Productivity Improvement through Process Optimization: Case Study of a Plastic Manufacturing and Sales Company

Lodrina Masiyazi, Kudzanayi Chiteka, Mncedisi Trinity Dewa, and Donald Museka

***Abstract*—** This paper outlines the improvement of productivity through process optimization at a plastic manufacturing company. The research was a direct application of the concepts of plant layout, reliability centered maintenance and Computer Integrated Manufacturing (CIM) in which focus was given to production facilities and manufacturing support systems. Modeling and simulation, Pareto analysis, root cause analysis, Weibull analysis, time study, experimentation, interviews, and historical data were used as research and analysis instruments. The production facilities were optimized through the application of optimization tools. The manufacturing support system was optimized through the design of a computerized manufacturing support system that automated the various business functions which include batching, production planning, inventory management and maintenance planning and scheduling. The research revealed that there is an important link between the various manufacturing systems (organization of people and facilities) within a company and that these need to be integrated by a computerized manufacturing support system for efficient and effective operation. It was recommended that companies need to adopt CIM systems since they open a good platform for higher productivity within an organization through automation of manufacturing systems and computerization of business functions to reduce manual labor. However, whenever a company wishes to adopt such a system, it is a good idea if the system is specially developed and customized for that particular company only as this will make it easy to implement and monitor

***Keywords*—** Manufacturing System, Process optimization, Productivity improvement

I. Introduction

TRK Plastics Manufacturing is a small company which specializes in domestic plastic ware. They manufacture products which include buckets, plastic cups, plates, lunchboxes and plastic containers. Presently the company has a staff complement of 11 workers and they are into batch manufacturing.

For the past years they have lost their skilled and experienced workers due to economic hardships that were being experienced in Zimbabwe. The remaining operators are less experienced and their performance cannot be compared to those who left. Much of the required knowledge and information for the efficient and optimum utilization of machines, workers and raw materials is not known to the remaining workers and managers as some are new to the system. Such information includes labour standards, production rates and equipment maintenance. This has dramatically manifested in a steep decline in productivity with current productivity performance indicators valued as in Table I.

TABLE I
CURRENT PRODUCTIVITY

Productivity Measure	Current %
Labour productivity	48.70%
Raw material productivity	88.72%
Equipment productivity	44.40%
Total factor productivity	50.40%

At times the company often runs on a loss. Meanwhile the company also find is very difficult to remunerate their workers. On the other hand, however, demand levels are still escalating. Their customer base is wide based on the previously built reputation since they offer unique products which are unparalled. Sadly the company has been failing to meet the demand despite their capacity to produce products at a level that will meet and exceed demand.

II. Methodology

The research methodologies that were used were mainly inductive applied research. The author investigated all states of productivity and processes and procedures within the company. Then, general conclusions were derived from the findings. However in certain situations the deductive approach was used. Highly reliable methods that could deliver valid results were used. These include; Modeling and Simulation, Pareto analysis, Root Cause analysis, Statistical analysis, Time study, Experimentation, Interviews, and

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Historical data.

A. Time-study

Motion and time study were used to establish labor standards. They involved evaluation of a worker in performing a specific task. A stop watch was used. The stop watch used in the time study was accurate and could measure 0.01of a second. This was used to time the time it takes to complete a work element [1]. Also, some videos were taken whilst the operators were mounting moulds. These were later analyzed and the standard times were established from that [2].

B. Pareto analysis and root cause analysis

A Pareto analysis was carried out to come up with the most important productivity measures that were used in productivity improvement and plant optimization. The Pareto Chart was used to provide a visual representation of the variables which contribute to problems. It was then used as a prioritization tool to aid in focusing on the top issues which contribute to low productivity. It was determined that labour productivity, machine productivity and raw materials productivity were the top most productivity key performance indicators. These were later used as the basis for productivity improvement. Root cause analysis was used to identify all the possible causes associated with low productivity before narrowing down to the small number of main, root causes which needed to be addressed [3].

C. Control charts

Control charts were used to determine whether a process was within statistical control or not [4]. Control charts were applied to detect variations in the processing and warn if there is any departure from the specified tolerance limits. This would verify that all the values are reliable enough to give valid conclusions. The $\overline{X}$ and R chart was used for all control charts where $\overline{X}$ and R are sample mean and range respectively and x is an individual measured value.

