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TECHNOLOGYPRODUCTIVITY IMPROVEMENT USING SIMULATION MODELING AND LEAN
TOOLS: A CASE STUDYHerbert Mapfaira^{*1}, Michael Mutingi^{2,3}, V.P Kommula¹, David Baiphisi¹, Magadi Kemsley¹^{*1}Department of Mechanical Engineering, University of Botswana, Botswana²School of Engineering, Namibia University of Science and Technology, Namibia³Faculty of Engineering and the Built Environment, University of Johannesburg, South Africa

ABSTRACT

The purpose of this study was to investigate ways to improve productivity of a local security garage door manufacturing company. The company is based in Gaborone, Botswana and faces serious productivity challenges, including long throughput time, high inventory, and low worker utilisation. The result of these challenges is poor product quality and high operating costs resulting in uncompetitive products. The company would like to transform their manufacturing system to a lean manufacturing system. This paper describes the company's current manufacturing system and proposes improvements that reduce wastes identified in the current system. Discrete event simulation is used to compare the performance of the current manufacturing system, and the proposed lean manufacturing system. The study showed that the proposed manufacturing system significantly improves material flow, assembly line balance efficiency, worker utilisation, and reduces manufacturing lead time.

KEYWORDS: Lean manufacturing, productivity improvement, layout design, worker utilisation, manufacturing lead time

INTRODUCTION

Manufacturing Small, Micro and Medium Enterprises (SMMEs) are an important economic engine in Botswana [1]. SMMEs are seen to be a potential source of employment for unskilled and semi-skilled employees thus their development is important in combating unemployment. From the Botswana Institute of Development Policy Analysis estimates, SMMEs account for about 50% of private employment in Botswana [2]. In spite of the recognized importance of manufacturing SMMEs in Botswana, their performance is limited and hindered from reaching their full potential by numerous well researched factors, which include:

- **Globalization:** Although globalization opens up opportunities for growth and expansion, it exposes manufacturing SMMEs to fierce and intense competition from all over the world, especially South Africa and China. In Botswana, larger manufacturing firms are often foreign owned and outcompete smaller manufacturing firms [3].
- **Poor product quality:** The poor quality of locally manufactured products is also cited as a factor that inhibits manufacturing SMMEs penetration of the market [4].
- **Inadequate financing:** Manufacturing SMMEs are faced with financial resources, financiers are often sceptical to provide funding due to the high failure rate of such enterprises [3].
- **Lack of technical expertise and appropriate technologies:** Technology and technical know-how play a major role in efficiency and effectiveness of production. Because of the relative rudimentary manufacturing sector in Botswana, manufacturing technologies and technical skills are often lacking, thus leading to reduced productivity [5].

Lean manufacturing has been identified as a manufacturing strategy with the potential to turn-around the fortunes of organisations adopting the strategy. As a result, many firms have taken lean manufacturing as a productivity

improvement approach and have adopted different lean manufacturing tools and techniques in order to improve their competitiveness [6]; [7].

Lean manufacturing is a productivity improvement methodology or approach that considers the expenditure of resources on non-value added activities to be a waste. Value-added activities are activities that are necessary to create value for the end customer. Value is defined as any activity carried out during the course of producing a product/service that the customer would be willing to pay for. Lean manufacturing is therefore focused on the elimination of all activities that do not add value to the end product [8]; [9].

By implementing lean manufacturing, organisations become more competitive; they deliver high quality goods at low cost with short lead times. The benefits of lean manufacturing can be grouped into two categories, the operational (enhancement of productivity, improvement in quality, reduction in work-in-process inventory etc.) and administrative (streamlining of customer service function, reduction of paper work, reduction of labour turnover, etc.) [10]; [11]; [12]. Wastes targeted by lean manufacturing are: Overproduction, Inventory, Over-processing, Motion, Waiting, Defects, and Transportation [13].

Productivity is the effectiveness and efficiency with which a firm converts inputs into outputs: that is, a measure of the effectiveness and efficiency of an organisation in generating output with the resources available. In improving the productivity of a company, the business will gain many benefits, which ultimately results in increased profitability of the organisation.

This research aims to design a lean manufacturing system for a local company, XYZ (Pty) Ltd, in order to improve their productivity (Name withheld for confidentiality). XYZ (Pty) Ltd is a small company based in Gaborone, Botswana, which manufactures security garage doors. The company is experiencing serious productivity problems which are impacting on its competitiveness. Productivity problems experienced by the company include long manufacturing lead time, poor worker utilization and disorganized workplace that makes workers lose time while searching for equipment/tools or material to use in manufacturing the doors. The culture is not only time consuming, but it inhibit productivity and quality achievement which may also make the company to lose customers.

