scores as risk information.

**Table 9** LI levels and recommendations

| NIOSH lifting index value | Risk level | Suggested actions |
|---|---|---|
| Less than 1.0 | Very low | None for healthy workers |
| From 1.0 to 1.5 | Low | Pay attention to redesign tasks or workstations |
| From 1.5 to 2.0 | Moderate | Give priorities to reduce the LI value |
| From 2.0 to 3.0 | High | Need high priority to reduce LI |
| More than 3.0 | Very high | Corrections should be made immediately |

Although the actual value of the LI for preventing most employees from having low back disorders is most probably at a level between 1 and 2, we have chosen a LI of 1.0 as a prudent threshold and, in fact, as a standard design restriction. The LI is thought to be a significant risk predictor for low back disorders when it rises above 1.5. Changes to the job to lower the LI value and thus decrease risk levels should be given top priority in circumstances where the LI value is above 2.0 or 3.0, which are regarded as high and extremely high risks, respectively.

The working postures of eleven workers were analysed through the NIOSH lifting equation. Sample images of the analysed posture of a worker before and after improvements is shown in Figure 2. The dimensions shown in the figure are in centimetres except for the weight.

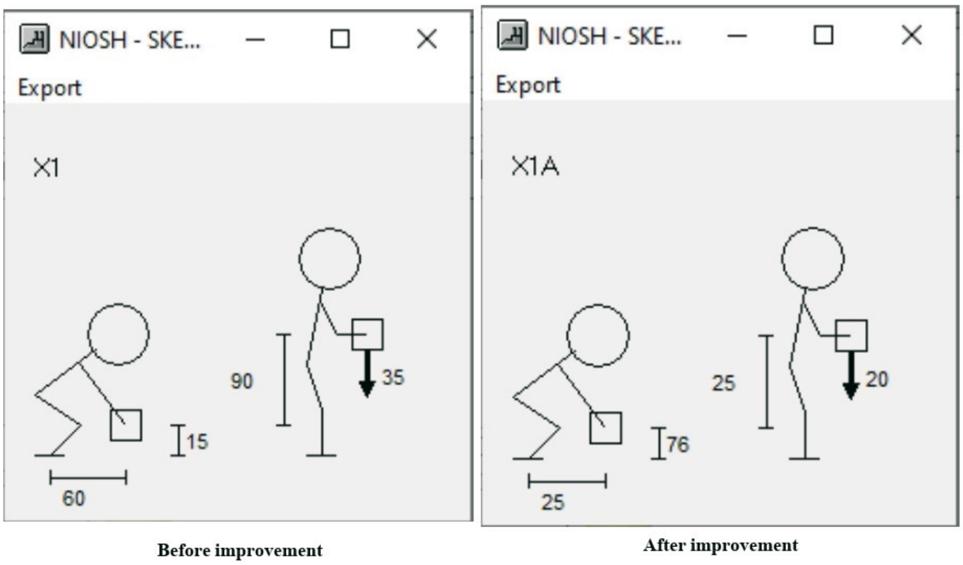


**Fig. 2** NIOSH lifting equation evaluation

The values of LI for the eleven workers were more than 1.0, which was bad for the employee's health and safety. To reduce the LI value, the following improvements were made to the workstations:

- Through proper training and floor lines, the horizontal distance of the hands away from the ankles (H) is reduced from 60 centimetres to 25 centimetres.
- Stands were provided to place the clothing, which increased the vertical distance of the hands above the floor (V) from 15 centimetres to 76 centimetres. The vertical travel distance (D) was reduced from 90 centimetres to 25 centimetres.
- Through proper training and changes in the cloth lot storage position, the angle of asymmetry (A) is reduced from 90 degrees to 20 degrees.
- The coupling component (C) was improved from 0.9 to 1.0 by providing a holder.

Overall, the LI value is reduced from 8.499 to 0.999, which ensures the safety of the workers.

