Journal of Industrial Engineering International (2018) 14:783–791
https://doi.org/10.1007/s40092-018-0260-z

ORIGINAL RESEARCH

Ergonomics and simulation-based approach in improving facility layout

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Received: 3 February 2017 / Accepted: 27 January 2018 / Published online: 3 February 2018

Abstract

The use of the simulation-based technique in facility layout has been a choice in the industry due to its convenience and efficient generation of results. Nevertheless, the solutions generated are not capable of addressing delays due to worker's health and safety which significantly impact overall operational efficiency. It is, therefore, critical to incorporate ergonomics in facility design. In this study, workstation analysis was incorporated into Promodel simulation to improve the facility layout of a garment manufacturing. To test the effectiveness of the method, existing and improved facility designs were measured using comprehensive risk level, efficiency, and productivity. Results indicated that the improved facility layout generated a decrease in comprehensive risk level and rapid upper limb assessment score; an increase of 78% in efficiency and 194% increase in productivity compared to existing design and thus proved that the approach is effective in attaining overall facility design improvement.

Keywords Efficiency · Ergonomics · Facility design · Safety · Promodel

Introduction

Strong market competition sets pressure on companies to streamline their processes and achieve overall operational efficiency. Several techniques are found effective in improving operational efficiencies such as work measurement, ergonomics, and facility design. Kazerouni et al. (2015) concluded that facility design is a major factor in efficiency. Previous studies have developed several approaches to improve and resolve facility design problems. One approach is the heuristic method which includes tabu search (TS), genetic algorithms (GA), ant colony, simulated annealing (SA) and hybrid approaches. However, these approaches are time-consuming and focus on material handling cost and distance improvements and do not incorporate actual setting and dimension of machines and equipment (Sharma et al. 2013; Dwijayanti et al. 2010). Another approach is the use of simulation software such as Promodel, Arena, Quest, and IGrip, which are a more efficient and convenient method in evaluating facility layouts before implementation (Sharma et al. 2013).

Nevertheless, both heuristic method and simulation are not capable of addressing inefficiencies due to worker's health and safety. Therefore, it is critical not only to ensure the efficiency through facility design, but also to consider the health and safety of the employees (Kazerouni et al. 2015).

Mustafa et al. (2009) discussed that the primary purpose of ergonomics is to ensure a good fit between the employees and their job to optimize worker's comfort, safety and health, productivity and efficiency. Previous ergonomic studies have shown the relationship of workstation design in worker's efficiency and safety. Shewchuk et al. (2017) provided a methodology in modeling and assessing the complex multi-worker physical processes which helped establish the ergonomic implications of the operations. Suhardi et al. (2016) improved the production process through ergonomic design. Other studies that applied ergonomics, workstation design and work system concepts include: the analysis on the effectiveness of the ergonomic prototype in reducing risks associated in a task (Fonseca et al. 2016); identification of work-related musculoskeletal disorders (WMSDs) using ergonomic

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assessment tools such as rapid upper limb assessment (RULA) and rapid entire body assessment (REBA) (Sahebagowda et al. 2016) and the methodological framework incorporating technological and environmental factors to improve productivity and ergonomics in an assembly system design (Battini and Faccio 2011). Table 1 summarizes the common techniques in improving facility layout, its purposes and, drawbacks. Although both the heuristic method and simulation approaches produce optimal or best layout, these were not capable of addressing the health and safety issues of the workers.

Table 2 summarizes the previous developments in ergonomics and facility design. Several studies have focused on obtaining the optimal solution to solve facility layout problems, nevertheless have not considered the needs of workers. The goal of this study is to improve efficiency and productivity of the facility design and at the same time address inefficiencies caused by workers due to health and safety issues.

Methodology

Figure 1 illustrates the framework for improving facility layout through ergonomics and simulation-based approach. The methodology considers the variables related ergonomic risks, efficiency and productivity.