As a result of poor productivity, the company's production cost is so high that its viability is threatened. The company now needs to work on improving their manufacturing productivity so as to reduce the cost of production which would allow them to have an edge over their competitors based on price. The involvement of the researchers in this study offers the company access to productivity improvement expertise, which is lacking in Botswana SMMEs.

In response to this problem, the study investigates several options for making the company more productive through the use of lean manufacturing tools and simulation modelling. Simulation modelling is used since it allows the company to experiment with various options and assess their viability before making any changes to their processes. The objective is to investigate how the company can reduce manufacturing lead time, increase worker productivity and how they can streamline production flow in order to reduce the amount of inventory held on the premises, and improve workplace organisation.

A simulation model is a computer model that mimics the operation of a real or proposed system, such as an airport passenger check-in and baggage handling, a manufacturing assembly line, staff assignment of a hospital, or queuing in a banking hall. Increasingly, simulation is being used as a complementary tool for the analysis and design of lean manufacturing systems [14], [15]. Simulation can thus be used to support management decisions [16]. Arena was used to write the simulation models used in this study. Arena has been widely used in simulating business processes and various kinds of discrete event operations [17].

LITERATURE REVIEW

Lean manufacturing has been successfully implemented across the world as a productivity improvement strategy with significant results, especially in developed economies, as well as the emerging economies. Gunasekaran and Cecille [18] defined productivity as the ratio of what is produced to what is required to produce it. The authors further explained that productivity measures the relationship between outputs such as goods/services produced, and inputs

such as transforming and transformed resources that includes labour, capital and materials. Productivity is seen as a critical success factor and the foundation of profitability.

Lean manufacturing is derived from the Toyota Production System, established by Toyota Motor Corporation. The methodology is implemented through a collection of tools and techniques into the business processes to optimize time, human resources, assets, and productivity, while improving the quality level of products and services to customers [19]. Its success is underpinned by a cultural change across the business, where the focus of the business is meeting the needs of the end customer. Lean manufacturing is a tried and tested productivity improvement approach. Its aim is to help simplify and organize a working environment to facilitate identification and elimination of waste from the value chain, and to keep people, equipment, and workspace responsive to what's needed by the customer at any given time.

Chakraborttya and Paulb [20] described Lean manufacturing as a term used to describe a system that produces what the customer wants, when they want it, with minimum waste. The main focus is to shorten the time between the customer order and the customer getting the ordered product by eliminating sources of waste. According Rameez and Inamdar [21], waste is all elements of production (activities) that only increase costs without adding value that the customer is willing to pay for. These activities do not change the form or function of the product or service provided. These can be excess inventory, unnecessary operations, scrap, rework or transportation. The core feature of this concept is that by reducing non-value adding activities, more resources are made available to concentrate on those activities that add value to the product or service. Islam and Khan [22] described value adding activities as activities that transform materials and information into products and services the customer wants, and is willing to pay for, and they must be done right the first time. Lean manufacturing is therefore about creating more value for the customer with fewer resources by focusing more on production costs, product quality and delivery, and worker involvement and eliminating wastes. Resources used on non-value adding activities are redirected into value added activities.

The benefits of successfully applying lean manufacturing were illustrated by Fargher [23]. These include, shorter production lead times, greatly reduced inventories, and significantly enhanced profitability. Lean also promotes improved flexibility, enhanced reliability and substantial cost reductions. Islam and Khan [22] further illustrated that the use of lean manufacturing approach results in improvements in productivity and quality which lead to competitive advantage over other similar companies (competitors). Ferdousi and Ahmed [24] also highlighted the benefits of lean by emphasizing the main purpose of using lean manufacturing which is to increase productivity, improve product quality and eliminate manufacturing waste. To achieve the benefits, lean manufacturing uses several concepts and tools such as one piece flow, kaizen, cellular manufacturing, inventory management, standardised work, work place organisation, and scrap reduction to reduce manufacturing waste [24]; [25]. Ferdousi and Ahmed [24] summarised the main reason for adopting a lean manufacturing system under three broad categories which are, reducing production resource requirement and cost, increasing customer responsiveness, and improving product quality. From the literature investigation, it clear that lean manufacturing is a suitable tool to address productivity challenges experienced by the case study company.