D. Inventory Modeling

Inventory modeling was used in production optimization problems. The determination of the economic batch quantities (EBQ) was done using inventory modeling.

E. Weibull analysis of Breakdowns (Reliability)

The operation of the six machines in the workshop was examined over a total of 50 observations. The length of time each machine can survive up to was recorded. The aggregate of the number of weeks each machine can survive up to was prepared. This was done as prescribed by [5].

F. Simulation

Simulation in Flexsim was carried out. The numerical results from other quantitative research methods were used for simulation. The present production system of the company and the intended production system were simulated. The simulated results acted as a basis for evaluation of the new designs.

G. Qualitative Methods

Qualitative research offered insights and understandings of all stake holders, which was unobtainable by quantitative research, but it was more than just non-numerical research. It aimed at studying the subject in its natural surroundings and to collect naturally occurring, non-biased data. It described in words, rather than numbers, the qualities of the subject through observation.

III. COMPANY AUDIT

A. Productivity

Productivity values were found to be as follows; direct labour productivity 48.7%, raw materials productivity 88.72%, and machinery productivity 44.4%, as such total factor productivity was therefore found to be 50.4 %.

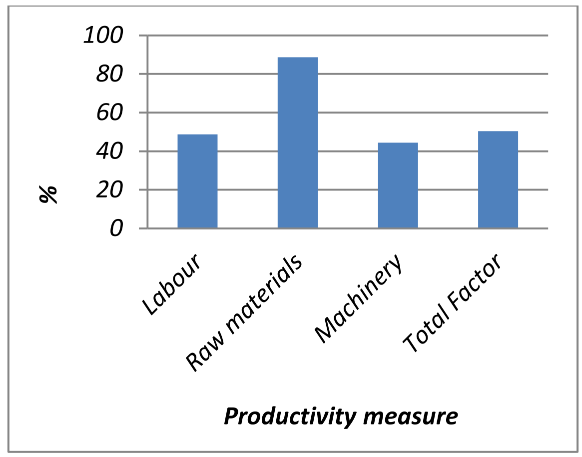


Fig. 1 Total factor productivity

B. The batching process

Currently there is no stipulated batching system that is being followed. The concept of Economic Batch Quantities (EBQ) has not been applied in the company. Products are being manufactured as they come regardless of the quantity.

C. Plant Layout

The current layout of machines does not facilitate high productivity. Whilst some machines are located close to each other, others are scattered either within the workshop or between different locations.

TABLE II
PRODUCTION LOSS PER MONTH DUE TO WORKER MOVEMENTS

Loss factor	Amount ($)/Month
Movements between locations	$11571.43
Movements within the workshop	$3332.32

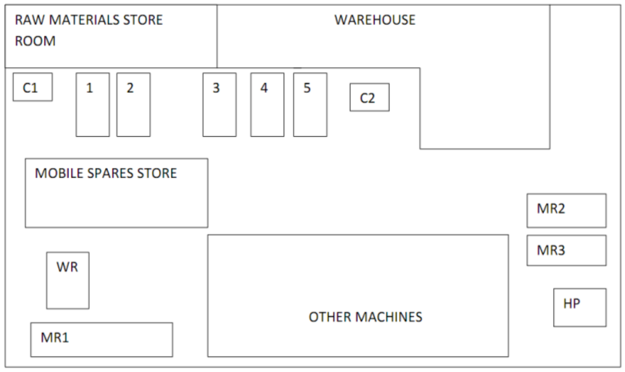


Fig. 2 Current plant layout

1,2,3,4 and 5 are injection machines, MR1, MR2 and MR3 are mould rakes, WR is a handle wire rake, C1 and C2 are chippers, HP is the handle press

D. The Manufacturing Process

The current manufacturing processes for the available products are somehow in a haphazard manner. Products like lunchboxes and buckets normally have their sub parts being manufactured on different days. This has an effect of high in process inventories. Buckets manufactured today may have their handles manufactured tomorrow or the day after yet they are required on the market. This is partly because some machines and facilities needed in the production of a certain product are located in one location and others in another location.

E. Mould arrangement

Moulds are not arranged in order. At times it takes only a minute to identify a mould whilst on the other hand it may take as much as 60 minutes to identify a mould especially when that particular mould has not been in use for a long time. It was established that on average it takes about 10 minutes to identify a mould. The company is then losing about $1550 per month in identifying the correct moulds to mount.

