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# Optimization of Printing Press Operations

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***Abstract**: Printing technology has seen technological advances in the field of automation because it is a very dynamic and innovative process. A good printing factory layout maximizes production with minimum investment in new equipment. However, a good factory layout alone cannot achieve the intended objectives unless tightly coupled with production process monitoring and improvement which entails monitoring of Overall Equipment Effectiveness (OEE) to pinpoint areas of production losses and identify areas of performance improvements.This research focused on carrying out a process and facility layout analysis with the aim of identifying gaps, bottlenecks and challenges in productivity that contributed to poor production throughput and to redesign the layout and optimize the production capacity. Input variables considered were: number of departments, flow matrix, floor area for each machine, design speed, actual speed, losses and rate of failure. Output variables were: dual graph and layout proposition, availability, performance, Quality, OEE.The facility layout add-in that implements the Computerized Relative Allocation of Resources (CRAFT) was used for layout redesign. ARENA was used, for the design of experiment (DoE), simulation, analysis, and optimization. Pareto chart was developed using Minitab statistical software. ThePareto analysis established that 69.6% of the distance covered was taken up by movement between machine and store and 78.2 % of the print volume was taken up by threeprinting machines, (Web, Print master and Speed master). Failures, breakdowns and setup times were found to have a less significant effect on the performance and hence OEE of the factory. The quality of paper affected breakdowns for the web whereas run speed significantly influenced the overall performance and OEE. The optimal conditions obtained at about 80% of design speed of each machine that gave OEE of 79% for 3 critical machines and 68% for all five printing machines (only three machines were considered for optimization). Experimental output values obtained during validation were Web printer at 130,000 runs per day (without auto- splicing), Printer master (PM) and Speed master(SM) printers at 70,000 each at runs per day. These results were closer to the software results since some changes in storage location and automation were not yet put in place.*

***Keywords:** ARENA, CRAFT, Optimization, OEE, Printing, Simulation*

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## I. Introduction

Facility layout is the arrangement of production machines and equipment in a physical space in order to achieve optimum production, determined by the interrelationship between processes that take place in these machines or equipment. This arrangement is meant to achieve greatest co-ordination and efficiency of 4M's (Men, Materials, Machines and Methods) in a plant so as to provide a service or make a product with the least use of resources [1]. A good facility layout maximises production throughput rate, facilitates manufacturing process and minimises material handling costs and bottlenecks, reduces movement and distance covered by workers and the waiting time for work in progress and also minimises investment in new equipment [2]. Heragu [3] has emphasised the importance of managing the facility such that the objective for which it was established are achieved even though these objectives may be in conflict with other organisational needs. Facility planning can be systematic or situational. Systematic planning considers all the stages of the entire lifecycle of the production facility from inception to phase-out while situational planning arises as a consequence of the changes in the operational decisions (changes in technology, requirements, quality specifications, demand etc.) where all or part of the processes or sequence of operations need to be changed. Good facility planning and layout alone cannot achieve the intended objectives unless tightly coupled with internationally accepted best practices in production process planning and management. Production process monitoring and improvement is achieved by monitoring Overall Equipment Effectiveness (OEE).

Overall equipment effectiveness (OEE) is a key metric used in total productive maintenance and lean manufacturing. It refers to the practice of monitoring the effectiveness of production processes and production equipment for continuous improvement [4]. OEE is a product of three ratios namely availability, performance and quality and uses these metrics to compare the actual capability of a machine to its ideal capability and therefore determining specific reasons for production losses and identifying areas of performance improvements [5]. Holland [6]has further explained that availability depends on uptime and downtime of the machine, efficiency measures the actual and ideal cycle times of the machines while quality considers the amount of rework and defects. These three factors are affected by six major losses at times referred to as six big losses which are: setup losses, shutdown losses (panned or unplanned), minor stoppages, speed losses, quality losses and start-up loses (time taken to reach steady state). In order to effectively and accurately calculate these metrics, accurate data is of paramount importance. Therefore there must be an accurate and reliable method of data capturing that is consistent to avoid errors that may lead to wrong decisions. This calls for organisations to invest in automated data collection systems since manual collection is tedious and time-consuming and most of the times the operators soon get tired and lose focus choosing to concentrate on what they believe is more pressing resulting to inaccurate data.

Stamatis [7] expounded on various methods of collecting data for calculating OEE and other metrics of maintenance and performance. The emphasis was on the need to observe and monitor equipment for their uptime and downtime thoroughly checking for net operating time, gross operating time and no-operating time, scheduled and unscheduled downtimes. In determining ideal cycle times, the emphasis was placed on establishing which factors affect cycle time so that a method of determining which ideal cycle time should be used known beforehand. It is important to be keen on the methods of collecting data for quality and to first define what quality loss is. In doing so, process line considerations should be made for any other factors that may affect machine quality in addition to process line quality issues leading to defects either upstream or downstream and choose which quality losses should be recorded. With accurate data, calculating OEE gives a true picture of the state of the equipment revealing areas of improvement. Testing of possible outcomes is expensive and time-consuming.

In India, Manugraph manufacturers produce web offset printing machines capable of 35.000 to 70,000 copies per hour (cph). Heidelberg who among the pioneers in printing (over 160 years) have advanced their printing technology and embraced lean processes and extensive automation. Autonomous printing that entails automated colour selection and measurement, plate making and changing, job selection and changing over and quality control, all take place automatically without operator intervention as long as some conditions are met. Sensors and cameras for quality control in modern machines ensures that no blank pages pass for packing, poorly printed copies are automatically rejected and no double picking of paper for sheet-fed printers(intelligent error elimination). Other advances in web printing are in the area of auto splicing of printing reels and automatically checking for desired quality without stopping the printer. These advances ensure printing of high volumes with high precision with minimum human intervention[8].

