

IMPLEMENTATION OF ERGONOMICS AND LEAN MANUFACTURING PRINCIPLES TO IMPROVE WORK ENVIRONMENT AND PERFORMANCE OF SOCCER BALL PRODUCTION LINE

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Abstract:

Value addition and performance improvement are important to deal with increasing local and global market competitiveness. Interventions and automation based on lean and ergonomics principles have strong influence on performance improvement of the production systems. This study focuses on implementation of lean manufacturing and ergonomics principles to improve work environment and performance of the soccer manufacturing production line. Work visualization and value stream mapping (VSM) techniques were employed to identify the opportunities for improvements. Time of value-added and non-value-added activities is recorded using time study method. Working postures and associated risk factors are evaluated using Rapid Entire Body Assessment (REBA) method. Lean manufacturing principles are employed to minimize wastes and non-value-added activities. Similarly, improvements in work environment are made through ergonomics interventions. Various models comprising different levels of lean and ergonomics interventions were evaluated through simulation before actual implementation. The results of the finalized model in terms of decrease in cycle time (8.64 to 7.018 seconds), increase in daily production (20505 to 24176 soccer balls), and improved work environment are evident of performance improvements. The integration of lean and ergonomics principles leads to improve the productivity and working environment in soccer ball manufacturing industry.

Keywords: lean; ergonomics; value stream mapping; REBA; performance improvement.

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1. Introduction

Industries are trying to adapt Lean thinking to compete by eliminating non-value-added operational activities from the value chain process. The primary goal of lean manufacturing is to minimize waste and non-value added activities (Wilson, 2010). The purpose of lean thinking is to improve productivity through efficient utilization of resources (money, time, labour, inventory, space, and equipment) and reducing different types of waste (Sakthi Nagaraj, Jeyapaul, Vimal, & Mathiyazhagan, 2019). Implementation of Industry 4.0 is positively related to lean production (LP) practices (Tortorella & Fettermann, 2018). Green lean implementation has a special importance for manufacturing sector to make it more sustainable (Cherrafi, Elfezazi, Garza-Reyes, Benhida, & Mokhlis, 2017)

On the other hand, the implementation of *human factors and ergonomics principles* are of prime importance to provide a safe, worker-friendly, and well-disciplined environment. Implementation of ergonomics principles helps reduce the fatigue experienced by the human body in different tasks (Kulkarni & Devalkar, 2019). *Ergonomics* interventions have strong impacts on expected outcomes and behaviour of workers, leading

to continual improvement and sustainability. It provides the basis for designing, analysing and establishing a high-quality working environment; however, it is difficult to communicate its potential value (Karltun, Karltun et al., 2017). The manufacturing industries can improve production, quality and working environment through industrial automation (Sakthi Nagaraj et al., 2019).

The implementation of lean principles to reduce waste may increase pressure on the workers. Also, the implementation of ergonomics interventions to make the environment worker-friendly may not facilitate lean interventions. Hence, simultaneous implementation of both ergonomics and lean manufacturing principles is important for eliminating waste and providing a safe and worker-friendly environment.

Based on the above-mentioned facts, this study discusses the simultaneous implementation of lean and ergonomics principles in a soccer manufacturing line. The soccer production line is selected because of low productivity, high waste and tough working conditions for workers. Provision of a good working environment with reduced risk factors and musculoskeletal disorders is necessary to retain skilled workers. Retention of skilled workers is

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not only necessary to improve quality and productivity but also for the simultaneous implementation of lean and ergonomic principles.

2. Related works

Lean manufacturing is an operational philosophy implemented to increase productivity by reducing different types of waste (Shrimali & Soni, 2017). The concept of lean was initially adopted by the Japanese Automotive Industry, which was named the Toyota Production System (TPS). The main objective of TPS was to maximize productivity and minimize cost by eliminating seven types of wastes and non-value-added activities (Leong & Teh, 2012). The implementation of Lean has been expanded to various industries, including service and manufacturing organizations (Antony, Kumar, & Labib, 2008; Ikuma, Nahmens, & James, 2011; Kumar, 2007; Taner, 2012; Taner, Sezen, & Atwat, 2012). Currently, it is impossible for organizations to compete in the global market by ignoring lean manufacturing tools and techniques (Alaskari, Ahmad, Dhafir, & Pinedo-Cuenca, 2013). The primary goal of lean manufacturing is to reduce costs and increasing productivity (Botti, Mora, & Regattieri, 2017). This aim can be achieved by implementing just-in-time (JIT), waste reduction strategies and process standardization (Oliveira, Alves, Carneiro, & Ferreira, 2018).