To measure the productivity and efficiency, this study incorporated Promodel simulation software both for the existing and improved layouts. Rapid upper limb assessment (RULA) (McAtamney and Corlett 2004) was used to determine the ergonomic risks in each process as well as Fuzzy Risk Predictive Model (McCauley-Bell and Badiru 1996) in determining comprehensive risk levels in the workstations.

Results and discussions

Existing facility layout

Process analysis revealed the delays in the operation specifically during the movement of the material. The cutter traveled around 28.39 m from sorting area to assembly area and vice versa. Moreover, from cutting operation, the worker traveled approximately 8.09 m going to sorting area. The existing layout did not show any concrete layout flow, which resulted in non-productive time due to the long distance traveled. Table 3 presents the simulation results of the existing facility layout.

Using RULA, most of the workstations fell under Class IV (investigate and implement change) category. This indicated that the workstations were prone to ergonomic hazards and risks, which may affect worker's performance and later on may result in musculoskeletal disorders (MSDs).

McCauley-Bell and Badiru (1996) developed the fuzzy predictive model to quantitatively predict the risk level of work-related musculoskeletal disorders (WMSDs). Three risk factors were identified namely: task-related, personal and organizational risks and were evaluated for relative significance. Levels of existence for each risk factor are the following: high (1.00), medium (0.50), low (0.20) and non-existence (0.00). The $w_{n,}$ x_n and y_n are relative weights for each factor and a_n, b_n and c_n are levels of existence for each factor. Relative weight for each risk factor is detailed in Table 4.

Table 1 Comparison of conventional techniques in improving operational efficiency

Some techniques in improving operational efficiency				
	Work measurement	Ergonomics	Facility design	
Tools/ techniques	Standard time Charts	Workstation analysis Physical and environmental assessments Safety and work-related musculoskeletal disorders (WMSDs) assessments	Heuristic methods Genetic algorithm Ant colony Simulated annealing (SA) and Hybrid approaches	Simulation Promodel Arena Quest IGrip Flexim Witness
Goal(s)	Standardization Efficiency improvement	Capable of addressing health and safety issues of workers Efficiency improvement	Optimal layout Efficiency improvement	Best layout Efficiency improvement
Drawback(s)	Process focused	Workstation and workplace environment focused	Time-consuming Not capable of addressing health and safety issues of workers	Faster and convenient Not capable of addressing health and safety issues of workers