Printing technology has seen technological advances in the field of automation of printing processes and good printing factory layout that maximizes production with minimum investment in new equipment. However, a good factory layout alone cannot achieve the intended objectives unless tightly coupled with production process monitoring and improvement which entails monitoring of Overall Equipment Effectiveness (OEE) to pinpoint areas of production losses and identify areas of performance improvements. This research focused on carrying out a process and facility layout analysis with the aim of identifying gaps, bottlenecks and challenges in productivity that contributed to poor production throughput and to redesign the layout and optimize the production capacity.

## II. Methods

### 2.1 Methods used

In this research, interviews,questionnaires, review production records, and reading of nameplate information were used to collect data. Process analysis was carried out that encompassed process mapping and time function mapping that helped create a value stream map for the factory.

### 2.2 Availability analysis and gap analysis

Metrics that affect OEE were calculated from Value stream mapping and time function mapping information that led to the calculation of the current OEE for carrying out availability analysis of the equipment. Pareto analysis and flow matrix for distances were used in Systematic Layout Planning (SLP) for layout design analysis.

### 2.3 Process Improvement

*The facility layout add-in that implements the Computerized Relative Allocation of Resources (CRAFT)* was used to proposition the improved factory layout together with manual intervening measures that considered the current equipment installing. ARENA software was used in the simulation of the parameters suggested for improvement of OEE. Fig 1 shows the CRAFTenvironment for defining the system to be designed or improved.

Department Information

| | Name | F/V | Area | Cells |
|---|---|---|---|---|
| Store | D 1 | V | 910 | 910 |
| WEB | D 2 | V | 110 | 110 |
| PM | D 3 | V | 55 | 55 |
| SM | D 4 | V | 55 | 55 |
| MOZP | D 5 | V | 45 | 45 |
| MOE | D 6 | V | 45 | 45 |
| Sholei | D 7 | V | 45 | 45 |
| MBO | D 8 | V | 50 | 50 |
| STM | D 9 | V | 60 | 60 |
| MI | D 10 | V | 60 | 60 |
| MII | D 11 | V | 60 | 60 |
| Sitma | D 12 | V | 65 | 65 |
| Guilotine | D 13 | V | 65 | 65 |
| Shredder | D 14 | V | 65 | 65 |

Flow Matrix

| FROM \ TO | D 1 | D 2 | D 3 | D 4 | D 5 | D 6 | D 7 | D 8 | D 9 | D 10 | D 11 | D 12 | D 13 | D 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| D 1 | | 630 | 400 | 380 | 170 | 150 | 170 | 160 | 380 | 170 | 160 | 150 | 142 | 0 |
| D 2 | | | | | | | 0 | 0 | 35 | 30 | 33 | 10 | | 60 |
| D 3 | | | | | | | 5 | 7 | 0 | 0 | 0 | 0 | 3 | 4 |
| D 4 | | | | | | | 5 | 7 | 0 | 0 | 0 | 0 | 5 | 10 |
| D 5 | | | | | | | 10 | 12 | 0 | 0 | 0 | 0 | 8 | 20 |
| D 6 | | | | | | | 13 | 15 | 0 | 0 | 0 | 0 | 11 | 24 |
| D 7 | | | | | | | | | 6 | 3 | 3 | 3 | 3 | 16 |
| D 8 | | | | | | | | | 6 | 3 | 3 | 3 | 3 | 20 |
| D 9 | | | | | | | | | | | | 0 | 5 | 30 |
| D 10 | | | | | | | | | | | | 0 | 7 | 40 |
| D 11 | | | | | | | | | | | | 0 | 7 | 40 |
| D 12 | | | | | | | | | | | | | 0 | 44 |
| D 13 | | | | | | | | | | | | | | 0 |

**Figure 1**:CRAFT environment for defining the system

**2.4 Experimental design**

A model was created in the ARENA software where the input parameters were chosen carefully. Failures were averaged and redistributed on a daily basis that was used as input in the failure module. Stoppages, Setup time and short breaks all were input in the failure module since they contributed to non-productive time. ARENA was set at fivereplications per run and the current state was simulated as a pre-test using data obtained for current machine performance. Once the current state was reproduced well in the ARENA, other parameters (effective working time, machine speeds, reduced failure rates) were changed iteratively for various simulations and results recorded until a preferred solution was arrived at. Fig. 2 shows the project design in ARENA students' version. Only 3 critical printing machines were considered because the other 2 could not sustain increased speeds for long without breaking down.