METHODOLOGY

A garage security door manufacturing company was selected to carry out the study. The company was purposively selected because of the productivity problems, limited use of lean as well as to ensure the best possible scenario of lean implementation. Site visits were conducted in order to get a clear idea about the company's existing products and the company's manufacturing processes. A garage security door production line was then selected for research and application of lean manufacturing. A study was carried out on manufacturing processes for the production of the selected product and relevant data was collected. Collected data included time taken at each process, and distances travelled by both workers and materials. A simulation model representing the behavior of the entire security door manufacturing process was developed.

The data used to feed the simulation program were obtained from time study of the production assembly line and observation of information and production flow. The model was validated by comparing actual results with those obtained in the simulation model. Areas of improvement were noted and a new improved model was developed with

some new changes to investigate the most optimal way of running the production line, in order to address the production line productivity problems. The optimal model was chosen, run and tested ten times (verified). A new layout was proposed, to fit the proposed simulation model.

SIMULATION MODEL DEVELOPMENT AND ANALYSIS

Simulation Modeling

A study was carried out of the current manufacturing system following which a conceptual model of the system was developed. The conceptual model was developed and validated through interactive discussions with workers, observation of production flow and time noted for each process. The conceptual model was used as the basis for simulation model development using Arena software. The next step was to input data in the simulation model. Pilot runs were run for checking the validity and verifiability of the developed computer simulation model. As a final step in the development of the simulation model, simulations run parameters, such as replication length, and number of replications, were set.

Input data: Observed data and recorded information were used for the input data. The production flow layout was reconstructed to capture the movement of workers and material, and the distance travelled. Time study was conducted to help in gathering accurate process times for each process.

Verification and validation: The model was verified by comparing the output data from the simulation with the actual data from the existing system. Performance measures, such as cycle time and throughput, were used as the basis for comparing the computer simulation results with the existing data. The developed model was verified and validated as a true representation of the existing system.

Run parameters: The model was run for 32 hours, which is 8 hours per shift times the 4 days it takes workers to complete one door. The number of independent simulation runs (replications) was 10, and this was done to eliminate variations that could be brought by the software during the process of the simulation

RESULTS AND DISCUSSION

Current Manufacturing Process and its Analysis

Figure 1 presents the business process for the security garage door manufacturing for the case study company, in the form of crossfunctional “swimlanes” process maps.