Table 2 Developments/published literature on ergonomics and facility design

Title of paper and name of authors	Methodology	Result and conclusions
Simulation modeling and ergonomic assessment of complex multi-worker physical processes (Shewchuk et al. 2017)	Discussed new method in a discrete simulation of complex multi-worker physical processes, for ergonomic and/or performance analysis	Applied the proposed method in panelized residential construction and was able to provide a cost-effective result to reduce ergonomic risks, but the said method was found to be time-consuming
Productivity improvement of a manufacturing facility using systematic layout planning (Naqvi et al. 2016)	Simplified the application of systematic layout planning (SLP) in the development of a new layout	Proved the effectiveness of simplified SLP in increasing productivity of the layout
Ergonomics study for injection moulding section using RULA and REBA techniques (Sahebagowda et al. 2016)	Identified the work-related musculoskeletal disorders (WMSDs) using rapid upper limb assessment (RULA) and rapid entire body assessment (REBA) techniques	Used the results of RULA and REBA as inputs in redesigning workstations and reduce WMSDs
Ergonomic checkpoints as the base of stamping station work facilities improvement (Suhardi et al. 2016)	Developed ergonomic checkpoints as an assessment tool for improving work facilities	Improved the health and safety of the workers, and thus, increased their productivity
Integrating human factors and ergonomics in a participatory program for improvements of work systems: an effectiveness study (Fonseca et al. 2016)	Analyzed the effectiveness of the implementation of a constructive measure defined through a participatory ergonomic program taking into account an ergonomic evaluation and workers' perception about risk factors related to task performance	Ergonomic improvement and increased workers' satisfaction
Integrating occupational health and safety in facility layout planning (Kazerouni et al. 2015)	Integrated occupational health and safety (OHS) features in designing a facility layout	Safer facility design
Optimal facility layout problem solution using genetic algorithm (Misola and Navarro 2013)	Developed a methodology that minimizes total material handling cost using genetic algorithm	The proposed method was more efficient than the four other compared methods and minimized material handling cost
A comparative analysis of facility layout design and optimization techniques (Sharma et al. 2013)	Reviewed various facility layout design techniques	Found out that simulation-based optimization technique was the suitable and preferable way of optimizing facility layout
New methodological framework to improve productivity and ergonomics in assembly system design (Battini and Faccio 2011)	Developed a theoretical framework to assess a concurrent engineering approach to assembly systems design problems, in conjunction with an ergonomics optimization of the workplace	Improved the assembly system layout configuration concerning both technological and environmental parameters
A proposed study on facility planning and design in manufacturing process (Dwijayanti et al. 2010)	Assessed optimization techniques in facility layout	Found the limitations of heuristic methods, which were the following: time-consuming, cannot get the feel of the actual setting and actual dimension of the machine and equipment Found out that simulation technique was a powerful tool in creating and evaluating the proposed layout design before implementation
A genetic algorithm for layout problems in cellular manufacturing systems (Kulkarni and Shanker 2007)	Used genetic algorithm to validate the performance of the quadratic assignment problems (QAP)	Obtained optimum solution for the problems selected Problem 1 obtained the minimum cost with less computation Problem 2 obtained better results than the reported in the literature Problem 3, for small size problems, GA outperformed others but, for large size, it deviated from the global optimum

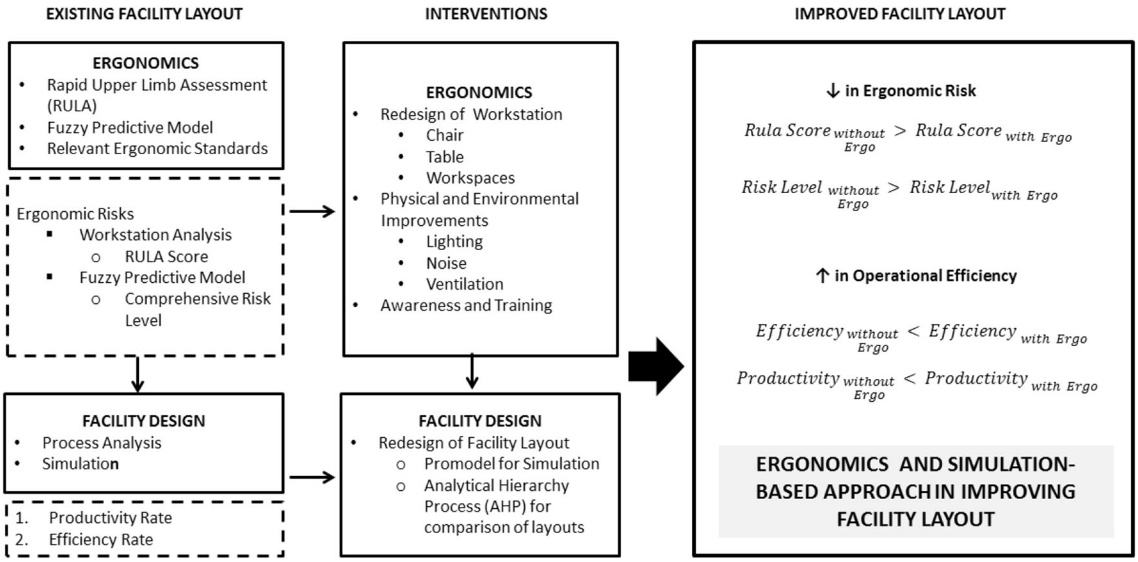

Fig. 1 Ergonomics and simulation-based approach in improving facility layout

Table 3 Existing facility layout summary

Existing layout	Result
Total units produced	51 units
Efficiency	20.39%
Productivity	1. 70 units/worker per day
Total distance traveled by workers (in one cycle)	64.87 m