#### 5.1.3 Evaluation by rapid upper limb assessment (RULA)

In all three case studies, 83 workers were observed and analysed through the RULA tool. The RULA analysis score levels are shown in Figure 3. The angles of the working posture are measured through the image. With the help of analysed images, the rapid upper limb assessment (RULA) score sheet is used to measure the risk level score during sitting postures. Ergofellow software was used to evaluate the risk score through the RULA tool. The unsafe basic score measured by the RULA score sheet of the sitting and standing postures for 16 employees is 7, and for 20 employees it is 5, which requires investigation and rapid changes. These higher ris-level scores belonged to machine-setting and cutting activities. Sewing activities have a moderate level of risk. Work station design and training methods are improved to reduce the RULA risk level score to 3. The angle measurements of the neck and trunk are shown in Figures 3a and 3b.

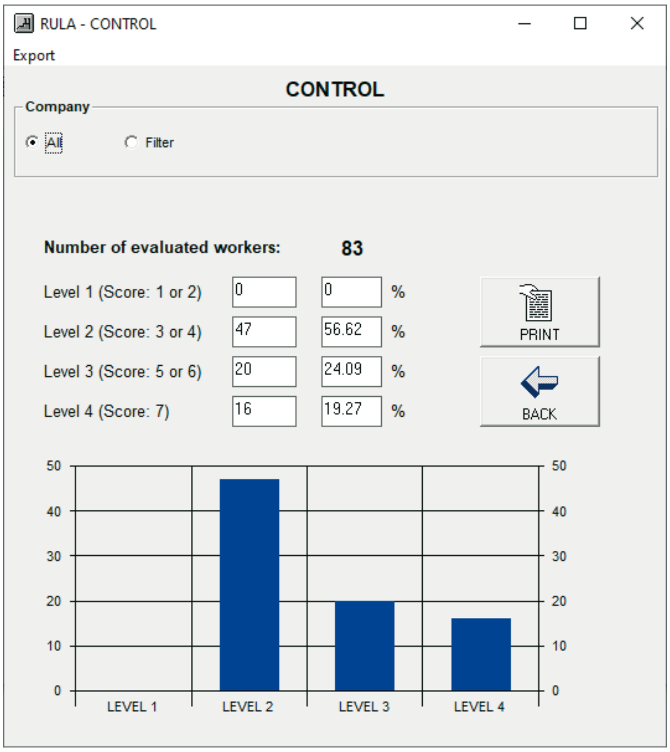


**Fig. 3** RULA analysis

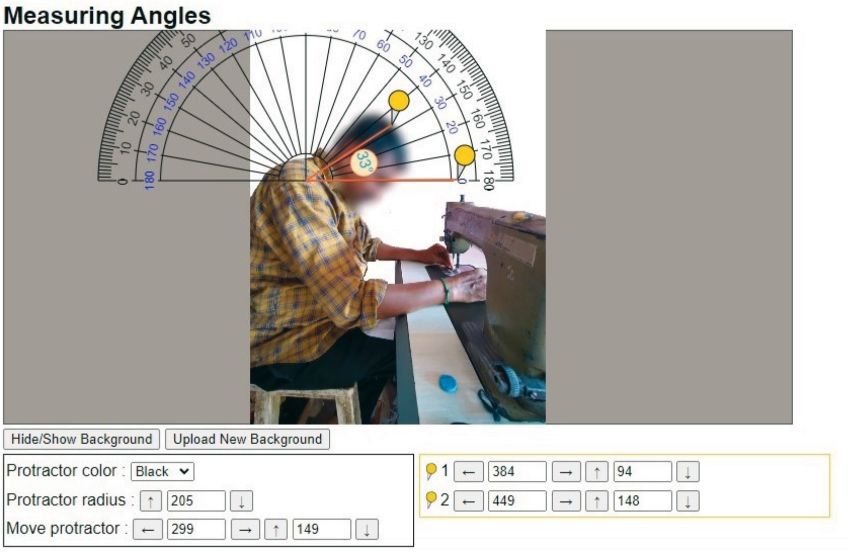


**Fig. 3a** Neck measurement

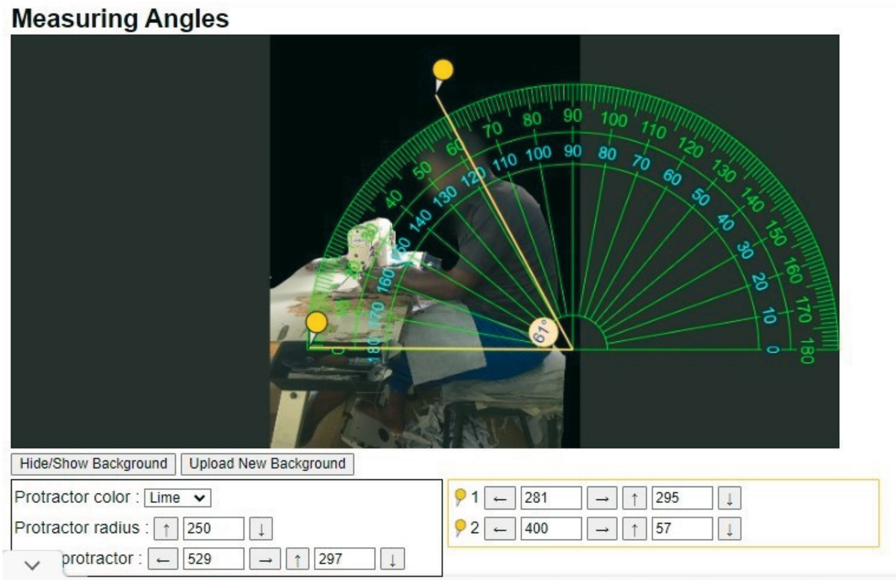


**Fig. 3b** Trunk measurement

Standing posture has the risk of causing leg pain and stress. Anti-fatigue mats and stretching exercises are suggested to reduce stress and pain during activities that include prolonged standing posture. In the quality checking activity, the work table has been modified for easy identification of different jobs and to grab the trims easily. Contrast colours are suggested for the stickers, which helps the sticker removal process during the quality check. Trolleys are recommended for movement activities to reduce repetitive walking and avoid uncomfortable postures while walking and lifting bundles. Breaks from the work were introduced to reduce the eye strain caused by the continuous staring at monitors and printed lot. Risk level scores are measured through the questionnaires suggested by the QEC method after the ergonomic improvements.

