Optimization of machine downtime in the plastic manufacturing

S.C. Nwanya, J.I. Udofia and O.O. Ajayi

cogent
engineering

PRODUCTION & MANUFACTURING | RESEARCH ARTICLE

Optimization of machine downtime in the plastic manufacturing

S.C. Nwanya[1]*, J.I. Udofia[1] and O.O. Ajayi[2]

*Corresponding author: S.C. Nwanya, Department of Mechanical Engineering, University of Nigeria, Nsukka, Nigeria
E-mails: snwanya@yahoo.com, stephen.nwanya@unn.edu.ng

Abstract: Reduction of downtime has a considerable effect in improving productivity and is a prerequisite for a profitable and flexible production. This study estimated the total production downtime for each production line per shift and developed an algorithm for an uptime maximization. A case study was conducted on one of the leading Nigerian plastic manufacturing firms experiencing a decline in its production efficiency. Robust interview sessions supplemented with well structured questionnaire were used for data gathering. The data on machine maintenance effectiveness and process pit-stop were evaluated followed by self-criticism of shortcomings of the results. Also, a factory layout of the company was obtained to highlight some issues involving material movement to the plant floor. A multiple regression analysis was also used to compare downtime and other variables such as cycle time, capacity, weight, overall equipment effectiveness (OEE). From the optimization model, uptime was maximised by 332 min per shift operation thereby reducing the downtime. This result showed remarkable increment in production rate for different categories of product, which increased by 140, 120, 120, 240 and 90 pieces, respectively, after optimization. The developed algorithm can be used to optimize production in any manufacturing concern and for reducing capacity losses.

ABOUT THE AUTHOR

S.C. Nwanya is a senior lecturer in the Department of Mechanical Engineering at the University of Nigeria, Nsukka. He is an industrial engineer, helping to advance the department's research and education mandate in industrial and management engineering.

His research interests include industrial production systems design; production inventory control; scheduling operations; industrial energy modelling and management technology. All these research endeavors aim at the development of methods and solutions for national engineering problems. He has attended many national and international seminars, conferences and workshops where he presented academic papers.

He has supervised successfully many postgraduate students and co-authored textbooks and journal articles of high repute. He has been involved in teamwork in professional, academic and community development groups. He has gained wealth of experience in academic, community service and administration. He is a registered engineer.

PUBLIC INTEREST STATEMENT

In a manufacturing system, the machine operates between two factors: technical and social. The first factor account for machine breakdown, also called downtime, due to obsolescence, design failure and wear out; while the later is responsible for machine breakdown as a result human error, boredom and inexperience. Downtime refers to a non operable condition, when the machine is not ready for an assigned work. It has adverse effect on production rate and business profit. In this study optimization was carried out by minimizing the effects of the factors. Minimizing of downtime is a value added activity that consequently enhances business profitability. This paper therefore described the procedure of optimization of machine downtime; how a mandatory planned maintenance technique- pit stop was used to affect productivity and achieve optimal uptime. Overall equipment effectiveness (OEE) of the company was also evaluated. The result showed a remarkable increment in production rate for five different categories of products, which increased by 140, 120, 120, 240 and 90 pieces, respectively, after optimization.

cogent--oa

cogent · engineering

Subjects: Industrial Engineering & Manufacturing; Plant Engineering & Maintenance; Reliability & Risk Analysis Maintenance; Manufacturing Engineering; Engineering Management; Production Engineering

1. Introduction

Downtime is an important subject in manufacturing because of its link to productivity and business profitability. Reducing downtime in production processes, including plastic manufacturing, therefore has become a necessity since it also serves the purpose of maximising machine uptime. This is because productivity rises as the use of productive equipment increases (Riggs, 1987). Machine downtime is one of the assignable causes of variation in a manufacturing system, resulting in poor production schedule reliability (Nwanya, Achebe, Ajayi, & Mgbemene, 2016) that should be minimized, if not completely eliminated. Machine downtime refers to off- the- time periods when machines are not productive or ready for assigned work. Although normally associated with manufacturing machines, the term can be used for any equipment usage.