The lean manufacturing technique aims at a smooth flow of production by eliminating wastes and increasing value of the activities (Taner, 2013). Principles of lean thinking are customer value, value-added activities, generation of flow, and finally continuous improvement. Toyota provided a unique example of employ empowerment through lean and continuous improvement, where operators design their procedures and participate in continuous improvement, leading to employ-employ relationships (Weigel, 2000). Lately, lean has been implemented in the sports industry to evaluate various alternatives for eliminating wastes and improving efficiencies (Supriyanto & Saputra, 2019). Brazilian manufacturing companies witnessed a positive relationship between lean and Industry 4.0 (Tortorella & Fettermann, 2018). Similarly, implementation of lean principles in warehouse of winter sports equipment industry leads to improvements in terms of productivity and efficiency (Valchkov & Valchkova, 2018).

Human factors engineering and ergonomics provide safe working environment and enhances performance of the system (Kartun et al., 2017). Multiple disciplines of Human factors engineering and ergonomics started developing during world war II (Kartun et al., 2017). It is evident from extant literature that there is a potential linkage between lean, ergonomics and occupational health and safety (Brito et al., 2018). Ergonomics has the potential for optimum utilization of technology by improving system development (Helali & Shahnava, 1996). The REBA is an ergonomics tool to evaluate working postures and associated risk factors. In the REBA worksheet, the evaluator gives the score to the body parts including: wrists, neck, forearms, trunk, shoulder, knees, back, and legs. This score and work related musculoskeletal disorder (MSD) risk factor is compared with score table according to find the level of MSD risk factor (Plus, 2018).

(Kulkarni & Devalkar, 2019) used Rapid upper limb assessment (RULA) and REBA for posture analysis and improvements in working environment of a construction industry. Ergo-VSM approach was used to implement lean and ergonomic principles in a textile industry and resulted in improvement of operational performance and workers' life quality (Sakthi Nagaraj et al., 2019). Ergonomics and Lean principles were integrated to improve internal transportation in a manufacturing environment by redesigning transportation carts (Aqlan, Lam, Ramakrishnan, & Boldrin, 2014). Integration of Lean and socio technical and ergonomics (SE) factors have also been discussed to overcome the implementation gaps in lean processes (Tortorella, Vergara, & Ferreira, 2017).

Lean and ergonomics based automation in manual production cells improve performance and quality of the production operations (Stadnicka, Litwin, & Antonelli, 2019). In lean production working cells, operations are divided into value-added and non-value categories (Shigematsu, Yamazaki, Kato, Kojima, & Takata, 2018). Non-value-added activities can be eliminated or minimized by introducing Lean based automation in the cell. Implementation of automation increases efficiency of the manufacturing process and quality of the product (Tortorella & Fettermann, 2018).

Integration of lean and ergonomics and automation based on the principles of lean and ergonomics can be a competitive solution (Bilberg & Hadar, 2012). For instance, (Bortolotti & Romano, 2012) integrated lean and automation in a service industry and concluded that streamlining (implementation of lean tools and techniques to highlight the wastes) is necessary before automation of the value-added activities.

From above discussion, integration of lean and ergonomics has been given less attention in extant body of literature (Aqlan et al., 2014). The scenario is similar about integrated implementation of lean and automation (Bilberg & Hadar, 2012; Bortolotti & Romano, 2012). To the best of authors' knowledge, implementation of integrated lean and ergonomics along with automation based on the principles of lean and ergonomics has not been discussed in extant body of literature. This study fulfils this gap by integrating lean, ergonomics and automation based on lean and ergonomics principles implementation in a soccer manufacturing production line.

3. Methodology

The methodology used for this study is divided into four parts: (1) Identification of the opportunities for improvement through *VSM and Work visualization techniques*, (2) recording of the time for value added and non-value-added activities using *Time study approach*, (3) workers' posture analysis through REBA method, and (4) evaluation of the simulated alternatives and implementation of the proposed model.

The above-mentioned methodology is implemented in a well-known soccer manufacturing industry with an approximate production of 750 000 balls per month.

The process flow diagram of the soccer manufacturing is presented in Figure 1. The area selected for proposed interventions are also mentioned in Figure 1.

In the last section of bladder winding hall, the workers measure the circumference of threaded ball and then manually throw the ball into the storeroom. The rubber bladders outsourced from foreign and local vendors, are inflated, and then weighed to record volume of air. The standard weight of the bladder should be between 200-210 grams. Inflated bladders are then sent to winding machines for thread-winding and are weighed again before latex attachment. The weight should be in a range of 255-270 grams. Threaded winded bladders are then forwarded to the heat conveyor where each bladder remains for 3-4 minutes to attach Tikra on latex. Some more air is blown to fully inflate the bladder. As a quality check, the circumference of the bladder is measured before placing it in the trolley. The worker pushes the trolley towards the storeroom and throws the balls manually in the storeroom for 24 hours conditioning. Finally, the bladders are inspected to check if air is leaked or not. If there is no leakage, the bladders are deflated and moved to upper stations for further processing. Figure 2 presents layout of the bladder winding hall.