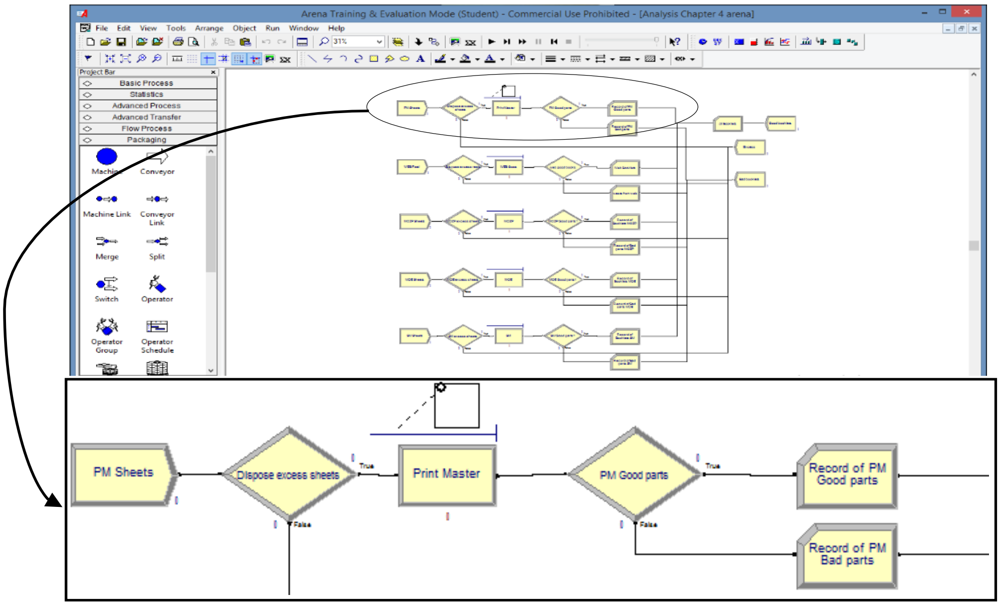


**Figure 2:** ARENA project design

The failure module shown in Fig. 3 was generated and populated with the values corresponding to each failure.

Failure - Advanced Process

| | Name | Type | Up Time | Up Time Units | Down Time | Down Time Units | Uptime in this State only |
|---|---|---|---|---|---|---|---|
| 1 | PM paper jam | Time | 60 | Minutes | TRIA( 1 , 3 , 5 ) | Minutes | Busy |
| 2 | PM breakdown MTBF | Time | 1 | Hours | TRIA(0.011428571, 0.033333333, 0.071428571) | Hours | Busy |
| 3 | PM setup time | Time | 9 | Hours | TRIA( 5 , 12 , 22) | Minutes | |
| 4 | Web papercut | Time | 3 | Hours | TRIA(3 , 5 , 10) | Minutes | Busy |
| 5 | Web setup | Time | 9 | Hours | TRIA( 5 , 10 , 15) | Minutes | |
| 6 | Web breakdown MTBF | Time | 1 | Hours | TRIA(0.011428571, 0.03, 0.057142857) | Hours | Busy |
| 7 | Web changeover | Time | 1.5 | Hours | TRIA( 5 , 10 , 15 ) | Minutes | |
| 8 | MOZP breakdown MTBF | Time | 1 | Hours | TRIA(0.011428571, 0.021666667, 0.057142857) | Hours | Busy |
| 9 | MOZP and MOE setup | Time | 9 | Hours | TRIA(7, 15, 22) | Minutes | |
| 10 | MOZP and MOE changeover | Time | 3 | Hours | TRIA(5, 7, 10) | Minutes | |
| 11 | MOE breakdowns MTBF | Time | 1 | Hours | TRIA(0.011428571, 0.018333333, 0.042857143 | Hours | Busy |
| 12 | SM breakdown MTBF | Time | 1 | Hours | TRIA(0.005714286, 0.013333333, 0.028571429) | Hours | Busy |
| 13 ▶ | MOZP and MOE paper jam | Time | 3 | Hours | TRIA( 3 , 6 , 9 ) | Minutes | Busy |

**Figure 3:** Failure module in ARENA

Several iterations were performed in ARENA software with this improved theoretical data to determine the expected output that would be produced. The runs considered several scenarios for improving the system performance, utilization and overall output. Time wasting areas were identified and mitigating measures put in place to eliminate time wasting and reduce setup times. There was the current scenario and 4 scenarios for improvement, scenario 1 was the current state then followed by four scenarios for improvement simulations. These were: reducing failures by half, failure rate and Setup time each reduced by half, planned production time increased from seven to ninehours and run speed increased to about 80% of ideal run speed.

## III. RESULTS AND DISCUSSION

Results for each simulation run were tabulated and graphs drawn where appropriate from the ARENA output results. Planner graph of the proposed layout from CRAFT was generated as shown in Figure 4