TABLE III
LOSS DUE TO MOULD ARRANGEMENT

Average time lost in identifying a mould	10 Min
No. of mould Changes per month	8 Times
No. of machines	6
Total time lost Per month	480 Min
Monetary Value per Month	$1,550

F. Maintenance

Currently there are no clearly laid down maintenance plan and procedures that can be followed to keep the plant in good working condition. The maintenance system that is currently being applied is the unplanned run-to-failure maintenance. There is a very significant time (MTTR) lost in trying to bring the machines to operating state when they fail. Nevertheless, massive breakdowns occur as a result of cumulative faults on the machines. The total time (in hours) taken to repair broken down machines was recorded in a total of 10 breakdowns that were experienced in a period of three months (from November 2010 to January 2011). The results were as shown in Fig. 3; Note that the time is in hours.

Task	*Time taken*										*average*
	breakdown No.										
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	
Primary diagnosis	2	2	1.5	0.5	1	3	2	1.5	2	1	**2**
Find technical personnel	4	4	2	5	7	2	3	8	5	8	**5**
Find the right technicians	0	0	0	24	96	0	12	0	0	0	**13**
Fault diagnosis	0.2	0.25	0.08	0.15	0.15	0.25	0.65	0.15	0.25	0.35	**0.25**
Find other technicians	0	0	0	98	0	0	0	0	0	0	**10**
Buy spares	2	4	5	1	2	1	2	3	4	1	**3**
Repair	0.15	0.25	0.35	0.4	0.5	0.2	0.45	0.15	3	2	**0.75**
Test run	0.01	0.03	0.05	0.06	0.25	0.05	0.08	0.05	0.05	0.25	**0.09**
Total	**8.4**	**10.5**	**9.0**	**129.1**	**106.9**	**6.5**	**20.2**	**12.9**	**14.3**	**12.6**	**33.0**

Fig. 3 Maintenance time lost

Much of the time is spend in non-value added activities. Out of the average 33 hours taken in trying to sort out a breakdown, only 1.09 hours have value added activities. Assuming that the machine operates 24 hours a day, the company loses an average of $12300 in non-value added maintenance activities each month and about $12750 in total downtime. The only justified cost is $450 which is the amount lost during the actual repair work. Much of the time is lost in trying to diagnose the fault type i.e. whether electrical or mechanical.

IV. RRELIABILITY

Experimentation has revealed that the reliability functions R (t) where t is time in weeks of the plant obtained from different methods are;

$$R(t) = e^{\left(\frac{-t^{(2.184)}}{44.84}\right)}, \text{and} \quad R(t) = e^{-\left(\frac{t}{11}\right)} \tag{1}$$

Where the former was obtained by Weibull analysis and the latter by reliability equation. The two functions revealed that if maintenance is done every month, the reliability is 65%. Also, the data that was collected and analyzed showed that there is a very strong positive correlation between breakdowns and time. The coefficient of correlation, r, was found to be (2);

$$r = 0.97 \tag{2}$$

This means that the number of breakdowns is directly proportional to the length of time the plant has been in operation.

A. OEE

The overall Equipment Effectiveness was found to be 45%.

V. SYSTEM DESIGN AND PROCESS OPTIMIZATION

Process optimization was attained through redesigning and optimizing production facility systems, and designing a computerized manufacturing support system. Plant layout, standard times, batching process, and maintenance strategies were the major candidates for optimization and design. The most common goals were minimizing cost and maximizing throughput.

A. Plant layout

The plant layout was optimised through minimizing the distances between dependent machines and facilities. This had an effect of facilitating an orderly flow of materials, and minimizing handling time.

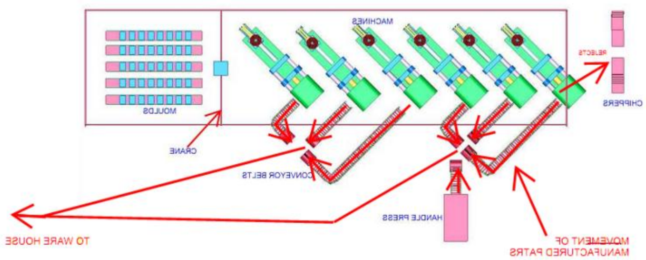


Fig. 4 Movement of materials in the new plant layout

Machines were arranged in a slanting manner. This enables easy coupling with conveyor belts. From the discharge of every machine, there is a conveyor that takes the component to an assembly station. The operator trims the part from the machine and places it on to the conveyor belt which carries the part to the assembly station where complementary parts from other machines are also taken to. Here the parts are assembled into a complete unit and palletized. After assembly and palletisation, the products are carried to the warehouse by a forklift. A crane was added to the machines in the workshop. The crane is used during mounting and dismounting of the moulds instead of a gantry. This makes it easier, faster and safer.