Task-related risk

$$R_1 = a_1w_1 + a_2w_2 + a_3w_3 + a_4w_4 + a_5w_5 + a_6w_6 \quad (1)$$

Personal risk

$$R_2 = b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_5x_5 + b_6x_6 \quad (2)$$

Organizational risk

$$R_3 = c_1y_1 + c_2y_2 + c_3y_3 + c_4y_4 + c_5y_5 + c_6y_6 + c_7y_7 \quad (3)$$

Comprehensive risk level/index

$$Z = d_1R_1 + d_2R_2 + d_3R_3 \quad (4)$$

The computed overall comprehensive risk level for the existing workstations was 0.83 which was defined as a very

Table 4 Fuzzy predictive model risk factors and relative weights

Ranking	Task-related		Personal		Organizational	
	Risk factors	Relative weights	Risk factors	Relative weights	Risk factors	Relative weights
1	Awkward joint posture	0.299	Previous CTD	0.383	Equipment	0.346
2	Repetition	0.189	Hobbies and habits	0.223	Production rate/layout	0.249
3	Hand tool use	0.180	Diabetes	0.170	Ergonomics program	0.183
4	Force	0.125	Thyroid problems	0.097	Peer influence	0.065
5	Task duration	0.124	Age	0.039	Training	0.059
6	Vibration	0.083	Arthritis or degenerative joint disease (DJD)	0.088	CTD level	0.053
7					Awareness	0.045

Table 5 Mean levels of existence for each risk factor (existing workstations)

Ranking	Task-related		Personal		Organizational	
	Risk factor	Level	Risk factor	Level	Risk factor	Level
1	Awkward joint posture	1.00	Previous CTD	0.50	Equipment	1.00
2	Repetition	1.00	Hobbies and habits	0.50	Production rate/layout	1.00
3	Hand tool use	1.00	Diabetes	0.50	Ergonomics program	1.00
4	Force	0.50	Thyroid problems	0.20	Peer influence	0.20
5	Task duration	1.00	Age	1.00	Training	1.00
6	Vibration	1.00	Arthritis or degenerative joint disease (DJD)	1.00	CTD level	1.00
7					Awareness	
Numeric level for each category	0.937		0.5344		0.915	

Table 6 Recommended chair specifications

Ref	Chair specification	Anthropometric measurement	Anthropometry				Recommended chair specifications
			5% female	95% male	Female mean	Male mean	
A	Seat height	Popliteal height + shoe allowance	14.17	18.5	16.88	18.08	14–18.5
B	Seat depth	Buttock-popliteal length − clearance allowance	10.75	15.47	12.77	13.27	10.75–15.47
C	Seat width	Hip breadth, sitting + clothing allowance	12.2	16.14	14.83	14.52	15.00–16.54
D	Backrest Height	Sitting height × 0.8	25.16	28.97	25.17	26.72	25.00–28.97
E	Backrest width	Waist breadth (ANSI standard = 11.81 min)	13.39	19.4	15.84	17.59	16.00–19.4
F	Backrest lumbar	None	7.00	11.00	7.00–11.00	7.00–11.00	7.00–11.00 Autofit technology
G	Armrest height	Elbow rest height (standard = 7.06–10.24)	7.06	10.24	7.06–10.24	7.06–10.24	7.06–10.24
H	Armrest length	Standard = 10–12	10	12	10.00–12.00	10.00–12.00	10.00–12.00
I	Distance between armrests	Hip breadth, sitting + clothing allowance	12.2	16.14	14.83	14.52	15.00–16.54

high risk with individuals presently experiencing musculoskeletal irritation and/or medical correction. Haworth (2008) concluded that the ergonomically and adjustable designed chair with adequate personnel training decreased the occurrence of ergonomic risks, work-related disorders, and injuries and promoted an increase in productivity of around 17.7%. An adjustable chair tied with proper office ergonomics orientation reduced musculoskeletal disorders (MSDs) growth over a period (Amick et al. 2003). Table 5 summarizes the mean levels of existence of each risk factor in the existing workstations.