## 6. Result and discussion

In all the cases mentioned above, management might improve the operator performance through ergonomic improvements in all activities. The optimization results of case studies 1, 2, and 3 are shown in Tables 10, 11, and 12, respectively. The cycle time of each activity is minimized in the optimization method. In case study 1, the overall cycle time is reduced from 285 minutes to 221 minutes, the operator performance is increased from 71.43% to 90.33%, and, after optimization, the ergonomic risk levels of activities 1 to 11 are 0.75, 0.66, 0.63, 0.76, 0.69, 0.63, 0.83, 0.79, 0.69, 0.82, and 0.60. In case study 2, the overall cycle time is reduced from 819 minutes to 659 minutes, the operator performance is increased from 73.68% to 92.76%, and, after optimization, the ergonomic risk levels of activities 1 to 8 are 0.75, 0.65, 0.63, 0.53, 0.71, 0.83, 0.79, and 0.66. In case study 3, the overall cycle time is reduced from 20 minutes to 16 minutes, the operator performance is increased from 72.60% to 93.70%, and, after optimization, the ergonomic risk levels of activities 1 to 6 are 0.63, 0.81, 0.69, 0.83, 0.83, and 0.63. The results show that the time-performance improvement model can be used in real-world examples to identify the optimal solution.

**Table 10** Optimization with optimal ergonomic risk level – Case study 1

| Activity | $S_t$ in minutes | $Q$ in numbers | Basic time in minutes | $C_t$ in minutes per $Q$ | $OP$ in % | $ERL'$ score | $Q'$ in numbers | $C_t'$ in minutes per $Q$ | $OP'$ in % |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 51.0 | 7 | 60.1 | 61.8 | 82.48 | 0.75 | 8 | 51.11 | 99.79 |
| 2 | 130.0 | 5 | 154.3 | 177.5 | 73.23 | 0.66 | 6 | 133.17 | 97.62 |
| 3 | 4.5 | 262 | 5.7 | 6.4 | 70.15 | 0.63 | 356 | 4.72 | 95.43 |
| 4 | 2.0 | 541 | 2.7 | 3.1 | 64.38 | 0.76 | 639 | 2.63 | 76.11 |
| 5 | 3.0 | 17 | 3.8 | 4.1 | 73.52 | 0.69 | 23 | 3.00 | 99.91 |
| 6 | 5.0 | 10 | 6.2 | 6.8 | 73.13 | 0.63 | 14 | 5.14 | 97.21 |
| 7 | 7.5 | 533 | 8.8 | 10.2 | 73.24 | 0.83 | 600 | 9.11 | 82.37 |
| 8 | 4.5 | 572 | 5.6 | 5.9 | 76.61 | 0.79 | 675 | 4.98 | 90.36 |
| 9 | 3.2 | 17 | 4.1 | 4.1 | 77.59 | 0.69 | 22 | 3.23 | 99.19 |
| 10 | 2.0 | 529 | 2.8 | 3.2 | 62.97 | 0.82 | 596 | 2.82 | 71.00 |
| 11 | 1.2 | 409 | 1.8 | 2.1 | 58.45 | 0.60 | 592 | 1.42 | 84.62 |