Minimising equipment downtime in manufacturing operations provides other benefits such as maximised efficiency and higher hands-on machines. Reducing downtime increases machine availability which in turn increases throughput. Minimising downtime also reduces order lead times and increases customer satisfaction.

The causes of machine downtime are diverse and differ from one machine to another. These can include problems with the actual machines such as breakdowns or jams but also due to other factors such as machine operator being unavailable, no materials, planned or unplanned maintenance. Other causes include personal allowances, planning and scheduling of meetings. Accurate information is a key to effective downtime management. Inaccurate data or the lack of it is the main barrier to achieving a reliable downtime management system for plastic manufacturing firms. Reliable data is critical to accurate and actionable information on the extent of downtime and its causes.

The plastic industry is usually characterised by injection moulding, extrusion and blow moulding machines, each with its unique method of taking in raw plastic (sheet, pellets, and powders). In these machines, the methods of operation can be very complex; plastic moulds can be used on specific machines in ways which add a time constraint to the manufacturing process apart from that due to the operator. Therefore, a breakdown of the machine would greatly affect throughput because of the long time required to recognize the factors that accounts for the machine downtime fully.

The plastic industry needs to be aware that machine downtime, whether planned or unplanned, is very costly. Aside from the obvious costs of idle production, labour and spares value, the cost of downtime extends to other resources within the facility, as well as to the organisation as a whole (Fox, Brammel, & Valagadda, 2008). So there is need to minimise downtime which continuously requires good information followed by appropriate action.

In this context, the process can only function well if all people involved have the tools and conviction to communicate well and work together carefully. Hence the human factor plays a major role in the registration, analysis and improvement phases of downtime (Habtoor, 2015).

1.2. Problem statement

There are increasing reports of long lead time for chair production at Innoson due to downtime. It was observed that production efficiency is on the decline. In this context, downtime is a management problem and constitutes a major setback for production growth by reducing profit. The case study firm is auditing its processes to meet rising demand and ensure more customer satisfaction.

Part of the requirements to attain the set goals is taking control of some bottlenecks including downtime.

To overcome this challenge, techniques to quantify and evaluate downtime are essential. In the context of this study, it seems sensible to associate the need for downtime control with Deming's principle of management which states that if you do not measure it, you cannot manage it. Downtime is an example of a significant source of production loss that should be measured in order to identify and correct the problems that cause it. Hence, this study is motivated to quantify downtime in a plastic manufacturing process and develop a method of reducing it for increased production efficiency at Innoson. To highlight the nature of research which has been done on the aforementioned problem we will review that below.

2. Literature review

Various investigative studies have been conducted on downtime, particularly about its impact on production activity. Hechtman (2011b) has defined downtime as any event that stops planned production for a period. Al-Chalabi, Lundberg, Wijaya, and Ghodrati (2014) conducted downtime analysis of drilling machine to identify which components and what type of problems (maintainability problems and/or reliability problems) contribute to downtime, and to determine which strategies, designs for maintainability and/or designs for reliability should be applied to reduce it. Machine downtime, whether planned or unplanned is intuitively costly to manufacturing organisations and often tough to quantify (Fox et al., 2008). Major equipment change over time (e.g. retooling, cell reconfiguration) is included in scheduled downtime unless specifically excluded by agreement, for example in turnkey systems (The Association for Manufacturing Technology [AMT], 2011). Shagluf, Longstaff, and Fletcher (2014) were of the view that reducing downtime would result in higher potential production time or machine performance measured by overall equipment effectiveness (OEE). According to them, reducing downtime boosts capacity and could reveal hidden production costs. However, Iannone and Nenni (2015) maintains that in calculating OEE it is important to consider machines as operating in a linked and complex environment. Jeroen and Rooji (2006a) pointed out that to succeed in increasing uptime, it is of vital importance to approach downtime reduction as a continual process to which proven strategies can be applied to improve and streamline the process effectively and efficiently. Lam and Zhang (2004) integrated some replacement policies into corrective maintenance. Any maintenance policy- preventive, predictive or corrective, towards reducing downtime continuously requires good information followed by appropriate action. This involves constant review and audit of manufacturing process aimed at detecting malfunctioning machine. However, unambiguous analysis of the resulting data is the basis for decision-making for the machine to be corrected (Shagluf, Longstaff, Fletcher, Denton, & Myers, 2013).