Interventions

Several standards have been considered to enhance the workstation chair, along with the analysis and consideration of the local anthropometry standard. Common standards employ the 5th‰ female and 95th‰ male, which could accommodate 90% of the population. The Business and Institutional Furniture Manufacturer's Association Guideline (BIFMA Guideline 2002) is a common standard used in designing an ergonomically designed chair. Design parameters include seat height, seat depth, seat width, backrest height, backrest width, backrest lumbar, armrest height, armrest length, the distance between armrest and provision for the footrest. The BIFMA (2002) standard includes shoe allowance, clearance allowance, and clothing allowance, which are 1, 5 and 0.5 in., respectively. This study measured the anthropometric sizes using the local anthropometry standard (Del Prado-Lu 2006), in terms of mean, female 5th‰, and male 95th‰. Table 6 and Fig. 2 detail the revised chair specifications using anthropometry standard.

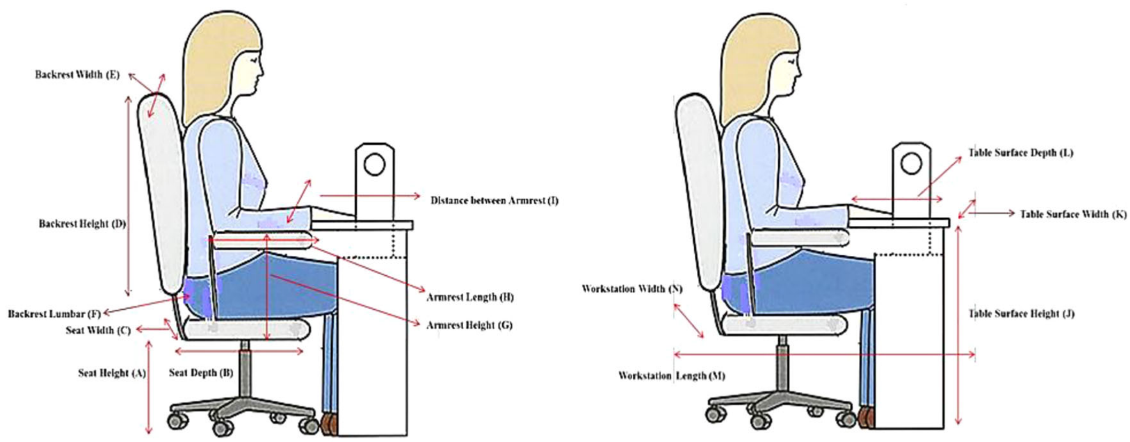

Fig. 2 Revised workstation chair and table

Table 7 Recommended workstation specifications

Ref	Workstation specifications	Anthropometric measurement	Recommended workstation specifications
J	Table surface height	Minimum table height = seat height + minimum 5th‰ (female) of seating elbow height + shoe allowance	27.56
	Table surface height	Maximum table height = seat height + functional elbow height + shoe allowance	29.92
K	Table width	Table width = 95th‰ of hip breadth (male) + 15% clothing allowance + 15% clearance allowance	16.97
L	Table depth	Acceptable distance reach	11.00–14.00
	Forward reach functional	5th‰ (female)	23.26
	Forward reach functional	95th‰ (male)	33.86
M	Forward reach functional	Actual table depth + seat depth	
N	Arm span	5th‰ (female)–95th‰ (male)	55.51–71.26

Table 8 Mean levels of existence for each risk factors (improved workstations)