**Table 11** Optimization with optimal ergonomic risk level – Case study 2

| Activity | $S_t$ in minutes | $Q$ in numbers | Basic time in minutes | $C_t$ in minutes per $Q$ | $OP$ in % | $ERL'$ score | $Q'$ in numbers | $C_t'$ in minutes per $Q$ | $OP'$ in % |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 143 | 7 | 160.11 | 176.12 | 81.20 | 0.75 | 9 | 143.57 | 99.60 |
| 2 | 415 | 2 | 463.46 | 509.81 | 81.40 | 0.65 | 3 | 416.16 | 99.72 |
| 3 | 80 | 8 | 91.08 | 109.30 | 73.19 | 0.63 | 10 | 80.50 | 99.38 |
| 4 | 3 | 29 | 4.43 | 4.88 | 61.52 | 0.53 | 43 | 3.26 | 92.16 |
| 5 | 5 | 11 | 5.70 | 6.27 | 79.77 | 0.71 | 14 | 5.03 | 99.48 |
| 6 | 4.5 | 810 | 5.62 | 6.74 | 66.76 | 0.83 | 915 | 5.97 | 75.38 |
| 7 | 1 | 1838 | 1.25 | 1.37 | 72.92 | 0.79 | 1951 | 1.29 | 77.44 |
| 8 | 3.5 | 174 | 4.38 | 4.82 | 72.65 | 0.66 | 237 | 3.54 | 98.91 |

**Table 12** Optimization with optimal ergonomic risk level – Case study 3

| Activity | $S_t$ in minutes | $Q$ in numbers | Basic time in minutes | $C_t$ in minutes per $Q$ | $OP$ in % | $ERL'$ score | $Q'$ in numbers | $C_t'$ in minutes per $Q$ | $OP'$ in % |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.6 | 979 | 0.74 | 0.86 | 69.96 | 0.63 | 1367 | 0.61 | 97.63 |
| 2 | 3.5 | 47 | 3.83 | 4.15 | 84.32 | 0.81 | 56 | 3.51 | 99.84 |
| 3 | 4 | 17 | 4.45 | 5.18 | 77.20 | 0.69 | 22 | 4.07 | 98.18 |
| 4 | 3 | 2023 | 3.60 | 4.15 | 72.25 | 0.83 | 2308 | 3.64 | 82.44 |
| 5 | 1 | 5191 | 1.40 | 1.62 | 61.80 | 0.63 | 6144 | 1.16 | 86.24 |
| 6 | 3.5 | 168 | 4.31 | 4.99 | 70.09 | 0.63 | 235 | 3.58 | 97.88 |

It is worth reducing the ergonomic risk level if the reduced cycle time of the process is nearer or equal to the standard time and the increased productivity is achieved within the existing resources and allocated manpower. The optimization findings demonstrate that a minimal amount of improvement in the ergonomic risk level is sufficient to generate a significant reduction in cycle time. Improving ergonomic conditions through exercise training by management can reduce the cycle time. The optimum outcome from the preceding section shows how the improvement factors for each activity vary from one another. The ergonomic risk level of improvement varies depending on the diverse workstation surroundings. The selective improvement of activities by genetic algorithms can achieve optimization. The optimized cycle time with operator performance and optimal ergonomic risk level obtained via genetic algorithm can be achieved while reducing lead time without going over budget. The improvement in operator performance is shown in Figure 4.