Sivaselvam and Gajendran (2014) emphasised the importance of proper data collection system in machine performance studies. According to them, most developing countries lack the culture of keeping production data and that hinders serious effort to improve machine performance using time series data. Also, Dhillon and Liu (2006) presented the impact of human errors on maintenance. They conducted a literature survey of human errors in maintenance and their impact on the manufacturing plant. Based on their report, human errors impact negatively on and could reduce production profit. Alsyouf (2007) highlighted the role of maintenance as a profit-generating functionality, by introducing a quality maintenance concept in the manufacturing system.

Fitchett (2016) pointed out that one way of monitoring downtime of a machine is through the overall performance of a single piece of equipment, or even an entire factory, governed by the cumulative impact of three OEE factors: availability, performance rate and quality. For this reason Fujishima, Mori, Nishimura, and Ohno (2017) opined that the key to providing customers with machine tools which do not break down is to improve quality during the production processes by assuring prompt maintenance.

This prescription requires robust planned maintenance management practice. For that reason, Palmer (1999) defines maintenance management as a control that must be taken to keep the equipment in its working state, by preserving it from any failures. The suggestion by Palmer, therefore, prioritizes preventive maintenance over corrective maintenance. Lewis (1999) addressed corrective maintenance as reactive maintenance, in which any emergency breakdown can potentially lead to a bigger impact on the operation. On the economics of downtime reduction, Jeroen and Rooij (2006b) suggested the application of business process improvement strategy. For the case of optimization, few techniques have been applied for downtime reduction strategies. Fadeyi, Oguoma, and Ogbonnaya (2013) used a reliability model to address downtime in a sanitary towel manufacturing firm. They identified subsystems of the production system responsible for downtime and then applied reliability model to reduce downtime. Prombanpong, Kaewyu, Thanadulthaveedech, and Matwangsang (2013) worked on downtime in an automobile transfer line, using a range of buffer capacities, then calculated improved line efficiency.

From the reviewed literature, it is the consensus among the authors that downtime should be reduced to scale up machine availability and process efficiency. However, there is a knowledge gap based on information available to authors in respect of determining what process parameter to be improved to increase the plant's uptime and overall productivity, particularly for the case study plastic manufacturing. Given the present challenges faced by plastic manufacturers in the reduction of production downtime, there is a need for detail investigation and analysis of process efficiency parameter. This forms the rationale of this research work.

The purpose of carrying out this research is to minimise production downtime and scale up productivity in a plastic manufacturing factory. The specific objectives include estimating the total output downtime for each product process and developing an optimisation model for downtime evaluation in the plastic manufacturing factory. Reducing downtime results in additional available time for production.

3. Materials and methods

A case study is conducted on one of the leading plastic manufacturing industries in Nigeria. Different research methods have been applied for this purpose; including interviews, factory visits and literature review. A robust interview session supplemented with well structured questionnaire were used for data gathering.The researcher used primary data from the factory and secondary data from public documentation as sources of information for the study. The questionnaire was administered to the staff working in the factory while oral interview was also conducted on highly technical personnel, where information such as cycle time of each product, the weight of each product, the number of workers per shift, the frequency of maintenance practice, etc. were obtained and analysed. A survey question form to investigate maintenance effectiveness was designed for completion at pitstop or inspection and breakdown stages.

Also, factory layout of the company was considered to extract information on some of the issues involved in the material movement on the factory floor. Among these issues include; time and distance which are key factors of downtime measurement. Also, an optimisation algorithm was formulated considering these items as constraints while product types were used as decision variables for the objective function, in order to maximise machine uptime or potential availability.

Loading time, downtime and machine availability for each of the products were determined as expressed in Equations (1)–(3).

$$\text{Loading time} = \text{scheduled operating time} - \text{downtime} \tag{1}$$

$$\text{Machine availability} = \frac{\text{Actual production time}}{\text{Planned production time}} \tag{2}$$

$$\text{Downtime} = \text{Scheduled operating time} - (\text{Availability} \times \text{Operating time}) \tag{3}$$

Five different products by the company were used for the analysis; they are boss chair, view chair, honour chair, dine leg, and dine top. Also, the number of defects for each product was evaluated and analysed.