3.1. Data collection

Two types of data were collected: (a) the data collected through time-study approach to record time of value-added and non-value-added activities, and (b) measurement of the positions of neck, trunk, leg, arm, and wrist while performing activities for REBA analysis. The activities included in part (a) of the data collection process ranges from “inflation of bladder balls” to “throwing the bladder balls in the store room”.

4. Results and Discussion

4.1. Work Visualization and VSM

After understanding the working system of the bladder winding and interacting with supervisors and management of the production department, work visualization technique and VSM are used to identify areas of problems. Figure 3 presents VSM of the soccer ball production line.

It is observed that after checking circumference of the ball, the workers manually push the trolley and throw balls into the storeroom i.e., an additional and unnecessary

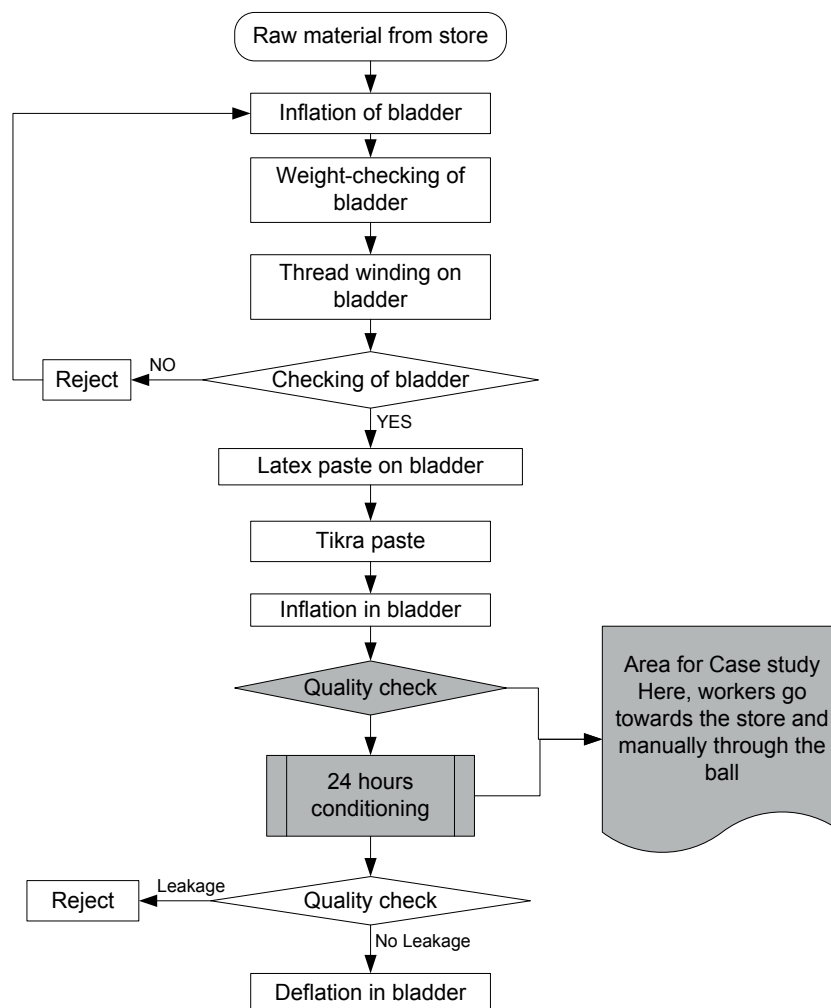


Figure 1: Process flow diagram.