B. Moulds

Moulds will be numbered, named and arranged on the mould rakes in order. This allows for easy identification of any mould when needed. Also rake positions are numbered and named after the mould names. Each mould will have a specific position which does not change. When a mould is used, it should be returned to its position. The mould arrangement and identification is supported by a computerized manufacturing support system. All moulds are entered into the computer system. Their names and rake position number are recorded as well.

C. Reliability Centered Maintenance (RCM) Strategy

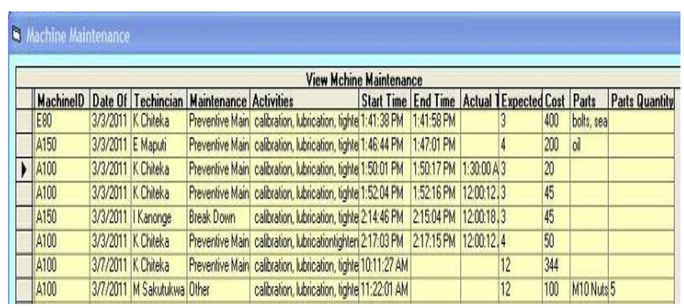
Maintenance management was considered to be one of the most important aspects of process optimization. It is common knowledge that a well maintained plant has high OEE which is made up of availability, performance and quality rate. The RCM strategy development was based on FMECA, (RPN) and RCM decision logic tree. Components with their lifespan very difficult to predict were to be replaced as and when they fail. Electric motors, Electric Contactors, Timers, Power Packs, Controllers, Sensors, etc. Critical parts that should fall under preventive maintenance were those with their lifespan strongly related to time of operation and hence they may be replaced before they actually fail. These included bearings, seals, nozzles etc. Condition based maintenance was also based on the fact that when the oil is dirty, the system produces a lot of noise and thus needs replacement.

D. Computerised maintenance Management system

The manufacturing support system designed has an embedded maintenance function. This serves a computerised maintenance management system. The reliability function determined from the Weibull analysis has shown that for the plant to be highly reliable, with a reliability of 65%, PM maintenance has to be done on a monthly basis. This increases the availability, performance and quality rate of the machines and hence the OEE of the machines will be improved. The calculated reliability function is shown in (3);

$$R(t) = e^{-t^{\left(\frac{2.184}{44.84}\right)}} \quad (3)$$

Whenever there is need to change the reliability of the plant either to a higher or lower value, the manufacturing support system will use the function given above to calculate the time period between successive preventive maintenance activities. All the maintenance activities done on a machine are recorded in to the support system. This will enable the analysis of the main problem areas and the solutions. Over time, recurring problems will be solved accordingly and design out maintenance can be even considered. The constantly used spare parts will be taken note of and they will have to be made available always.



Machine Maintenance

View Mchine Maintenance

MachineID	Date Of	Techincian	Maintenance	Activities	Start Time	End Time	Actual T	Expected	Cost	Parts	Parts Quantity
E80	3/3/2011	K Chiteka	Preventive Main	calibration, lubrication, tighte	1:41:38 PM	1:41:58 PM		3	400	bolts, sea	
A150	3/3/2011	E Maputi	Preventive Main	calibration, lubrication, tighte	1:46:44 PM	1:47:01 PM		4	200	oil	
A100	3/3/2011	K Chiteka	Preventive Main	calibration, lubrication, tighte	1:50:01 PM	1:50:17 PM	1:30:00 A	3	20		
A100	3/3/2011	K Chiteka	Preventive Main	calibration, lubrication, tighte	1:52:04 PM	1:52:16 PM	12:00:12	3	45		
A150	3/3/2011	I Kanonge	Break Down	calibration, lubrication, tighte	2:14:46 PM	2:15:04 PM	12:00:18	3	45		
A100	3/3/2011	K Chiteka	Preventive Main	calibration, lubricationtighten	2:17:03 PM	2:17:15 PM	12:00:12	4	50		
A100	3/7/2011	K Chiteka	Preventive Main	calibration, lubrication, tighte	10:11:27 AM			12	344		
A100	3/7/2011	M Sakutukwa	Other	calibration, lubrication, tighte	11:22:01 AM			12	100	M10 Nuts	5