Quantity of plastic produced by the company was calculated as expressed in Equation (4).

$$\text{Quantity of plastic product} = \frac{3600}{\text{Cycle time}} \times \text{shift in hours} \tag{4}$$

Cycle time is the period required to complete one cycle of an operation or to fill out a function, job and it varies depending on the type of product produced as shown in Table 1 for plastic manufacturing.

The company operates in three 8 h shifts per day. "Pit Stops" (30 min of maintenance practice) affected the first shift of the day, thereby reducing the 8 h shift to 7.5 h. Thus, Overall Equipment Effectiveness (OEE) is calculated as expressed in Equation (5.0).

$$\text{OEE} = \text{Availability} \times \text{performance rate} \times textquality \times 100\% \tag{5.0}$$

OEE works by breaking down the reasons for productivity losses into three main factors, namely Availability, performance and Quality. The availability factor measures productivity losses resulting from downtime. Availability is determined by dividing actual production time by planned production as expressed in Equation (2). Also, performance and quality rates are expressed in Equations (6) and (7), respectively.

4. Results and discussion

At the firm, three major operations were carried out during plastic manufacturing namely: Mixing, Pouring and Injection moulding in which the outputs are: boss chair, view chair, honour chair, dine leg and dine top. Their weight, number of defects, quantity per shift per day, cycle time, etc. were also considered. Regular periods of inspection and repair of the injection moulding machine were performed every 24 h for 30 min and it normally affects the first shift of 8 h.

4.1. Boss chair (8 h)

Operating time for the first shift is 8 h × 60 min = 480 min

The following activities constitute planned downtime:

- Movement of raw materials from where it is stored to where mixing takes place = 10 min.
- Movement of mixed materials from mixing machine to the hopper = 10 min.
- Regular maintenance (pit-stop) = 30 min.
- Mixing of raw materials = 5 min.
- Pouring of mixed materials into the hopper = 3 min.
- Break time = 60 min.

Table 1. Cycle time (s) per type of plastic product	
Product	**Cycle (s)**
Boss chair	100
View chair	90
Honour chair	90
Dine leg	45
Dine top	120

![cogent·engineering]

Therefore the total planned downtime = 118 min and based on Equations (1)–(3), we have that:

Loading time = 362 min; availability = 0.75 and downtime = 120 min. Furthermore, the performance and quality rates can be calculated as expressed in Equations (5.1) and (5.2).

$$\text{Performance rate} = \frac{\text{Current production rate}}{\text{Ideal production rate}} = \frac{253\,\text{pieces}}{288\,\text{pieces}} = 0.88 \tag{5.1}$$

$$\text{Quality rate} = \frac{\text{Conforming parts produced}}{\text{Total parts produced}} = \frac{251\,\text{pieces}}{253\,\text{pieces}} = 0.99 \tag{5.2}$$

Therefore, the OEE through the procedure of Equation (5.0) is 65%. The computed OEE for Boss at varied shift hours is shown in Table 2. In a similar way, computations were carried out for the View Chair, Honour Chair, Dine Leg and Dine Top. In Table 2 column 2, availability accounts for downtime losses (Subramaniam, Husin, Yusop, & Hamidon, 2013). Since availability expressed in Equation (2) as ratio of actual production time less downtime to planned production time, it means that downtime is responsible in Table 2, for 0.25 unavaiability index in column 2 row 1 and same rule applys to the rest.