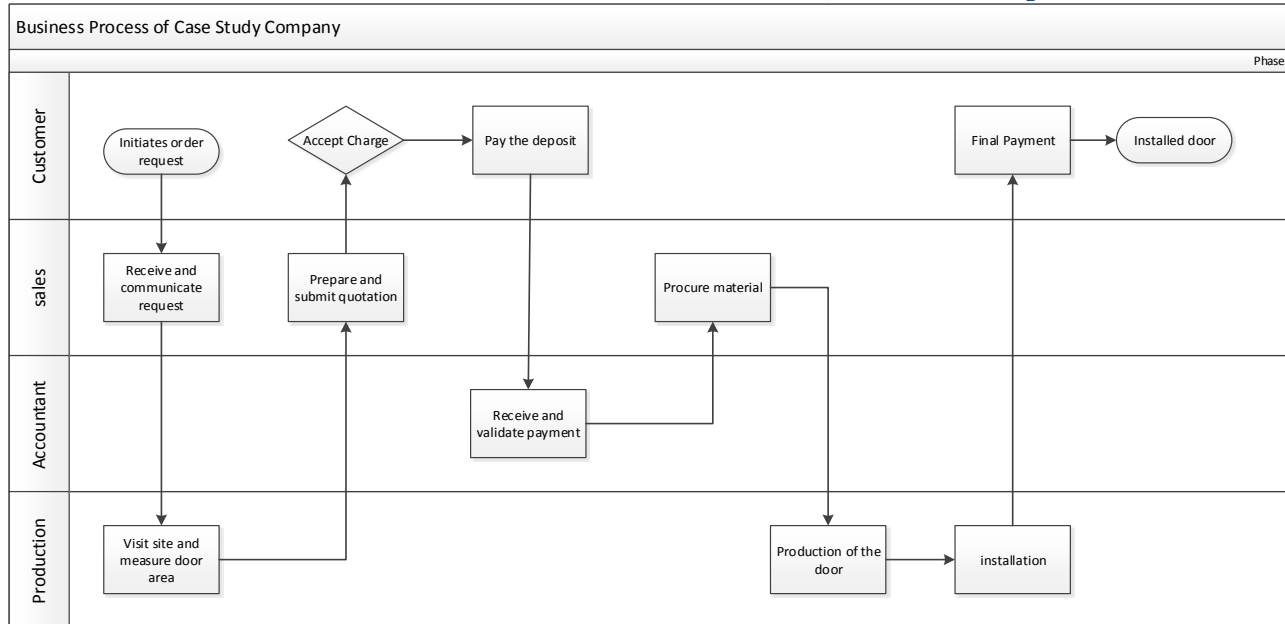


Figure 1: Business Process Map for Security Door Manufacturing

The functions responsible for each sub process are shown on each swimlane section. The as-is process map gives a clear visual of the process flow from the customer who initiates the process through each department until the final product is delivered back to the customer, ending the process. Order from the customer is received by the receptionist who informs the production workers about the placed order. The production workers will do a site visit in order to take measurements on the dimensions of the entrance where the security door is to be installed, to confirm the information given earlier by the customer. After confirmation of the dimensions, a quotation is issued to the customer, and upon acceptance of the quotation, the customer is requested to pay a deposit, and upon verification of payment, production is authorized to commence.

Material Flow and Work Allocation

The “Production of the door” process was identified as the process experiencing the most productivity challenges, and was therefore the focus of this study. The current production system is depicted in figure 2. The current manufacturing system is inefficient, characterized by haphazard movement of materials between workstations and storage locations. This layout has the following disadvantages:

- Layout is inefficient because jobs do not flow through in an orderly fashion
- Backtracking of jobs is common
- High risk of workers tripping off due to material placed all over the workshop.
- High risk of injuries to workers due to falling into sharp objects
- Blocked pathways
- More time is taken looking for equipment and tools

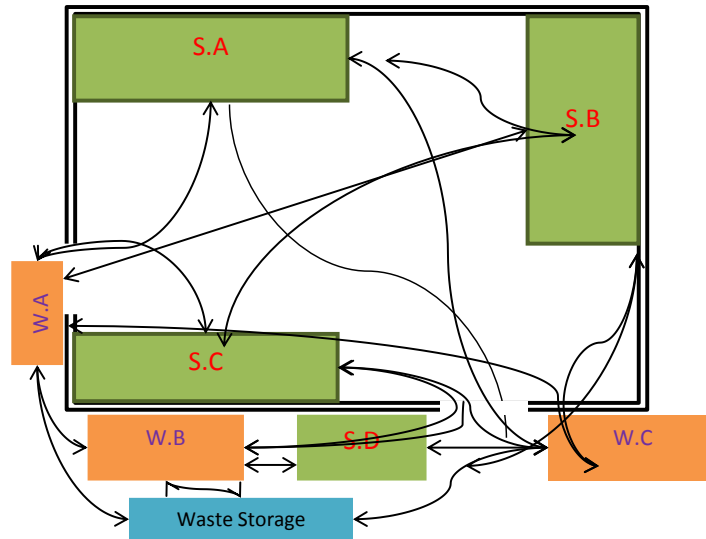


Figure 2: Schematic scenario of present manufacturing system layout

Key:

W.A: work station A: cutting of parts for making the rail guides, and cutting of slats and parts for making roller shaft to required dimensions.

W.B: work station B: welding and assembling roller shaft parts

W.C: work station C: painting of components from workstation A and C

S.A, S.B, S.C, and S.D are storage areas for work in progress

The manufacturing systems is manual and material is moved by the workers from one workstation to another, and there is a lot of material handling taking place. High handling of material can reduce the quality of the material as they can drop, resulting in bends, dents or scratches on final products. Layout is inefficient because jobs do not flow through the system in an orderly fashion, but rather in a ‘spaghetti’ fashion where a number of flow paths cross each other.

Table 1: Summarized average time for each workstation and idle time

Workstation	Min Time (min)	Max Time (min)	Average Time(min)	Idle Time (min)
Workstation A	165	175	170	43
Workstation B	138	144	141	72
Workstation C	210	215	213	0
Total			524	115

Time study was carried out to assess the time taken on tasks at each of the door manufacturing production line workstations. Table 1 summarises the time spent on manufacturing tasks undertaken at each workstation. Workstation C, where painting is done, takes an average of 213 minutes to complete its task, this being the longest time of the three stations. It is followed by work station A, which takes 170 minutes, where measuring and cutting of various parts that are used in making the security doors is carried out. Workstation B takes the least time at 141 minutes and it involves welding and assembling of roller shaft parts to make the security door. On average, the time spent adding value to make a complete security door is therefore 524 minutes (9.57 hours), even though it currently takes 4 days (32 hours) to make one complete security door. This indicates that of the 32 hours spent on making one door, 22.44 hours is spent on none value added activities. Value added activities therefore constitute only 29.9% of the door production time. One key target for productivity improvement is therefore shortening the manufacturing lead time.