Fig. 5 Viewing Maintenance Activities

E. Batch

When a new product is entered into the production system, it requests information relating to its EBQ. This EBQ will be used in the batching process. When an order is entered from the sales department, the batch function has to group the product into one of the existing products in the production system. It then adds on to the present quantity of units awaiting production. The production system will then have to compare each quantity of the products awaiting production to its EBQ. When the EBQ has been reached, the production system should advice the production manager about the new development. All this is done so that each time a mould is mounted; it must first manufacture a quantity equal to the EBQ before it can be dismounted so as to manufacture other

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batches.

TABLE IV
ECONOMIC BATCH QUANTITIES (EBQ)

Product	EBQ
Cup	23298
Mug	23523
Big plate	4406
Small plate	21162
7 litre bucket	12306
9litre bucket	4437
20 litre bucket	13333
Size 1 Lunchbox	4715
Size 2 Lunchbox	10173
Size 3 Lunchbox	9617
Size 4 Lunchbox	3935

The economic batch quantities in Table IV will be used during the manufacturing process. These values means that once a mould has been mounted on to a machine, it can only be dismounted when the quantities produced are equal to the economic batch quantities.

F. *Computerised manufacturing support system*

The computerized manufacturing support system, is a system that supports and consolidates the components that have been discussed above. It allows for data recording which creates a good platform for manufacturing system monitoring and evaluation so that corrective measures are taken when necessary. The main components of the system are production, maintenance and inventory management.

G. *Production*

The throughput variables were used here. Information such as cycle times, weight per unit ratio clamping force and temperatures is fed into the system. When a new shift is entered, the production manager selects an operator, machine, materials, shift length, and the product to be manufactured. The system in turn searches for the cycle time and the weight per unit ratio and use this information to calculate the total amount of raw materials needed and the number of units to be produced depending on the shift length.

The system also gives an analysis of the just ended shift and gives the productivity of the worker, raw materials and the machine. On the other side it should evaluate equipment performance i.e. the quality rate, performance, availability and OEE. The aggregate of these data will be given by the system periodically to evaluate the performance of the plant in general.

H. *Inventory*

The plant is so small that the company can afford to keep an inventory of all important spare parts and raw materials. These parts include O-rings, conductors, controllers and seals and also all different types of materials. These units can be kept in very low quantities and replacements done just before they are used up. Here comes the concept of JIT.

The inventory function is important in that it should give the amount of raw materials, spares and products in inventory before production or maintenance is done. The amount of raw materials is necessary to be known in that it can determine whether the manufacture of a certain product is viable considering the amount of the raw materials available. Here the information regarding the EBQ is used to determine whether the raw materials in stock can produce the quantity equal to the EBQ of a certain product. This is done by making use of the weight per unit ratio of any required particular product. If the materials present cannot produce a certain type of product, that product is automatically removed from the product selection combo box on the new shift form so that by any means you cannot manufacture that product if you obey the production system.

I. *Performance Measurement*

The performance measurement function should analyze all the operations within the production system and gives reports. This function gives information regarding productivity and OEE. Fig. 6 shows how the system measure performance.

Fig. 6 Performance measurement

The data that is collected after every shift is aggregated and displayed on a graph as shown. Worker productivity, say, will be seen from the graphs. The production manager can therefore quickly carry out a root cause analysis to determine the cause of the unsatisfactory performance with a particular operator. If the cause is because he does not understand the operation of the machine then, some further training is advised to the department responsible for worker development. Besides this, information will also be used for rewarding purposes so that the highly performing workers are rewarded of their effort. This will in turn boost productivity.

Likewise the information regarding the other performance factors should be displayed as shown above. The overall performance of the plant as a whole can be visualized. In this case it can be shown that our availability and quality are quite high whilst the total factor productivity is low. The manager can then find out which part of productivity performance indicators is unsatisfactory. Then, necessary

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measures will be taken to rectify the actual problem.