Ranking	Task-related		Personal		Organizational	
	Risk factors	Levels	Risk factors	Levels	Risk factors	Levels
1	Awkward joint posture	0.00	Previous CTD	0.00	Equipment	0.00
2	Repetition	0.50	Hobbies and habits	0.00	Production rate/layout	0.00
3	Hand tool use	0.20	Diabetes	0.50	Ergonomics program	0.00
4	Force	0.20	Thyroid problems	0.20	Peer influence	0.00
5	Task duration	0.50	Age	1.00	Training	0.00
6	Vibration	1.00	Arthritis or degenerative joint disease (DJD)	0.00	CTD Level	0.00
7					Awareness	0.00
Numeric level for each category	0.2341		0.1434		0.00	

Table 9 Criteria used in AHP

Criteria	Percentage (%)
Efficiency	35
% in-operation time	10
In-system time	15
Material movement (distance traveled)	10
Productivity	55
% unit produced	20
Unit per worker per day	20
Total productive time	15
Resource utilization	10
Total	100

The sewing table along with the workspace was also calculated to suit the sizes and needs of the workers. Isamail (2013) detailed the calculation of table surface width and depth that would be appropriate to the workstation chair. The revised workstation specifications is summarized in Table 7.

The RULA of the improved workstation design including the chair, table, and workspaces rendered better score than the current design. The score of most of the operations in various workstations resulted in Class I (acceptable posture) category. This means that the improved workstation eliminated ergonomic risks among workers. Interventions improved the levels of existence of the risk factors and are summarized in Table 8.

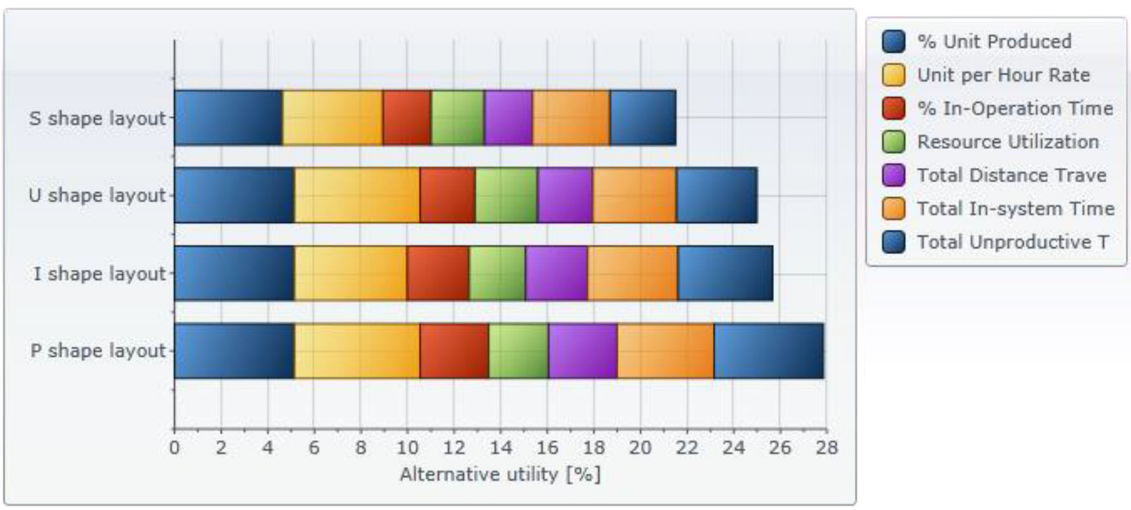

Fig. 3 AHP result of simulated facility layouts (redesigned)