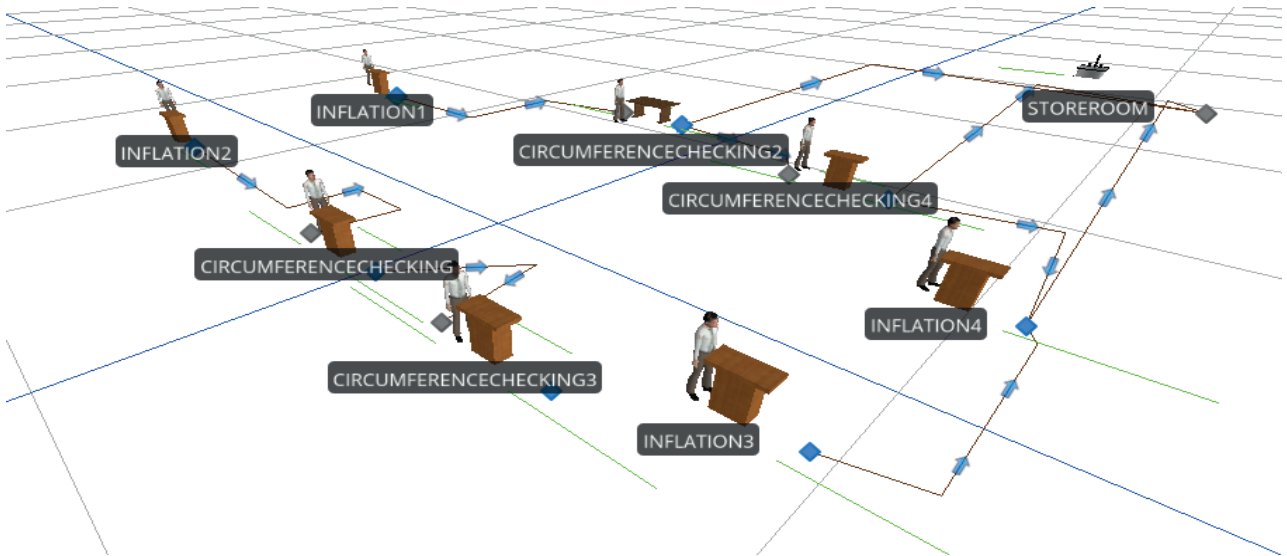


Figure 2: Layout of Bladder Winding Hall.

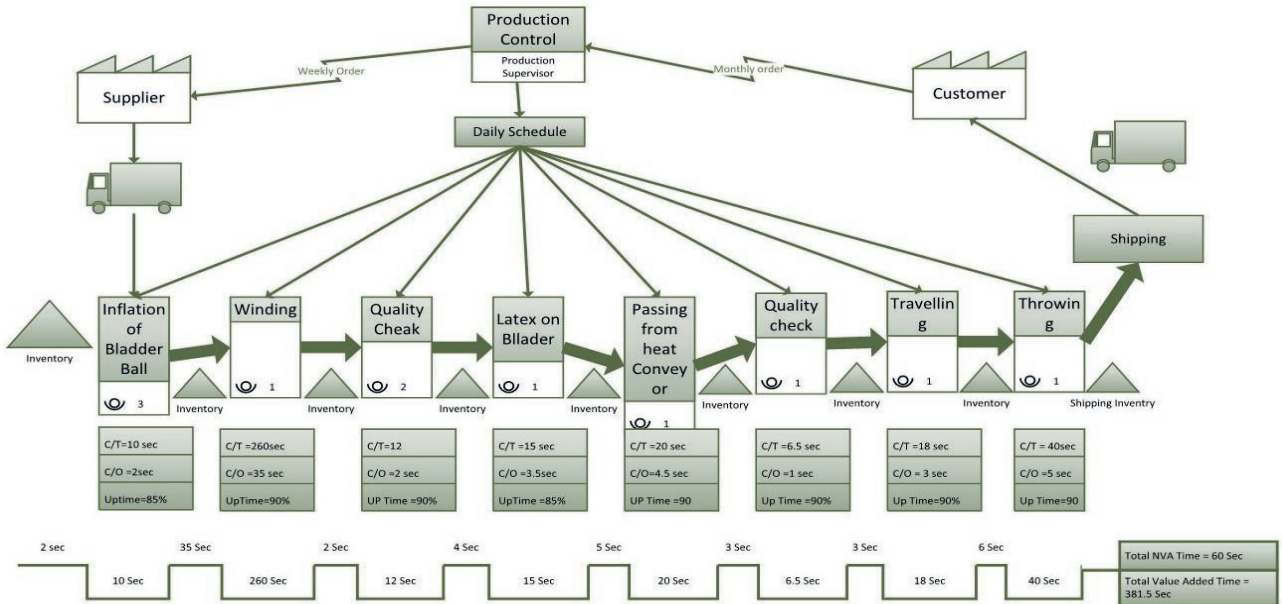


Figure 3: VSM of soccer ball industry.

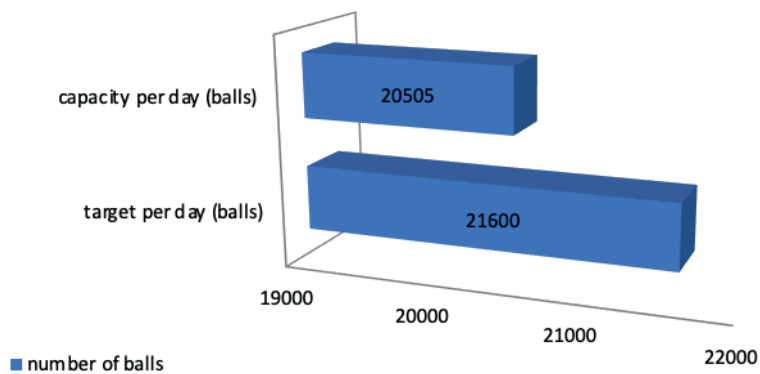


Figure 4: Capacity vs. Target.

process, leading to an increase of more than 0.14 minutes to the process cycle time. Increased cycle time becomes the reason of gap between actual production and target as shown in Figure 4. Furthermore, these additional processes of picking and throwing cause unnatural body movements and postures.