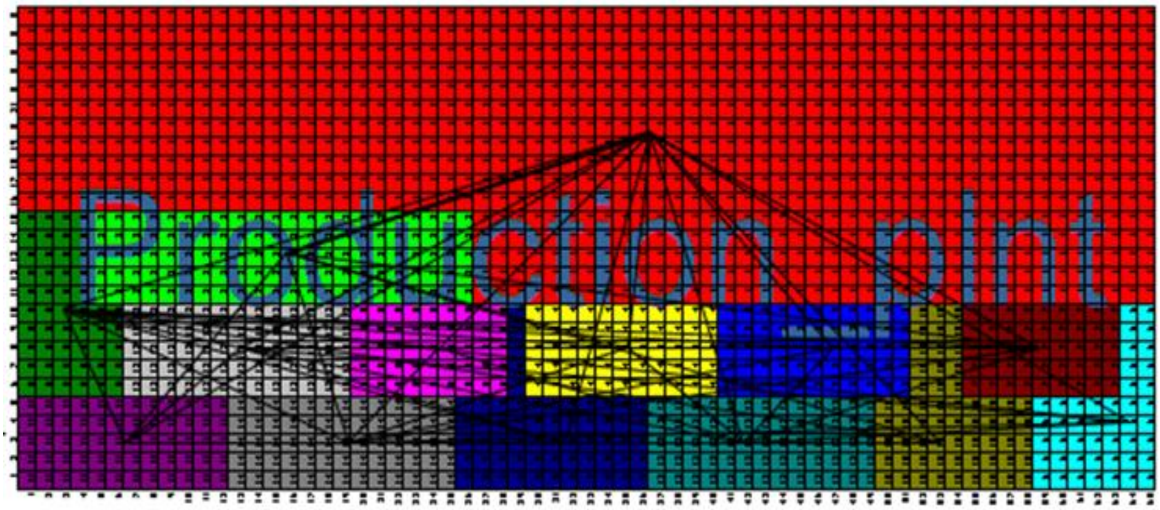


**Figure 4:** Planar graph of the proposed layout

### 3.1 Discussion of the results

Pareto Analysis was done on the distances and machine capacities to determine which areas to concentrate on for improvement. After performing simulation runs, the results were analyzed in terms of the percentage effect each factor had on the overall performance and OEE of the equipment. These factors were: machine run speed, the rate of failure and time losses. Reports generated from ARENA were summarized and exported into Minitab for graphing and further analysis.

### 3.2 Pareto analysis

Pareto analysis for distances revealed that 65.9% of the distance travelled was between printing machines and the storeroom. As for the printing machines, there are 3 machines that account for 78.2% of the print volume. These were the target areas for improvement.Figure 5 and Figure 6 show the Pareto charts for distances from the store and cumulative print volumes for the machines respectively.

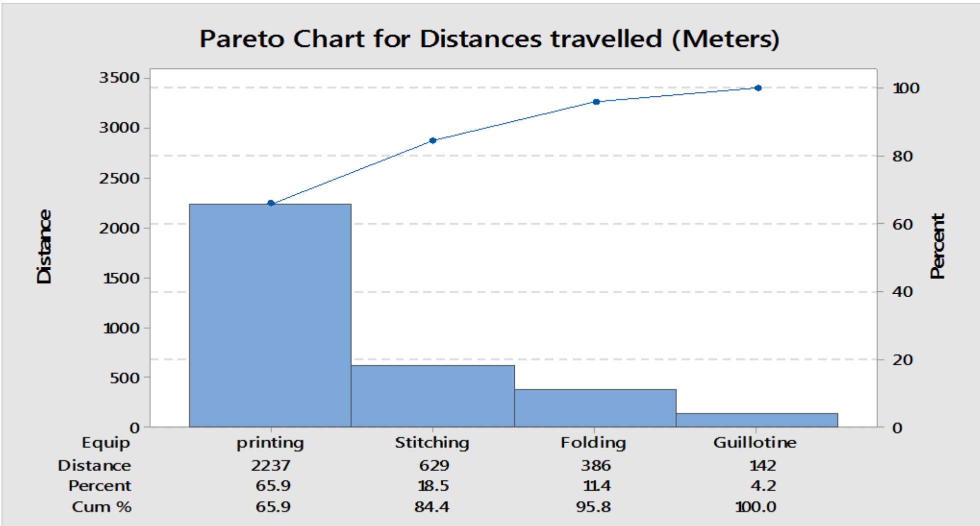


**Figure 5:** Pareto analysis graphs for distances

Fig. 5 shows that 65.5% of the distance covered by movement of materials on the shop floor was due to work involving printing machines while 84.4% of this cumulative distance was due to printing and stitching machines. Emphasis for improvement was placed on printing machines due to the critical role they play in the process as an entry point to value addition.

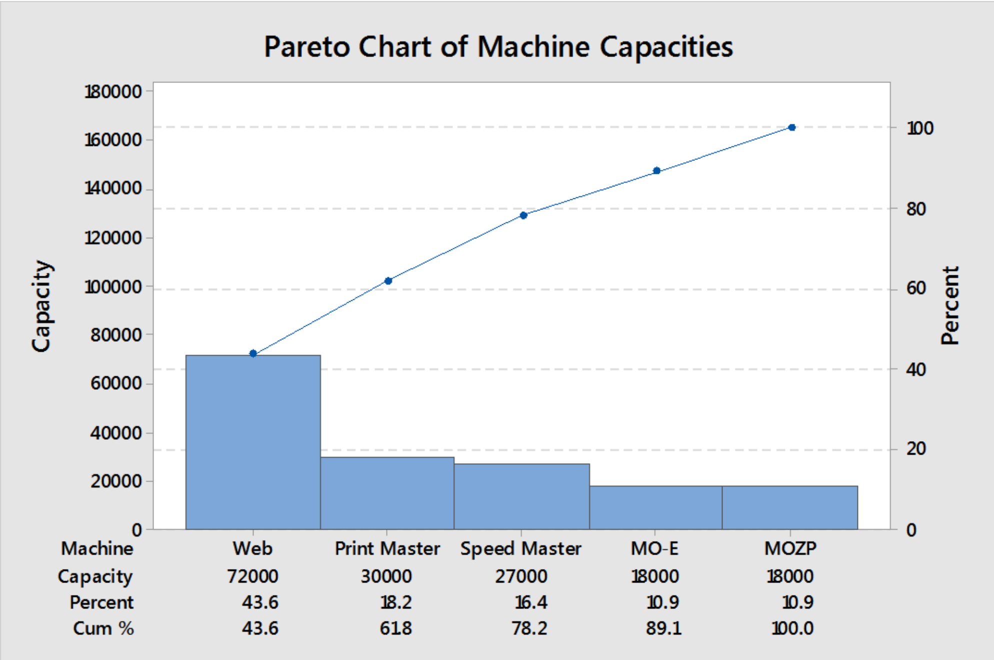


**Figure 6:** Pareto analysis graphs for print volumes

Fig. 6 shows the Pareto analysis for printing machines. The Web printer accounted for 43.6% of the print volumes while cumulatively, the Web, PM and SM machines accounted for 78.2% of the total print volume. Improvement efforts were concentrated on these three machines with emphasis placed on the web printer**[9]**.