VI. Results, Recommendations and Conclusions

A. Plant layout

The plant layout that was developed minimized the distances travelled by the operators during their operations. The total distance travelled within the workshop was reduced from an average of 2880.25 m to an average of 564.6 m. This reduced the travelling and material handling cost from $3332.86 to $653.32 each month. Table V gives a summary of the results;

TABLE V
COST REDUCTION BY NEW PLANT LAYOUT

Loss Factor	Current ($)	Intended ($)	Cost Reduction	% Reduction
Movement between locations	11571.42	0.00	$ 11571.42	100%
Movement within the workshop	3332.86	653.32	$ 2679.54	80.3%
Total	14904.29	653.32	$ 14250.97	90.2%

B. Batching and standard times

Due to lack of proper batching procedures, the company was losing $6950 every month due to frequent mould changes. From the economic batch quantities and standard times established, it was found that mould changes will be made on an average of 1 mould change in seven days (using the EBQ values). The time taken in mould mounting and dismounting was found to be 40 minutes. The total cost of mould changing was reduced to $3100 each month. Table VI gives the summary of the results;

TABLE VI
COST REDUCTION BY NEW BATCHING RULES AND STANDARD TIMES

	Facts and Figures			
	Current	Intended	Reduction	Percentage Reduction
Time	90 Min	40 Min	50 Min	55.6%
Cost / Month	$6,950.00	$3,100.00	$3,850.00	55.6%

C. Maintenance

Maintenance was intended at increasing the overall equipment effectiveness (OEE) of the plant. Table VII summarizes the results;

TABLE VII
OEE

	Current	Expected	World Class	Percentage Change
Quality Rate	90%	99.6%	99.9%	9.6%
Performance	63.2%	98.96%	95%	35.96%
Availability	79.2%	97.2%	90%	18%
OEE	45%	95.8%	85%	50.8%

D. Productivity

Productivity used to be low because there were no labour standards or planned maintenance. It is therefore expected that the following improvements in productivity outlined in Table VIII will be attained.

TABLE VIII
PRODUCTIVITY IMPROVEMENT

	Current	Expected	World Class	%Change
Labour	48.70%	95.00%	69% - 72%	48.50%
Material	88.72%	97.50%		08.78%
Machinery	44.40%	97.25%		55.60%
Total factor	50.40%	92.21%		41.81%

E. Simulation results

Two simulation models were developed; one for the current production system and the other for the proposed production system. The simulation models integrated the distances travelled between machines break downs (MTTR), planned maintenance, setup times, economic batch quantities, standard times and the computerized manufacturing support system into a single model. The effects of each of these were used by the simulation model during the simulation process. The simulation model was run for a period equal to a year and the results were as shown in Table IX below;

TABLE IX
SIMULATION MODEL RESULTS FOR THE CURRENT PRODUCTION SYSTEM

Object	Class	Idle	Processing	Break down	travel empty	setup
Injection	Processor	25.25%	56.55%	4.72%	0.00%	13.48%
Operator 1	Operator	4.96%	0.00%	0.00%	0.54%	0.00%
Operator 2	Operator	23.21%	0.00%	0.00%	0.39%	0.00%
Operator 3	Operator	7.58%	0.00%	0.00%	2.84%	0.00%
Operator 4	Operator	12.98%	0.00%	0.00%	16.53%	0.00%

TABLE X
SIMULATION MODEL RESULTS FOR THE PROPOSED PRODUCTION SYSTEM

Object	Class	idle	Processing	Break down	travel	setup
Injection 1	Processor	0.01%	74.73%	1.00%	0.00%	0.23%
Injection 2	Processor	0.04%	99.23%	0.44%	0.00%	0.28%
Injection 3	Processor	0.01%	98.87%	0.82%	0.00%	0.31%
Operators	Operator	0.21%	0.00%	0.00%	0.21%	0.00%

TABLE XI (A)
COMPARISON OF CURRENT AND PROPOSED PRODUCTION SYSTEM SIMULATION RESULTS

Entity	Idle Current $	Idle proposed $	Break down Current $	Break down proposed $	Setup current $	Setup proposed $
Machine	416,835.46	102.98	81,506.44	16,908.04	130,472.09	3,812.43

TABLE XI (B)

Entity	Idle current	Idle proposed	Travel current	Travel proposed
Operator	$59,756.84	$3,559.59	$98,284.62	$3,502.62

VII. CONCLUSION

All the results got from analysis and simulation of the production systems are in favor of the proposed system. All the objectives were met. It was also shown that the combined effect of maintenance, batching, standard times and plant layout proposed have a positive bearing on the minimization of production costs and thus improves productivity.

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