4.2. Time Study

The time study method is employed to measure time taken for each process including value-added and non-value-added activities. The time taken by different workers to perform same task is also noted on numerous occasions. Measurement of circumference with m measuring tape is taken as value added activity while travelling and throwing of balls are declared as non-value-added activities. The data of circumference (66 cm) measurement is recorded in Table 1. The standard time for this activity at 10% allowance is 6.71 seconds, as calculated by the following formula.

$$\text{Standard time} = \text{Normal time} (1 + \text{Allowances}) = 6.1 (1 + 0.10) = 6.71 \text{ seconds}$$

Table 2 shows time taken for travelling (non-value-added activity). Table 3 presents time taken for throwing (non-value-added times).

Table 1: Total time for measuring circumference.

No. of Stations	Ave. Time for Measuring (Sec.)	Total time for process (VA + NVA) (Min.)	Total Time per day (Min.)	Existing Output/Day	Target / Day
Worker No. 1	6.91	8.4	480	3422.81	3600
Worker No. 2	7.10	9.05	480	3182.22	3600
Worker No. 3	7.06	8.56	480	3363.62	3600
Worker No. 4	7.09	8.55	480	3367.74	3600
Worker No. 5	6.92	8.55	480	3367.78	3600
Worker No. 6	7.04	8.73	480	3298.85	3600
Total				20 003.05	21 600

Table 2: non-value-added time (travelling).

No. of Stations	Average Time (Sec)	Total time per day (min)	Balls that can be made in this time
Worker No. 1	0.49	28.20	245.06
Worker No. 2	0.50	26.92	227.48
Worker No. 3	0.41	23.07	196.09
Worker No. 4	0.45	25.68	217.41
Worker No. 5	0.49	27.87	241.78
Worker No. 6	0.52	28.92	246.55
Total		160.6	1374.39

Table 3: non-value-added time (throwing).

No. of Stations	Average Time (Sec)	Total time per day (min)	Balls that can be made in this time
Worker No. 1	1.013	57.83	502.52
Worker No. 2	1.44	76.42	645.71
Worker No. 3	1.09	61.15	519.71
Worker No. 4	1.00	56.44	477.82
Worker No. 5	1.13	63.88	554.20
Worker No. 6	1.16	64.00	545.49
Total		379.76	3245.47

4.3. Rapid Entire Body Assessment (REBA)

Rapid Entire Body Assessment (REBA) tool is used to evaluate working postures and associated risk factors. In REBA, scores are given to the body parts including: wrists, neck, forearms, trunk, shoulder, knees, back and legs (Plus, 2018) and based on postures of the workers, scores are recorded in REBA sheet (Table 4). The activity of throwing balls is performed for (8 hours × 60 minutes/hour) 480 minutes (total time as given in Table 1) in a day and REBA score is calculated for all the workers working at that station. As each worker has to throw the ball in same way, the score for all of them is same.

The REBA score is 10 shows that the risk is high which may cause several muscular skeleton disorders (MSD) (Hignett & McAtamney, 2000; Kulkarni & Devalkar, 2019). Implementation of various integrated lean and ergonomics-based solutions is evaluated through simulation.

4.4. Eliminating Non-Value-Added Activities

Implementation of innovative tools and techniques to reduce wastes and focus only on value adding operations is need of the hour (Alaskari et al., 2013). The cycle time can be reduced by eliminating non-value-added activities of travelling and throwing which take 0.48 and 1.13 seconds, respectively. It results in 540 minutes of total non-value-added time out of 2880 for all six workers collectively, considering 480 minutes of total time per day for each worker. If these 540 minutes are utilized for value-added activities, 4619 balls can be made in this time that will be an increment in production. Another option is, to meet the same production quantity with 5 workers instead of 6.

4.5. Simulation Models

Arena Software version 10 is used to simulate the existing model of bladder winding as shown in Figure 5. There are six production lines in presented system. Simulation model is verified by solving it for existing system that shows accuracy of the developed model. The warmup period for the simulation model is 1.5 minutes with error of almost 200 balls. This error may be due to diversity in terms of skills of the workers and tiredness with passage of time. However, simulation assumes constant output during given working time.

Table 4: Ergonomic analysis of the postures.