### 3.3 Availability

In establishing current availability, the uptime for the three critical machines was 60% to 62%. Time loses due to meal breaks was 19% while the other losses accounted for 16% of the losses, this is summarised in Table 1. It is clear from table 1 that eliminating breaks for machines and reducing transport time would increase availability to above 80%. As summarised in **Error! Reference source not found.**showing a comparison of initial to improved uptimes. We can realise improved uptimes by eliminating unnecessary breaks for machines. The effect of additional uptime was analysed during simulation as shown in the results of the scenarios for simulation.

**Table 1:** Uptime for the Printing Machines (%)

| **Process** | **Printing Machines** | | | | | **Stitching Machines** | | | **Folding Machines** | |
|---|---|---|---|---|---|---|---|---|---|---|
| | ***MO-E*** | ***MOZP*** | ***Speed master*** | ***Web*** | ***Print Master*** | ***Muller I*** | ***Muller III*** | ***Stitch master*** | ***Stahl*** | ***MBO*** |
| Transport and retrieval | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| Initial setup Time (S/T) | 6 | 8 | 11 | 11 | 11 | 8 | 6 | 4 | 8 | 6 |
| Change over Time(C/T) | 4 | 4 | 2 | 4 | 2 | 8 | 6 | 6 | 2 | 0 |
| Tea and lunch breaks | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 |
| Uptime | 66 | 63 | 62 | 60 | 62 | 58 | 64 | 66 | 65 | 69 |

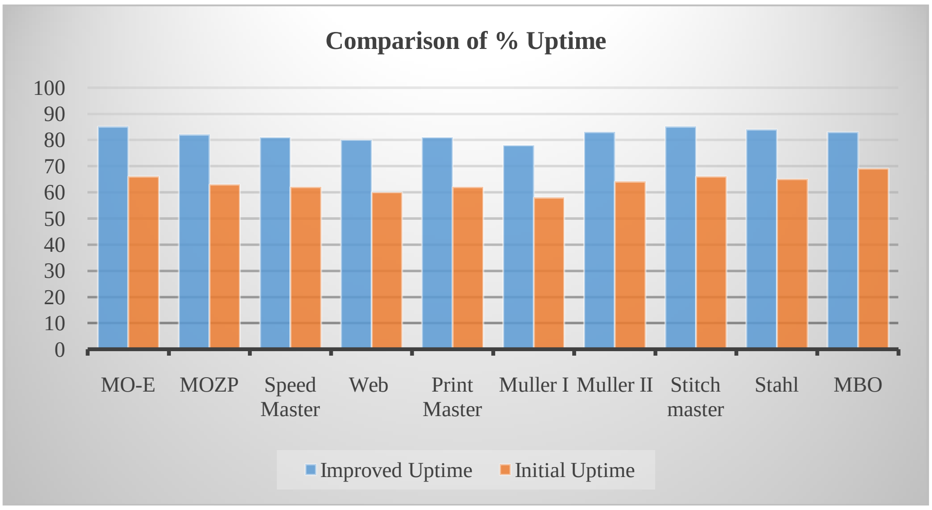


**Figure 7:** Improved uptime against initial uptime

Figure 7 shows initial and improved percentage uptimes was recorded as:
Initial uptime: MOE-66, MOZP= 63, SM=62, PM=62, MI=58, MII=64, STM=66, Stahl= 65 and MBO=69
Improved uptime: MOE-85, MOZP= 82, SM=81, PM=80, MI=78, MII=83, STM=85, Stahl= 84 and MBO=83
.

Availability analysis was carried out to determine the current effective utilization of the equipment. These components were calculated as follows:

$$\textbf{Availability}= \frac{\textbf{Operating time}}{\textbf{Planned production time}}$$

$$\textbf{Performance}= \frac{\textbf{Total units produced} \div \textbf{Operating time}}{\textbf{Ideal run rate}} \textbf{x100}$$

$$\textbf{Quality}= \frac{\textbf{good units produced}}{\textbf{total units produced}}$$

**OEE=Availability x Performance x Quality**

The OEE for the printing machines stood at 23% compared to the international average of 65% and world-class standard of 85%

**Process improvement**

Performance would be improved by increasing the total number of pieces produced per minute. Theoretically increasing the run speed to 80% of the ideal run speed and reducing the downtime (including setup time) to not more than thirty minutes while eliminating breaks for meals (machines don't break for meals) gave better performance results. This improved OEE from 23% to a theoretical value of 58.4% when all five printing machines were considered while OEE of73.42%was realised for the three critical printing machines.

Parameters for the six scenarios for improvement simulations which were: reducing failures by half, failure rate and Setup time each reduced by half, planned production time increased from seven to nine hours, increasing machine speed at initial conditions, run speed increased to about 80% of ideal run speed and 85% of ideal run speed were each input into the ARENA module. The graphs in Figure 9,Figure 10and Figure 10show the improvement in performance for each scenario considered for the three machines that were considered for performance optimisation. There were seven scenarios labelled as S1, S2, S3, S4, S5, S6 and S7 which have been explained in detail below.