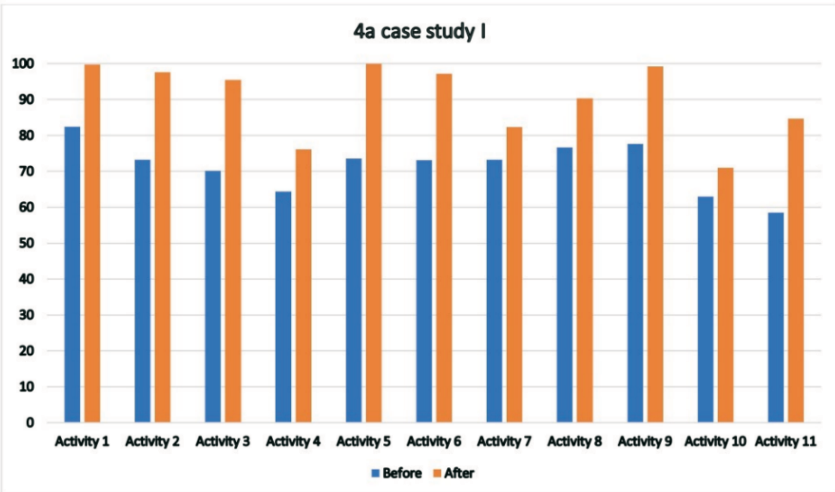


**Fig. 4a** Operator performance improvement in case study 1

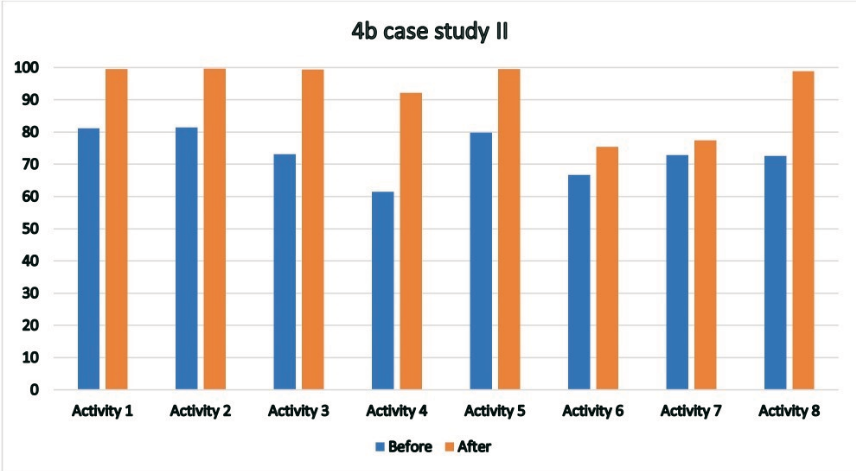


**Fig. 4b** Operator performance improvement in case study 2

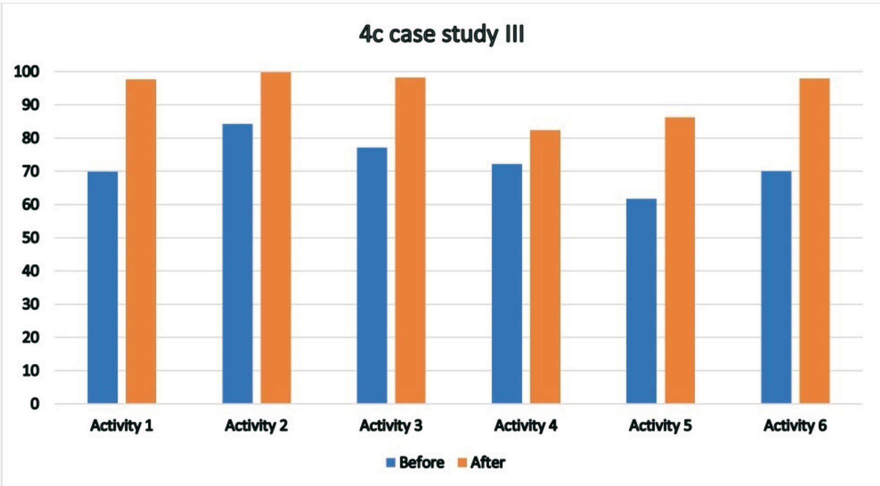


**Fig. 4c** Operator performance improvement in case study 3

The final result shows that this time-performance improvement model can satisfy both the production parameters from a management point of view and the ergonomic factors from a worker's point of view. Considering the production target and order budget during the improvement of the workstation conditions is necessary to balance the expectations of both workers and management. The improvement in cycle time is shown in Figure 5 for all case studies. The pareto front chart of the optimized solution is shown in Figure 6.