A: Neck, Trunk & Leg Analysis	Respective Posture
1. Locate Neck Position Score = 2+1=3	
2. Locate Trunk Position Score = 3+1 = 4	
3. Legs Score = +2	
4. Locate Neck Position Score = 2+1=3	
5. Locate Trunk Position Score = 3+1 = 4	
6. Legs Score = +2	
7. Look up posture score in Table A: Posture Score = 07	
8. Add Load Score Add =+0 Total Score = 7 B: Arm and Wrist Analysis	
9. Locate Upper Arm Position: Score = 3	
10. Locate Lower Arm Position: Score = +2	
11. Locate Wrist Position: Score = 1 Table B: Table Score = 04	
12. Add Coupling Score Add =+0: Total Score = 05 Table C Score: Score = 9	
13. Activity Score 9+1 = 1 REBA Score = 10	
10= High Risk, Investigate and Implement Change (Hignett & McAtamney, 2000; Kulkarni & Devalkar, 2019)	

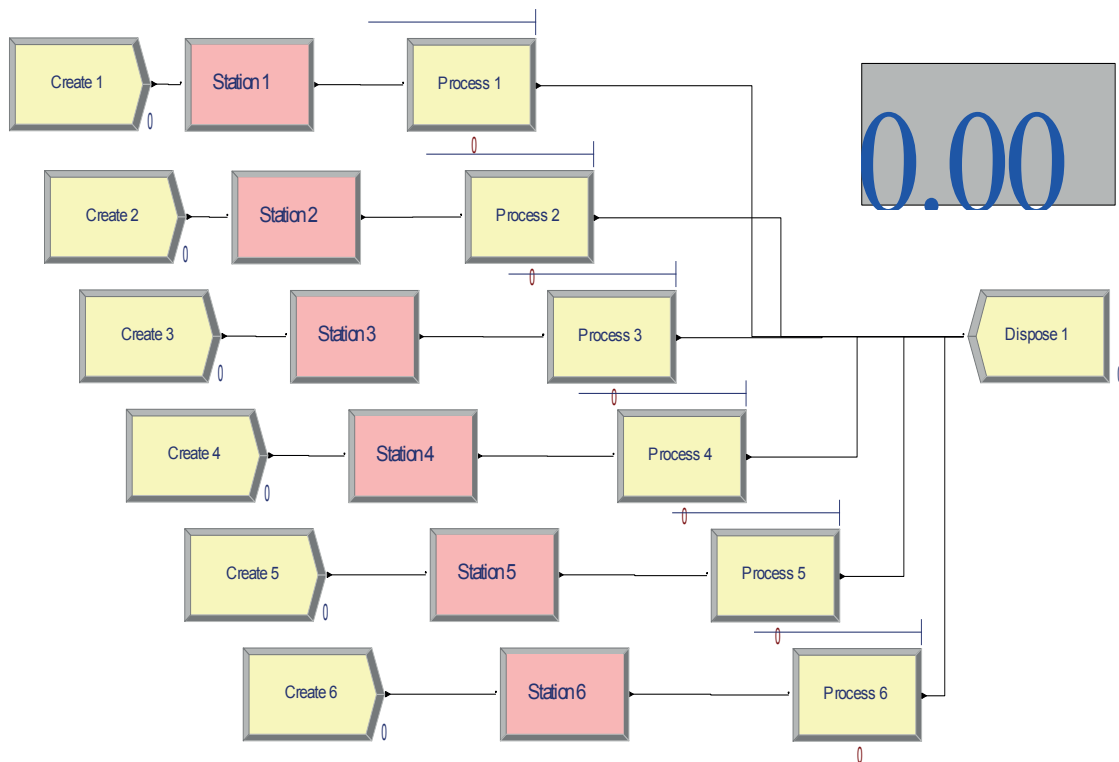


Figure 5: Simulation model for existing system.

After simulating the existing model, a proposed model is built up to evaluate the results for different scenarios. A 12 inches wider conveyor, installed at a height of 4 feet (from ground) is suggested to move at a speed of 65 feet/min in proposed model to save the time of workers in travelling and throwing the balls to storeroom (non-value-added times), as shown in Figure 6. Warm up period for new production line is also taken as 1.5 minutes. The model was run for 480 minutes and produced 24 176 balls as output. This output will be future production after bringing improvements in current working situations that are discussed as proposed model. Results show that the daily output of proposed model is higher than existing model.

Figure 7 presents the simulation model with 5 workers. The output is 20 483 balls per day. Results show that output of proposed model with 5 workers (20 483 balls) is nearly equal to the output of existing system with 6 workers (20 505 balls).