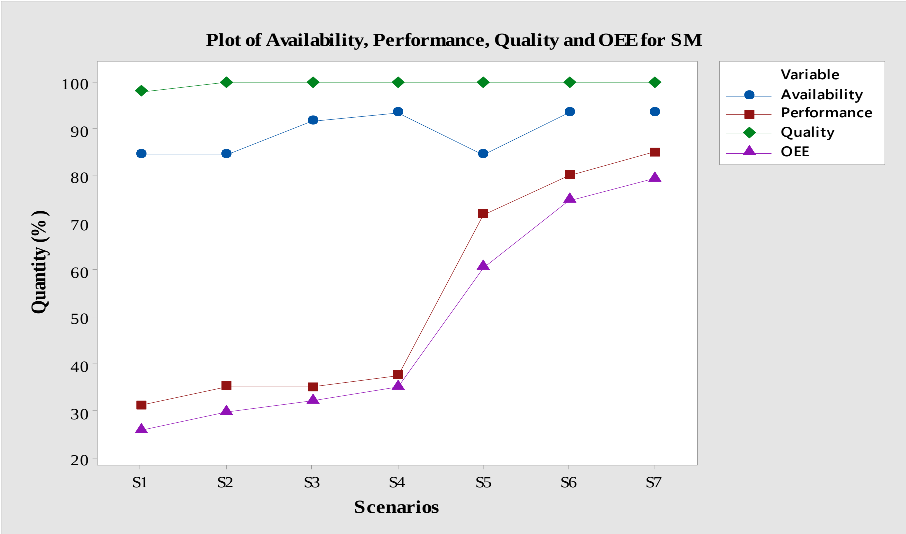


**Figure 8:**Performance Improvement Graphs for Speed Master

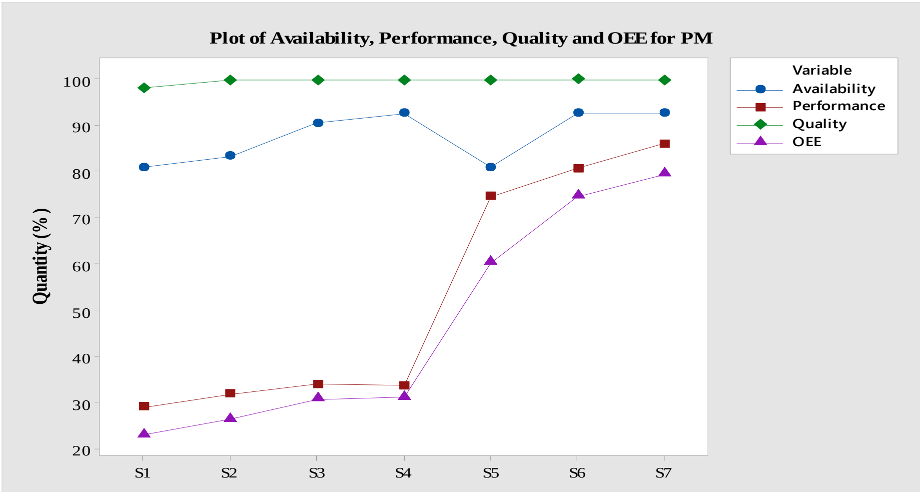


**Figure 9:** Performance improvement graphs for Print Master

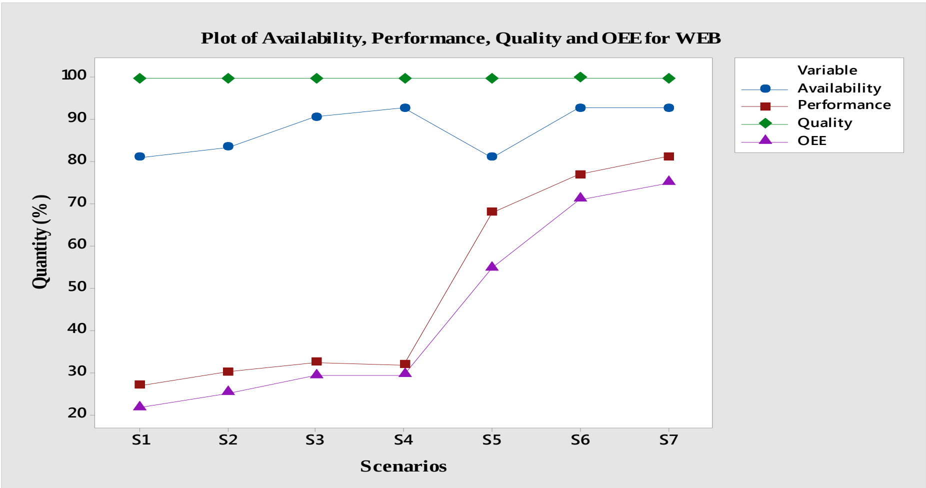


**Figure 10:** Speed Master Improvement Graph

The scenarios considered were as explained below. This information applies to **Figure 9, Figure 10 and Figure 10**. The graphs were put separately for each machine for clarity.