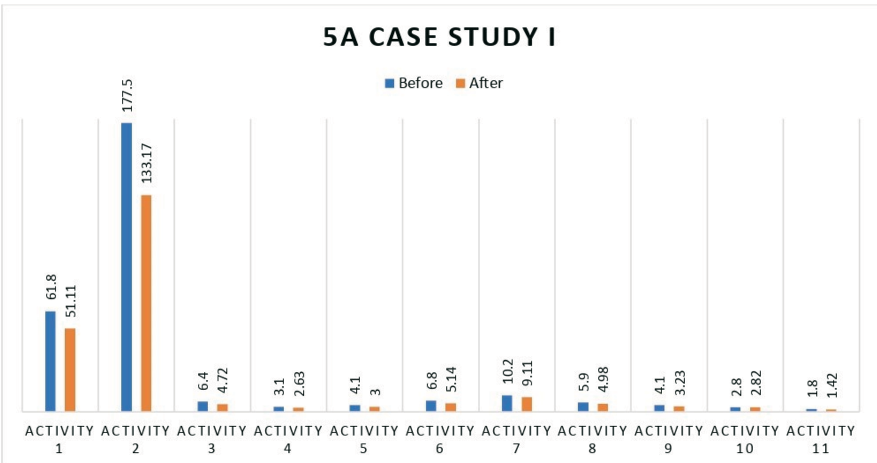


**Fig. 5a** Cycle time improvement in case study 1

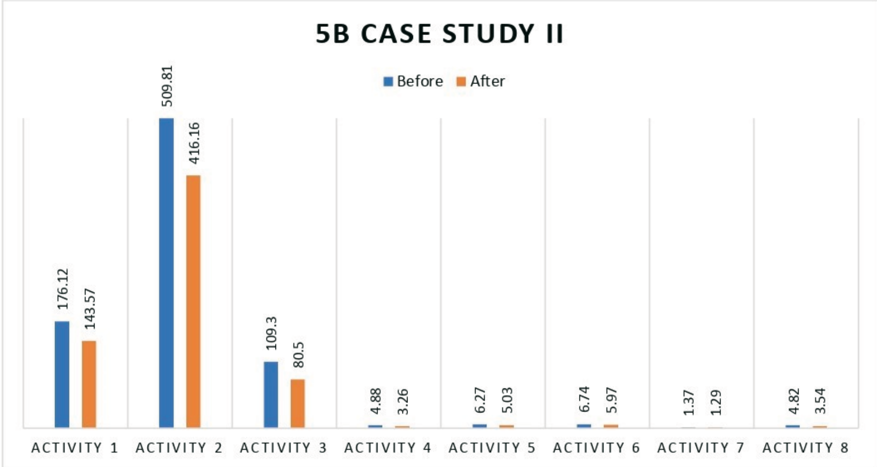


**Fig. 5b** Cycle time improvement in case study 2

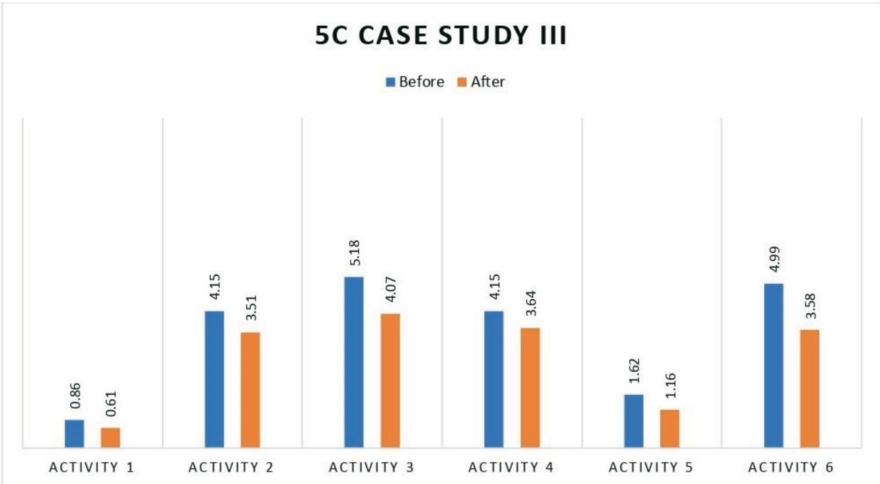


**Fig. 5c** Cycle time improvement in case study 3

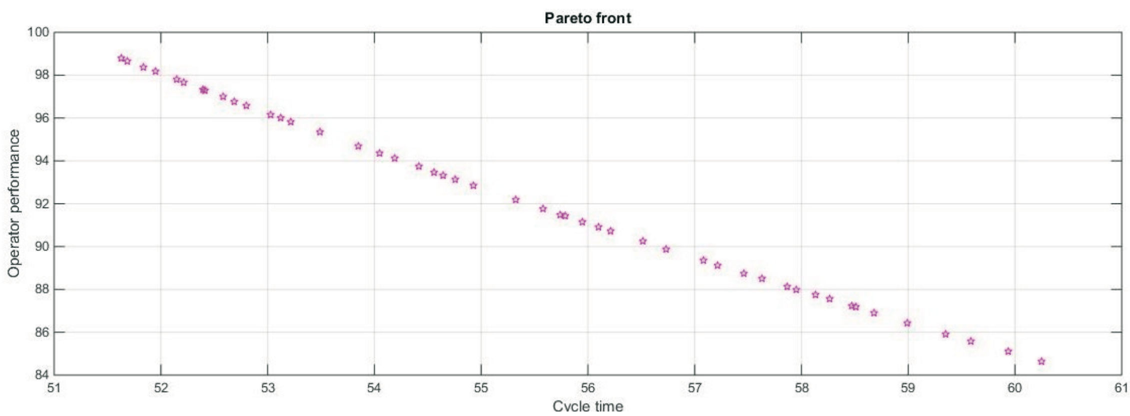


**Fig. 6** Pareto front

## 7. Conclusion

The time-cost trade-off model was typically implemented using optimization approaches in the majority of earlier studies by increasing external resources, overlapping tasks, or substituting external resources. However, among such methods, boosting the performance of current crews was not included. This research has given an optimization strategy for shortening the cycle time after examining earlier critical investigations. The time-performance improvement approach uses GAs on the most widely used programme platform rather than a specific programme to search for an optimum solution while taking into account the variable ergonomic risk level that is affected by the working environment and management. As a result, both researchers and practitioners will find it simpler to apply the suggested model to actual initiatives. The outcomes from a real-world situation show how the decision-maker can minimize cycle time while still avoiding negative impacts like stress and fatigue. The optimal solutions with variable ergonomic risk levels under diverse working environment restrictions can serve as a basis and a starting point for future improvements. The key contribution of this study is the application of management improvement of ergonomic risk level to time-cost trade-off optimization, which has not been addressed in earlier studies. As a result of improved performance of existing crews rather than wasteful overmanning, overlapping, or costly substitution, cycle time can be minimized. Also, it would be advantageous to organizational effectiveness in the long term. This study suggests that senior managers use the proposed optimization model as their first consideration when attempting to reduce cycle time. This research adds to the collection of knowledge and connects the developed framework to a practical application. However, the following constraints must be considered: 1. The success of management-led development needs a time delay. Supervisors with varying levels of experience evaluate the improvement factor. It may result in increased burden and time at the start of textile work. 2. Future research can improve the proposed system by incorporating other acceleration methods or resources; using fuzzy logic to reduce bias when analysing the improvement factor; or separating surroundings and management into more specific factors to investigate the influence of optimal ergonomic risk level. 3. In terms of sample size, this investigation does have limitations. For the investigation, outsourcing processes were not measured. A larger sample size is preferable for validating the results. 4. The case study industry had two years of experience with lean environments; therefore, the results vary based on experience. 5. Due to time constraints, ecological and protective factors were disregarded. However, there is potential for the application of the time-performance improvement model in a variety of industries.

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