4.6. Automation

Laser light emitter and LDR sensor are used on the conveyor. The purpose of this automation is to save electric energy. It means as far as balls are present on the conveyor the motor remains ON and when there is no ball on the conveyor, the motor will turn OFF. Laser light is fixed at one end of the conveyor and LDR sensor on the

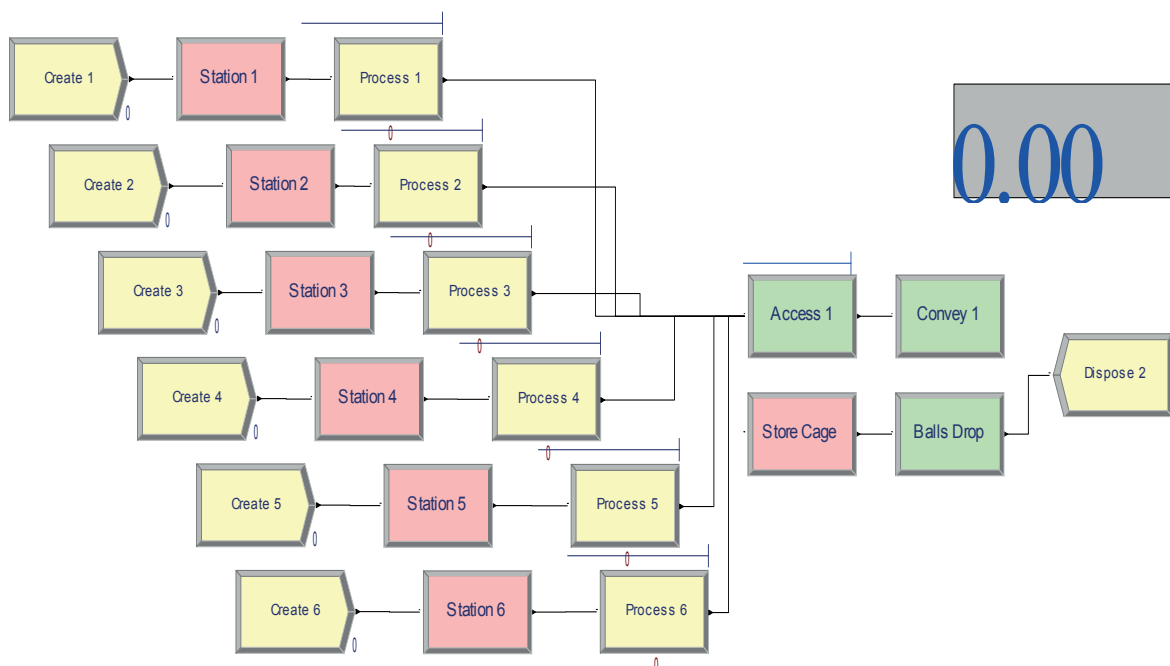


Figure 6: Proposed simulation model with 6 workers.

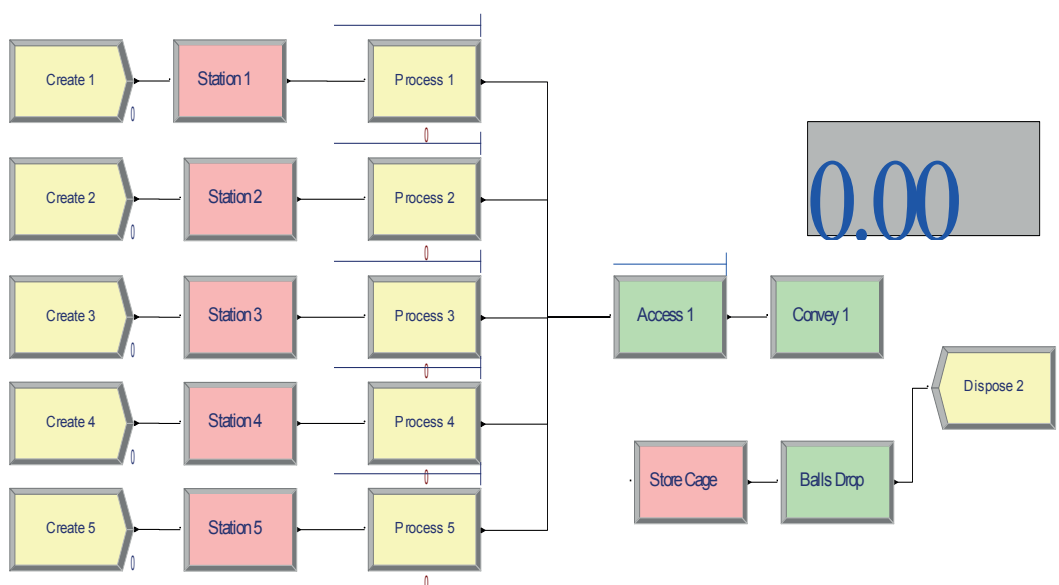


Figure 7: Proposed simulation model with 5 workers.

other. The laser beam is dropped on the sensor which is at the other end. A continuous beam of laser means that there is no ball and discontinuous beam shows that one or more ball/s is/are present on the conveyor. The model is made on breadboard and a sample model is shown in Figure 8.



Figure 8: Automation Model.