***Initial state (S1)***

This was the initial state depicting the current OEE for the printing machines. OEE was 23% at a print volume of 12 million for 100 working days 6½ hours effective working day. The average availability was 83%, performance was 29% while quality was 98%. For individual machines, Web: A=80%, P=26%, Q= 99% and OEE=21%, PM: A=80%, P=29%, Q= 98% and OEE=23% and SM: A=84%, P=31%, Q= 97% and OEE=25%

***Effects of reducing failures by half (S2)***

Parameters were changed to simulate a scenario of reducing failures to half of the current rate. The intention was to establish the overall effect of improving maintenance practices and how much it would affect productivity. The average Availabilitywas 85%, performance was 32% and quality was 99%. The result was an improvement of OEE from 23% to 26.5% and print volumes from 12 million to 13.8 million. This was still below the world average of 65 and world class of 80. This meant that improving maintenance alone to reduce the rate of failure would not yield much in terms of performance.Web: A=83%, P=30%, Q= 99% and OEE=25%, PM: A=83%, 319%, Q= 99% and OEE=26% and SM: A=84%, P=35%, Q= 99% and OEE=29%

***Effects of reducing the failure rate and Setup by half (S3)***

As in scenario 2, this was to determine the effect of setup time together with failure rate on productivity. Parameters were changed in the model and several runs iterated through to depict scenario 3. Average availability was 90%, performance was 33% and quality was 99%. It was observed that the OEE improved to 28.4% and print volumes went up to 15 million. The increase attributed to reducing setup time by half was only 1.2 million pieces. The implication was that the effect of setup time while the rest of the parameters remained constant would not contribute much change in the production. For individual machines, Web: A=90%, P=32%, Q= 99% and OEE=91%, PM: A=90%, P=33%, Q= 99% and OEE=30% and SM: A=91%, P=34%, Q= 99% and OEE=31%

***Effects of increasingplanned production time from 7 to 9 hours (S4)***

Increasing operating hours results in increased production. The purpose of this scenario was to establish how OEE and performance would be affected by the increase in working hours with reduced failures and improved setup time. The effect of the change was increased production to 20 million copies with availability of 92%, performance of 31, quality of 99% and an OEE of 31%. The OEE is still low although the increase has more than double the current output. This was attribute to the fact that there was increased the useful time from 390 minutes to 510 minutes (an additional 120 minutes) achieved by eliminating breaks and increasing operating time. Individual machines recorded as follows: Web: A=92%, P=31%, Q= 99% and OEE=29%, PM: A=92%, P=33%, Q= 99% and OEE=31% and SM: A=93%, P=37%, Q= 99% and OEE=35%.

***Effects of operating at 80% of ideal run speed with initial conditions(S5)***

This scenario considered increasing run speed to 80% of design speed of the machines but without affecting the initial operating parameters. S5 for the graphs shows increased performance and OEE but reduced availability compared to S1-S4. Print volume recorded was 25.8 million for an availability of 83%, performance of 53%, quality of 99% and an OEE at 44%. It was noted that the other hand, availability reduced from 94% to 83%. This is obvious due to time wasted on meal breaks and setup times. For individual machines, the values recorded were: Web: A=80%, P=67%, Q= 99% and OEE=54%, PM: A=80%, P=74%, Q= 99% and OEE=60% and SM: A=84%, P=71%, Q= 99% and OEE=60%

***Effects of increasing machine run speed to about 80 of ideal run speed (S6)***

From literature printing speed should be 80 of design speed for optimum output for a world-class OEE. The speed of the machines was increased to 80 of design speed for simulation purposes. This gave an output of over 42 million pieces which is a fair result for the expected optimised output and OEE of 56% when all the machines were considered in the calculations while OEE of 73% for 3 critical machines. average availability was recorded as 94%, performance was 60% and quality was 99%. Individual machines recorded as: Web: A=92%, P=76%, Q= 99% and OEE=70%, PM: A=92%, P=80%, Q= 99% and OEE=74% and SM: A=93%, P=79%, Q= 99% and OEE=74%.When improving the speeds, only 3 machines were considered. The two machines that were not considered as a result of their inability to sustain higher speeds during trials. There wasn't enough data from maintenance team to indicate the failures of machines to sustain higher speeds hence they were left out of the improvement plans.

Table 2 shows the percentage improvement in the OEE at optimum run speeds,

Table 3 shows the percentage improvement by volume printed at this optimised speed while Figure 11 shows the performance improvement graph that could be realized when the changes envisaged in the previous analysis were implemented.

***Effects of increasing machine run speed to about 80 of ideal run speed. (S7)***

Machines were run at 85% of design speed with conditions similar to S6, OEE was recorded as 58.8% for five machines and 77.8 for three machines. This trend implies that obtaining a world-class OEE of 85% would require an operating speed of above 90% of design speed if it can be sustainable with minimum failures. Individually, machines posted the following values: Web: A=92%, P=81%, Q= 99% and OEE=74%, PM: A=92%, P=85%, Q= 99% and OEE=79% and SM: A=93%, P=85%, Q= 99% and OEE=79%

The performance and OEE for the web were low since the changeover method considered was manual. With Auto-splicing, the changeover time could be eliminated improving performance for the web to 88% and its OEE to 81% that eventually improves the OEE for the threemachines to 80%