Table 2 provides material movements between workstations and storage locations during the four days needed to make a single door. From Table 2, it can be noted that there is more movements between workstation A and storage B, storage B and workstation B, and workstation B and workstation A. This suggest that the three areas should be situated close to each other. Workstation C should be closer to Workstation B, workstation C to workstation A and workstation C to Storage B. This means that if they can be placed close to each other, then the traveling distance will be reduced significantly. Also, when process steps are located next to one another, it's easier for workers to visualize, identify and resolve quality issues. One focus during the redesign of the manufacturing system will be to ensure that areas with frequent movement of material between them will be located as close to each other as possible, in order to reduce travelling distance.

Table 2 Average number of movements made by workers between workstation and storage areas

	Storage A	Storage B	Storage C	Workstation A	Workstation B	Workstation C
Storage A	-	3.8	1.8	4.0	3.3	3.0
Storage B		-	1.0	5.5	5.5	4.8
Storage C			-	1.3	1.0	1.3
Workstation A				-	5.5	4.8
Workstation B					-	4.8
Workstation C						-

From the information in Table 2, and distances between the workstations and storage areas, the average travelling distances between the workstations and storage areas can be computed. Table 3 provides the average travelling distances between workstations and storage areas.

Table 3: Average travelling distances between storages and workstations in four days

	Storage A	Storage B	Storage C	Workstation A	Workstation B	Workstation C
Storage A	-	23.3	27.6	28.6	48.9	53.9
Storage B		-	9.6	20.4	48.7	56.0
Storage C			-	16.6	9.7	15.8
Workstation A				-	29.0	73.5
Workstation B					-	44.3
Workstation C						-

The values in Table 3 are obtained by calculating a load-distance score (LD score) for each pair of work centres. The LD score between work centres i and j is found as follows:

$$LD \text{ score } (i,j) = \text{Load } (i,j) \times \text{Distance } (i,j) \quad (1)$$

The *load* value is a measure of “attraction” between two work centres. In our case the load represent the number of movements between the two work centres during the production of a single door. Hence, the higher the number of movement is, the more attractiojn there is between the two work centres. The aim is to find a design that will minimize the total LD score. A sample calculation is provided below.

Sample calculations: LD Score between Workstation A and B

$$\begin{aligned} \text{Average number of movements} &= 5.5 \\ \text{Distance between the two stations} &= 5.27 \\ \text{LD Score (i.e Average travelling distance)} &= 5.5 * 5.27 \\ &= 28.99 \text{ m (or 29.0 m)} \end{aligned}$$

As depicted by table 3, workstation A must be located close to workstation C to reduce the average travelling distance between the two as the travelling distance between each other is so high. Also storage A and B must be situated close

to workstation C for the same reason. From Table 3, the average total distance travelled can be calculated by adding the LD scores.

$$\begin{aligned} \text{Total distance travelled on average} &= 23.3+27.6+28.6+48.9+53.9+9.6+20.4 \\ &+48.7+56.0+16.6+9.7+15.8+29.0+73.5+44.3 \\ &= \underline{5.2 \text{ km}} \end{aligned}$$

On average, during the production of one door, workers travel 5.2 kilometres in four days between the workstations and storage locations. This is too much and is a target for reduction in the redesigned system. This distance travelled contributes to the overall inefficiency of the company as too much time is wasted just travelling, not doing anything that add value to the door production. This is an example of motion waste in lean language, where workers walk without working (away from workstations) and searching for tools, materials or information. This waste will take much of the product throughput time, hence delaying getting the product to the customer.