Now, considering the constitutive activities, the optimization model was developed using MATLAB as expressed in Equations (6.0)–(6.5).

$$\text{Maximize uptime } Z = 66x_1 + 67x_2 + 66x_3 + 66x_4 + 66x_5 \tag{6.0}$$

Subject to:

$$\text{Material Movement: } 30x_1 + 45x_2 + 90x_3 + 40x_4 + 90x_5 < 295 \tag{6.1}$$

$$\text{Mix raw plastic: } 30x_1 + 45x_2 + 90x_3 + 40x_4 + 90x_5 < 295 \tag{6.2}$$

$$\text{Pouring mixed Matl: } 30x_1 + 45x_2 + 90x_3 + 40x_4 + 90x_5 < 295 \tag{6.3}$$

$$\text{Regular maintenance: } 40x_1 + 80x_2 + 80x_3 + 80x_4 + 90x_5 < 370 \tag{6.4}$$

$$\text{Break time: } 30x_1 + 90x_2 + 90x_3 + 90x_4 + 90x_5 < 390 \tag{6.5}$$

where x_1, x_2, ... $x_{5\geq0}$, and are variables representing view, honour, dine leg and dine topy chairs, respectively.

Table 2. Compute OEE (%) for boss chair at different shift periods					
Shift (h)	**Availability**	**Downtime (min)**	**Performance**	**Quality rate**	**OEE (%)**
8	0.75	120	0.88	0.99	65
16	0.86	134	0.94	0.99	80
24	0.89	158	0.92	0.99	81
32	0.86	269	0.91	0.99	77
40	0.88	288	0.93	0.99	81
48	0.88	322	0.93	0.99	81
56	0.87	437	0.92	0.99	76
64	0.87	499	0.91	0.99	78
72	0.87	561	0.92	0.99	79

In Equation (6), the objective function seeks to maximize uptime thereby reducing downtime, the variable in the objective function is the uptime during the production of boss chair, view chair, Honour chair, dine leg and dine top respectively for three days.

Equations (6.1)–(6.5) are the constraints that seek to express the time taken to move the raw material, mixing of plastic raw materials, pouring of mixed material and conduct regular maintenance activities which constitute downtime.

Also, multiple regression analysis in Statistical Package for Social Sciences (SPSS) was used to predict downtime from uptime, weight, cycle time and capacity for 8, 16, 24, 32, 40, 48, 56, 64, and 72 h, analyses were made, and graphs plotted accordingly. The element of multiple regressions is expressed in Equation (7).

$$Y = a + b_1 c_1 + b_1 c_1 + b_2 c_2 + b_3 c_3 \qquad (7)$$

where Y = dependent variable (downtime), a = constant, b_i = beta coefficients or slope of c_i, c_i = independent variables that explain variance in Y.

In addition to these variables, one crucial area that every plant can improve on is efficiency and one of the best measures of efficiency is OEE (Hechtman, 2011a). The key to this argument is that organisational efficiency has relevance for business sustainability.

Figure 1 shows the variations in OEE and cycle time when plotted against downtime for 8 h pit-stop of the products. OEE gradually declines as downtime increases. The highest increment in the cycle time occurred for the Dine's leg at 120.

It was observed that when pit-stop was extended to weekly, there was an increment in production time. Table 3 shows the difference between Pit-Stop for every 24 h in a week and pit-stop for 168 h (weekly) and their differences.

Figure 1. Illustration of the products pit stops for the first shift of 8 h.
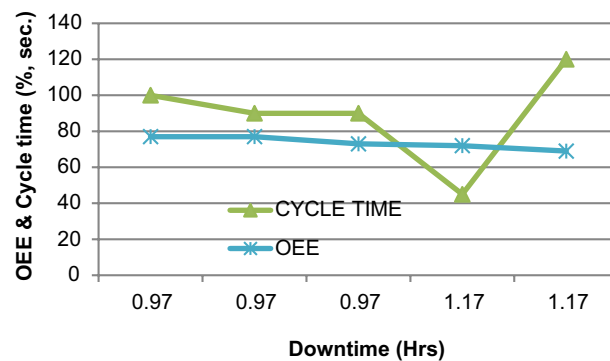

Table 3. Increment in production time due to weekly pit-stop				
Product	**Pit-stop every 24 h**	**Production rate 24 h**	**Pit-stop weekly**	**Production rate weekly**	**Differences**
Boss chair	5,908	251	6,030	391	140
View chair	6,580	281	6,700	401	120
Honour chair	6,580	281	6,700	401	120
Dine leg	13,160	546	13,400	786	240
Dine top	4,935	205	5,025	290	90