**Table 2:** Improved OEE for the Printing Machines (daily output)

| | OEE WITH SHORT BREAKS (ALL 5 PRINTING MACHINES) | | | | | OEE WITHOUT SHORT BREAKS (3 CRITICAL PRINTING MACHINES) | | |
|---|---|---|---|---|---|---|---|---|
| | ***WEB*** | ***PM*** | ***SM*** | ***MOZP*** | ***MOE*** | ***WEB*** | ***PM*** | ***SM*** |
| Shift Length (Minutes) | 540 | 540 | 540 | 540 | 540 | 540 | 540 | 540 |
| Short breaks (Minutes) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Meal Break (Minutes) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Downtime (Minutes) | 40 | 40 | 35 | 25 | 20 | 40 | 40 | 35 |
| Idea Run Rate | 500 | 250 | 200 | 150 | 150 | 500 | 250 | 200 |
| Total pieces (Count) | 192,254 | 100,871 | 80,793 | 24,641 | 24,644 | 192,254 | 100,871 | 80,793 |
| Rejected Pieces (Count) | 591 | 157 | 157 | 57 | 57 | 591 | 157 | 157 |
| planned production time (Minutes) | 540 | 540 | 540 | 540 | 540 | 540 | 540 | 540 |
| operating time (Minutes) | 500 | 500 | 505 | 515 | 520 | 500 | 500 | 505 |
| Good Pieces (Count) | 191,663 | 100,714 | 80,636 | 24,584 | 24,587 | 191,663 | 100,714 | 80,636 |
| Availability (%) | 92 | 92 | 93 | 95 | 96 | 92 | 92 | 93 |
| Performance (%) | 76 | 80 | 79 | 31 | 31 | 76 | 80 | 79 |
| Quality (%) | 99 | 99 | 99 | 99 | 99 | 99 | 99 | 99 |
| OEE (%) | 70 | 74 | 74 | 30 | 30 | 70 | 74 | 74 |
| **PLANT OEE (%)** | **56** | | | | | **73** | | |

Figure 11 shows the total print volumes for all the scenarios S1 to S7. S1=12 million, S2 =13.8 million,S3=15.2 million, S4=20.8 million, S5 = 25.8 million, S6=42.3 million and S7= 44.5 million. Volume, Performance and OEE slowed down beyond the 80% speed mark of speed increase whichpoints to the likelihood of higher inputs with less associated output.

Table 3shows the details of volumes printed for each individual machine over a one hundred day period including rejects, and the percentage utilization for each machine.

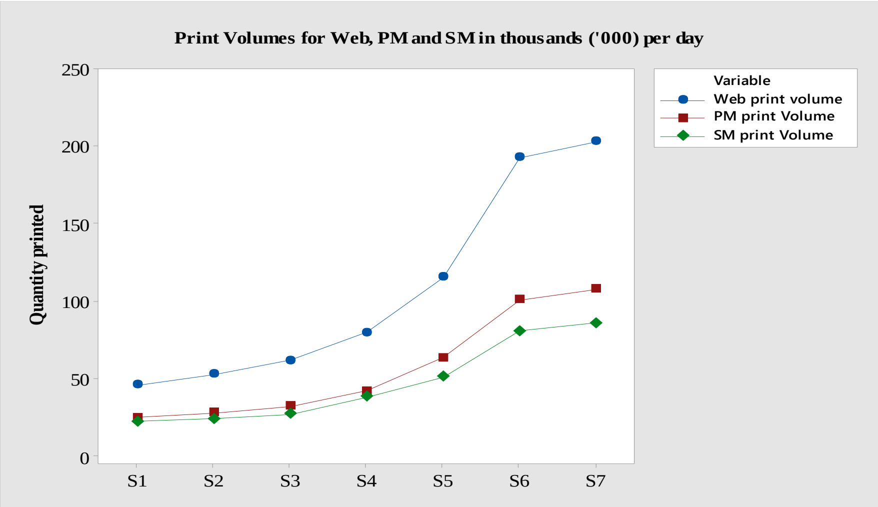


**Figure 11:** Percentage Performance Improvement and OEE Improvement

**Table 3:** Print Volumes at 80% of Ideal run speed (annual output)

| | | | | |
|---|---|---|---|---|
| | **5 REPLICATIONS** | | **TIME UNITS: 100 DAYS** | |
| **SPEED OF 80% OF DESIGN SPEED WITH REDUCED FAILURES TO HALF OF THE INITIAL** | | | | |
| ***Machine*** | ***Number of prints produced*** | | | |
| | ***Average*** | ***Minimum*** | ***Maximum*** | ***Utilization (%)*** |
| MOE Good pieces | 2,464,420 | 2,456,440 | 2,470,210 | 91% |
| MOE rejects | 4,920 | 4,690 | 5,080 | |
| MOZP Good pieces | 2,464,180 | 2,456,240 | 2,471,990 | 91% |
| MOZP rejects | 4,674 | 4,410 | 4,970 | |
| PM Good pieces | 20,180 | 19,880 | 20,570 | 93% |
| PM rejects | 10,087,178 | 10,061,690 | 10,097,780 | |
| SM Good pieces | 8,079,396 | 8,051,800 | 8,102,830 | 93% |
| SM waste | 16,286 | 15,620 | 16,700 | |
| Web Booklets | 19,225,488 | 19,200,980 | 19,266,650 | 89% |
| Web rejects | 65,448 | 64,510 | 66,190 | |
| **Total Booklets Printed** | **42,320,662** | **42,293,410** | **42,358,410** | |

These results from the sevenscenarios show that the combined effect of breakdowns, setup times and planned production time were not contributing significantly to the total print volume of the printing machines. The run speed of the machines combined with planned production time were however noted as the major contributors the production volume of the printing machines. But improving the maintenance practices, changing the timing schedule of the effective working day and eliminating meal breaks would ensure optimized production capacity and improved OEE.

## IV. Conclusion

This research investigated the gaps existing in the printing factory that contributed to poor production throughput. The data was collected and the metrics for each factor tested for its contribution. System simulation and improvement was done using ARENA students version. Finally, a trial run for validation was done using the threecritical machines.Improved output of 130,000 runs per day for the web and 70,000runs per day each for PM and SM were realized though below the simulated values. This was attributed to low-quality paper used for the trials.


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## Conflict of interest declaration

This research was funded under a scholarship from the African Development Bankthrough the Dedan Kimathi University of Technology. The research was carried out in the institutions' factory which provided the machines and equipment. A non-exposure agreement was signed in order to protect the contents and processes of the stated organization.


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