Automation on conveyor is programmed in such a way that it saves electric energy. The parts used in automation model are: (1) Arduino UNO, (2) Laser light emitter, (3) LDR sensor and (4) DC Motor. Figure 9 presents the program on Arduino software.

```
#define DETECT 2 // pin 2 for sensor
#define ACTION 8 // pin 8 for action to do something
void setup () {
  Serial.begin(9600);
  pinMode (DETECT, INPUT);//define detect input pin
  pinMode (ACTION, OUTPUT);//define ACTION output pin}
void loop () {
  int detected = digitalRead (DETECT);// read Laser sensor
  if (detected == HIGH)
  {digitalWrite (ACTION, HIGH);// set the Motor ON
  Serial.println("Balls Detected");
  delay (200);}
  else
  {digitalWrite (ACTION, LOW); // Set the Motor OFF
  Serial.println("No Ball!");}
  delay (200);}
```

Figure 9: Arduino program.

4.7. Improvements

Implementing the proposed model provides better results and improvements in cycle time, daily production and work environment. Cycle time in existing system was a

total of circumference measuring time, travelling time and Throwing Time. However, in proposed system, travelling and throwing times are eliminated, that reduced the cycle time of the process from 8.64 seconds to 7.018 seconds (Figure 10).

In proposed system, there is no need to throw the balls so their working posture that was harmful has been removed. This method will help them preventing any muscle injury. Hence the risk that was suggested by REBA method in Table 4 has been eliminated.

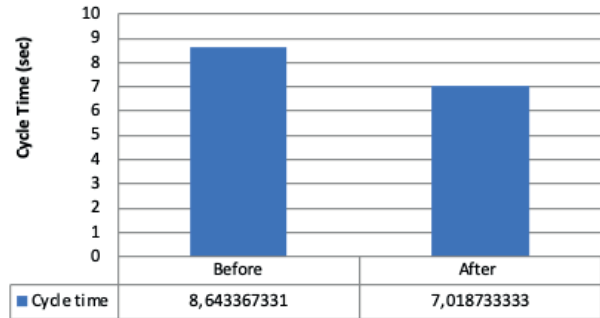


Figure 10: Improvement in Cycle Time.

The introduction of Standard Operating Procedures (SOPs) is instrumental in facilitating the implementation of proper working postures, ergonomics principles, and safe handling techniques. By adhering to these procedures, workers can minimize the risk of muscle injuries, aligning with the proposed system’s aim of enhancing workers’ well-being. SOPs also help optimize the allocation of resources (including labour and equipment) toward more productive and value-generating aspects of the production process, by eliminating unnecessary tasks and activities that may have posed risks.

Figure 11 shows that the production of the footballs has increased from 20 505 to 24 176 in proposed system due to installation of automated conveyor.

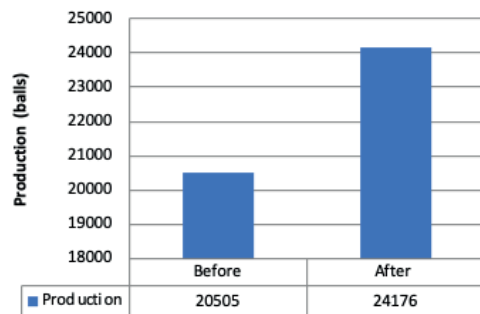


Figure 11: Improvement in Daily Production.

4.8. Payback Analysis

For implementing new method, economic analysis is important to know about payback period. Two methods are used to find out payback period. The first method is to check the number of products that has been increased at

the final station and multiply it to the price of the product. In this way, we can get the money back. In the second method, the worker can be removed from that station. In this way, we can get our money back. This study uses the second method for cost analysis and results are presented in Table 5. Results show that the estimated cost of conveyor is 0.1 million and it can be recovered in 5 months.

Table 5: Automation and Installation Cost Analysis (PKR).

Estimated Cost of Conveyor	Rs: 100 000
Direct Labour Reduce	1
Pay per Labour	Rs: 20 000
Monthly Savings	Rs: 20 000
Pay Back Period	5 months

5. Conclusions

This study discusses the implementation of Lean and ergonomics principles in manufacturing industries. Automation based on lean and ergonomics interventions has also been studied. Integration of lean and ergonomics principles are applied on a case of soccer ball manufacturing industry. Arena simulation is used to evaluate different alternatives and a new model is proposed. The results show that this integration leads to improve the productivity and working environment for workers. The improvement is found in different terms including a decrease in cycle time, an increase in production, and ergonomically safe work environment for worker. Five months payback period was found to install the automated conveyor in proposed model. And results showed that this proposed model will give economic and ergonomics benefits.

As this study is focused on a particular area in soccer manufacturing line, further work can be done by identifying and improving other areas of the production line.

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