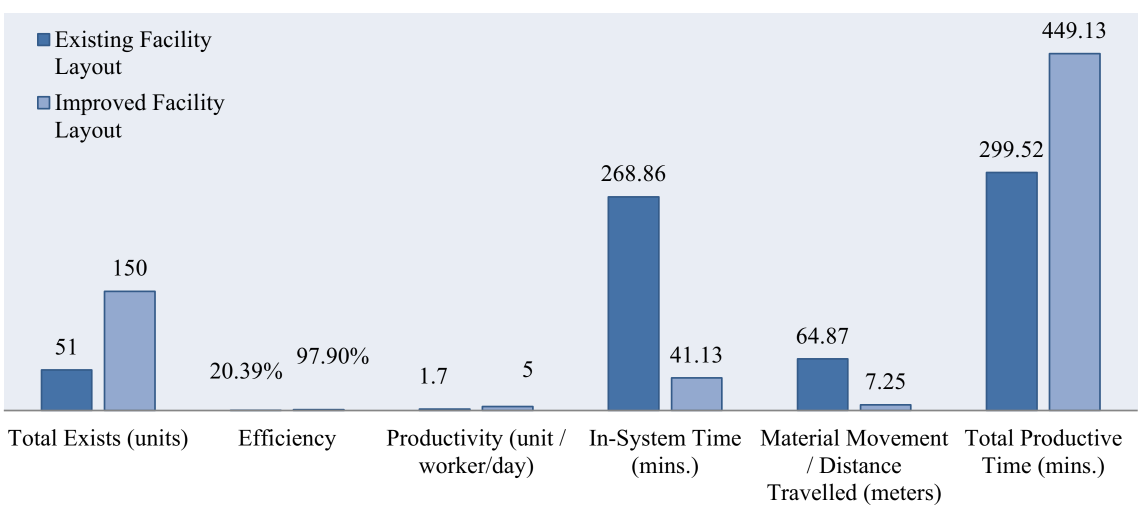

Fig. 4 Comparison of existing and redesigned facility layout

Table 10 Summary of improvement

Criteria	Existing facility layout	Improved facility layout
RULA score	Class IV (investigate and implement change)	Class I (acceptable posture)
Comprehensive risk level	0.83 very high risk	0.19 minimal risk
Efficiency	20.39%	97.90%
Productivity (unit produced/worker/day)	1.70	5.00

The computed overall comprehensive risk level for the improved workstations was 0.19 which was defined as minimal risk with individuals not experiencing any conditions that indicated musculoskeletal irritation. Both RULA score and comprehensive risk index decreased indicating more ergonomically designed workstation.

Other interventions were done such as the provision of pin light near workstation table, earplugs to protect workers from the harmful noise level, and additional exhaust fans to further improve the ventilation (OSHA 2001). Awareness and training programs for employees were also provided.

Since the inefficiencies caused by the worker due to their health and safety issues were addressed, redesign of facility layout through Promodel simulation followed. Using Analytical Hierarchy Process (AHP), the proposed layouts were evaluated using the following criteria. Table 9 details the percentages or relative weights of the criteria used in evaluating the proposed facility layouts. Relative weights were calculated based on the average response of company's stakeholders.

Figure 3 shows the AHP result of the simulated facility layouts. From the set criteria, it was found that the best among all simulated layouts was P-shaped. Figure 4 presented the graphs generated from AHP software that summarizes the comparison of simulated facility layouts.

Upon comparison, it showed that the redesigned layout improved the total units produced from 51 units to 150 units, increased the efficiency from 20.39 to 97.90% and decreased the total cycle time from 268.86 to 41.14 min. Results indicated a 78% increase in efficiency and 194% increase in productivity compared to existing design and thus proved that the model is effective in improving overall operational efficiency and productivity. Table 10 summarizes the improvements in facility layout based on the RULA score, comprehensive risk level, efficiency and productivity.

Conclusion

Incorporating ergonomics in facility design simulation addressed the needs of the workers thereby eliminating, if not reducing associated risks to their health and safety and further increased efficiency and productivity. Results indicated that the improved layout generated a decrease in comprehensive risk level and rapid upper limb assessment (RULA) score; an increase of 78% in efficiency and 194% increase in productivity compared to existing design and thus proved that the approach is effective in attaining overall facility design improvement.

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