Line balance

As indicated in Table 1, the allocation of work to the three workstations, A, B, and C is unequal, indicating that the production line is not balanced. There are therefore instances when workstations with fewer work allocation are idle, waiting for work. Workstation C, with the most work allocation determines the cycle time for the production line (213 Minutes), with workstation A and B idle for 43 min and 72 minutes per cycle. The idle time is a waste since workers still have to be paid for a full shift even though they are not doing any work for the time they are idle. From the information in Table 1, the balancing loss and line balance efficiency of the production line can be determined as follows:

Balancing Loss = total idle time/(no. of workstation*cycle time)

$$\begin{aligned} \text{Balancing Loss} &= \frac{115}{3 * 213} \\ &= \mathbf{18\%} \end{aligned}$$

$$\begin{aligned} \text{Line balancing efficiency} &= 1 - \text{Balance Loss} \\ &= \mathbf{82\%} \end{aligned}$$

Balancing loss is the quantification of the lack of balance in a production line. It is defined as the percentage ratio of idle time and number of workstation multiplied by cycle time. The balancing loss of the current model is quite high at 18% and its reduction would greatly improve productivity as it will reduce the time workers spend waiting for work from slower workstations. The high line balancing loss result in a poor assembly line balancing efficiency.

Evaluation of Performance of the Current System Using Simulation Modelling

Simulation was used to evaluate the performance of the current system. For the current model, the replication length was set to 4 days because so as to mimic the real system. Replication length is the duration the modeler wants to run the simulation for. Time units used is hours and the model was run for 10 replications in order to eliminate variations that could be brought by the software during simulation. The output from the current model was 1 door in 4 days, which matches with the real production line.

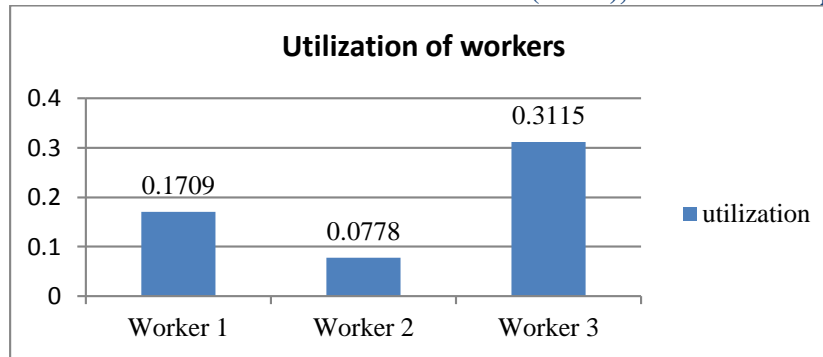


Figure 3: Utilization of each worker

Figure 3 presents the utilization for each worker and as can be seen from the diagram all the three workers are underutilized, with the most utilized worker, worker 3, only busy 31.15% of their time. On average worker 3 does more work than the other two which indicates that work load on the production line is not evenly distributed. The underutilization of the three workers and the uneven distribution of work explain the inefficiency of the system. Underutilized resources means that the resource is not working up to its production capacity, hence the company doesn't get full value for its investment in the resources. Instead of being on their workstation performing their production tasks, the workers spent most of their time on non-value adding activities like unnecessary movements in the workshop and waiting for work. These are examples of lean wastes. Below is a summary of the wastes identified in the current manufacturing system.

Waiting Time: The most basic cause of waiting time is an unbalanced process. When one part of a process runs faster than other parts, there will be waiting in the process; the processes immediately after a slower process have to wait for work from the slower process.

Transportation: Inside a facility, transportation is caused by waiting time and inventory, as well as processes and storage locations far away from each other. Every break in a process that causes waiting time has the potential to allow Work In Progress (WIP) to accumulate. As WIP accumulates, it needs to be stored, and in turn, transported to and from storage locations. Storage areas are farther apart which also contribute to workers having to travel longer distance within the workplace. With high finished goods and raw material inventories, transportation costs also rise.

Motion: It is evident from figure 3 that there is a lot of zig-zag movement by workers, hence workers travel long distances without doing any value added activity. This is a typical lean waste that needs to be eliminated.

As shown in table 4, all the waste identified from the current manufacturing system can be addressed by an efficient layout design of the production line.

Table 4: Identified waste from current manufacturing system

Waste identified	Possible lean tool to use
Motion	Layout design to reduce distance and frequency of material movement
Transportation	Layout design to reduce distance and frequency of material movement
Waiting	Layout design to balance work allocation
Worker underutilization	Layout design to balance work allocation

Design and Analysis of the Proposed Manufacturing System

After identifying the wastes, the only lean tool that is applicable to eliminate the waste, all at once, is layout design. From the data collected, as discussed under current manufacturing system analysis, it can be noted that the layout is the root cause of the wastes identified hence if it can be improved then the whole system will be improved.

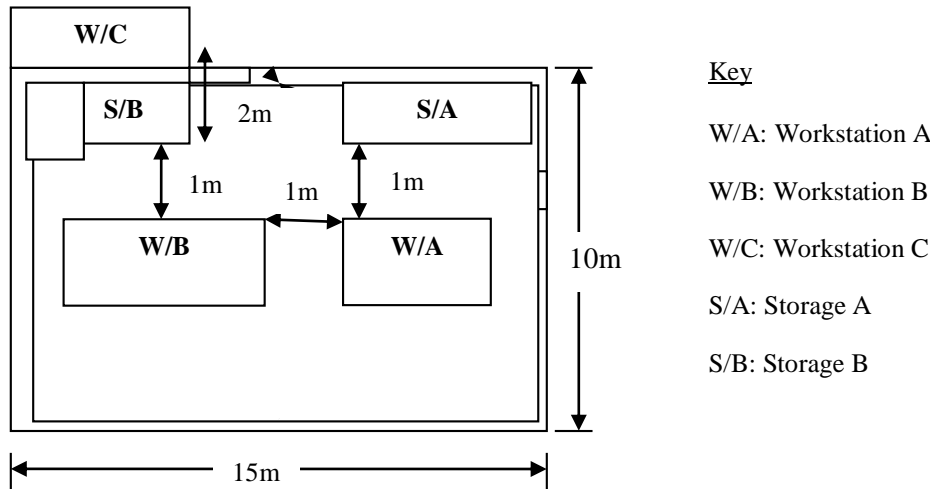


Figure 4: Proposed security door manufacturing plant layout.

Figure 4 presents the proposed layout for the door manufacturing production line, and in this layout workstations are closer to each other and to storage locations. The layout was chosen because it reduces employee movement and space requirements while enhancing communication, and facilitating inspections. In the new system, production worker 1 does all the markings and cutting at workstation A before the work in progress is transported to workstation B where worker 2 does the welding. Welded components are then transported to workstation C where worker 3 does the painting.

Criteria used to locate the workstations

Since the aim is to have smooth directed flow of material from one workstation to another and to reduce travelling distances, workstations were arranged such that the workstation for the first operation was located closer to the storage area where the material to be used in that workstation is located. This is to eliminate long worker movements between the storage location and the workstation. The placement of the second workstation was done based on the fact that the station proceed from the first workstation hence it should be located after the first workstation (workstation A) was placed. For workstation C, it was located outside the workshop because it's used for painting, so when outside, it's easy and quicker for the paint to dry. Both workstation A and B will be enclosed by a shielding curtain for safety reasons since some of the tasks involve welding and grinding. This is to protect other workers from exposure to the light and sparks from welding and cutting using grinding machine respectively used in the workstations as they are harmful to the eyes. Storage B was located based on the fact that it is used to store equipment for both workstation B and C, that's why it is located in between the two stations.

Table 5: Summarized total time for each workstation and idle time

Workstation	Descriptive	Total Time (min)	Idle Time (min)
Workstation A	Measuring + Cutting	175	4
Workstation B	Bending + Welding	170	9
Workstation C	Painting	179	0
Total		524	13

After placing the workstations and storage locations, work was reallocated to the workstations in order to achieve a more equitable allocation of work. Some tasks were therefore removed from the workstations with the highest allocation and redistributed to the other workstations, taking into account technical constraints. Table 5 shows work allocation among workstations in the proposed manufacturing system. Workstation C, where painting is done, now takes an average of 179 minutes to complete its task (down from 213), this being the longest time. It is followed by work station A, which takes 175 minutes (up from 170), where measuring and cutting of various parts that are used in making the security doors is carried out. Workstation B takes the least time at 170 minutes (up from 141) and it involves welding and assembling of roller shaft parts to make the security doors.

Material Flow and Work Allocation in the Proposed System

Tables 6, 7 and 8 summarise material flow within the proposed layout. Table 6 provides the number of expected movements made between workstations and storage areas. Compared to the current layout, fewer movements will be made. Table 7 provides the distances between workstations and storage areas. The distances are shorter, which is the desired outcome as workers will spend less time moving from one place to another. Table 8 provides the average travelling distances between workstations and storage areas. On average, during the production of one door, workers will travel 16 metres between the workstations and storage locations. The travelling distance in the proposed layout has been reduced to 16 metres from 5.2 km in the current system. This massive reduction will ensure more time is spend working on the manufacturing process, rather than moving around, and will ultimately reduce manufacturing lead time.

Table 6 Expected number of movements between workstations and storages

From/To	Workstation A	Workstation B	Workstation C	Storage A	Storage B
Workstation A	-	2	0	2	0
Workstation B		-	2	0	2
Workstation C			-	0	2
Storage A				-	0
Storage B					-

Table 7 Distances between each workstation and storage in meters

From/To	Workstation A	Workstation B	Workstation C	Storage A	Storage B
Workstation A	-	1	4	1	2
Workstation B		-	3	2	1
Workstation C			-	5	2
Storage A				-	3
Storage B					-

Table 8 Estimated travelling distance between workstations and storage areas in meters

From/To	Workstation A	Workstation B	Workstation C	Storage A	Storage B
Workstation A	-	2	0	2	0
Workstation B		-	6	0	2
Workstation C			-	0	4
Storage A				-	0
Storage B					-

The values in Table 8 are obtained by calculating a load-distance score (LD score) for each pair of work centres. The LD score between work centres i and j is found as in equation (1)

From Table 8, the average total distance travelled can be calculated by adding the LD scores.

$$\begin{aligned} \text{Total distance travelled on average} &= 2+2+6+2+4 \\ &= \mathbf{16\ m} \end{aligned}$$

Line Balance

As indicated in Table 5, the allocation of work to the three workstations, A, B, and C is now more equitable, even though there is still some idle time of 14 minutes (down from 115 in the current system). From the information in Table 5, the balancing loss and line balance efficiency of the production line can be determined as follows:

Balancing Loss = total idle time/(no. of workstation*cycle time)

$$\begin{aligned} \text{Balancing Loss} &= \frac{14}{3 * 179} \\ &= 2.6 \% \end{aligned}$$

Line balancing efficiency = 1 – Balance Loss

$$97.4 \%\%$$

Balancing loss of the new model have improved significantly from 18.0 % to 2.6% which is desirable as it means that there is now almost a continuous flow of work among the workstations, thus less time waiting for work from slower stations This also means that the line balance efficiency of the line has improved (from 82% to 97.4%). The improved line balance efficiency will therefore reduce waiting time within the proposed manufacturing system.

Evaluation of Performance of Proposed System Using Simulation Modelling

Simulation was used to evaluate the performance of the new system. For the new system, the replication length was set to 4 days because we are comparing it to the current model. For accurate comparison, all the parameters used for the new model are the same as the current model. Time units used is hours and ten replications where run in order to eliminate variations that could be brought by the software during the simulation run. The output from the new model is 2 doors in 4 days. This is an indication that the proposed model is more economical and efficient than the current model, indicating a 100% productivity improvement in manufacturing lead time.

The proposed layout is cell layout which has fast throughput and promotes group work which can result in good motivation among workers. Cell layout is where machines are grouped according to the process requirements for a set of similar items (part families) that require similar processing. These groups are called cells. This is to say that production work stations and equipment are arranged in a sequence that supports a smooth flow of materials and components through the production process with minimal transport or delay. Each workstation does all its work and transfers the completed work to the next work station. Workers in cellular layouts are cross-trained so that they can operate all the equipment within the cell and take responsibility for its output.



Figure 5: Worker utilization

Figure 5 shows that the proposed model improves worker utilization. Worker 3 still does relatively more but the workload is more equitably allocated, indicating a better line balance. With the proposed system, non-value added activities have been reduced; the workers don't waste as much time on less profitable tasks like unnecessary movements in the workshops. More time is now spent in doing the actual work of satisfying the needs of the customer or adding value to the product the customer wants. Since output of the production line has doubled, this indicates that value-added time has also doubled from 29.9% for the current system to 59.8% for the proposed system.

This model also shows that workers are now using more of their production capacity and the company thus benefits in return through reduced lead times and satisfied customers. The proposed model will therefore help improve the productivity of the company.

CONCLUSION

A study of how to improve the productivity of a small company using lean manufacturing tools was carried out in this research. The company's current manufacturing process was analyzed to identify its weaknesses. Production flow analysis and simulation modeling were used to analyse the current manufacturing system. A number of non-value added activities were identified and suitable lean tools were identified for their elimination. A proposed manufacturing system was developed in order to improve the productivity of the case study company. The proposed system was analysed using production flow analysis and simulation modeling, and its productivity was found to be better than the current system. Production output doubled, worker utilization has significantly improved, and the production line is more balanced. Space utilization has improved due to workstations and storage locations being brought closer to each other, which provides management with an easier way to coordinate and integrate the factory production with the current level of resources. The study has therefore demonstrated that the company can significantly improve its productivity through the redesigning of the door manufacturing production line layout as suggested in the proposed manufacturing system.

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