4.2. Discussion

To determine the influence of downtime on performance, mean of OEE for a sample size of nine elemental values is computed. This is repeated for the five workstations being represented by five products: the boss chair, view chair, honour chair, dine leg, and dine top products. Within these workstations, the mean OEE range between 60 and 81%. Comparatively, the ideal value for plant OEE is 100% which means all machines have zero downtime, full availability and are not making any non conforming parts. Studies show that average OEE in the manufacturing industry is about 60% whereas world class OEE is 85% (Anand, 2010). These statistics if related to the case study, it means that it operates with OEE below top class level in all the workstations with low availability and high cycle time as shown in Table 2.

It is clearly seen from OEE values in Table 2 the need to maintain close link between availability or highly reduced downtime and cycle time with OEE. The importance of OEE level can be further decomposed into income and quality effects for the firm's product mix. The variety of products offered by a firm is called the product mix. Since most, if not all, of the firm's revenue is going to be obtained from the sale of its products, it is important that the variety and quality of the product mix be frequently evaluated and amended. The implication is that cycle time is a critical parameter for improvement to increase the plant's uptime and overall productivity. Quality consideration is also important because customers generally want to acquire the benefits of the product, rather than its features. This expectation is possible at high plant availability or continuity of service and operational efficiency. From Table 2, if a product is high in both availability and quality, it can also be high in OEE.

As part of the plan to maintain high-level OEE and reduce downtime, the firm should operate at optimal efficiency as an important quantitative criterion of business sustainability. Continuous improvement of the metrics: availability, performance and quality are needed for optimal efficiency. Therefore, the interpretation of low OEE is that it represents low efficiency. Appropriate process management is also important in improving OEE. In plastic manufacturing, failure to manage the process successfully restricts flexibility in the use of raw materials and hence contributes to rising costs. This is because it has three kinds of separate variables yet inter-related namely raw material, process and product quality variables. The first variable affects the second which in turn affects product qualities, all must be well managed in order to realize high efficiency.

Analysis of the contributions of planned downtime elements, such as pit stop, is important in addressing cause-effect relationship as part of measures to increase efficiency. Pit stop contributes 25.64% of planned downtime duration. It has more diminishing impact on productivity when observed 24 h, than once on weekly basis. For the above reason, reductions in frequency of pit stops have large positive effects on productivity as Table 3 has shown.

To further examine the effects of process parameters on product mix, linear programming and multiple regressions results are provided. The linear programming (LP) tool used is MATLAB. The algorithm is formulated and solved for five independent variables, x_1–x_5, which represent the level of production of the boss chair, view chair, honour chair, dine leg, and dine top products, at the workstations respectively. Solution of the LP when it converged gave the following values in terms of $x_1 = 1.0$, $x_2 = 2.0$, $x_3 = 1.1418$, $x_4 = 0.7412$, $x_5 = 0.1170$. After running the optimisation in MATLAB, the uptime was maximised to 332 min per shift.

Table 4 shows results of the multiple regressions used to relate downtime with uptime, weight, cycle time and quantity/shift for a pit stop of 16 h. Table 4 indicates that uptime has an unstandardised coefficient (*B*) of −0.290 at a probability value of 0.015. This indicates that uptime is not significant. The data reveals that for every rise of 1hr in uptime, the downtime decreases by 0.290 h.

Furthermore, the data also shows that weight has a coefficient of 0.840 at a probability value of 0.049. Hence, it is significant. This indicates that downtime increases by 0.840 h when the weight

cogent ·· engineering

Table 4. Multiple regression results for 16 h					
Subhead		**Unstandardized coefficients**		**Standardized coefficients**	**Significance**
		B	Std. error	*β*	
1	Uptime	−0.290	0.007	−3.635	0.015
	Weight	0.840	0.065	2.317	0.049
	Cycle time	0.001	0.002	0.103	0.674
	Quantity/shift	0.004	0.000	2.578	0.019

Note: $R^2 = 1$ ($p < 0.05$).

increases by 1 kg when all other independent variables are held constant. It can then be inferred that weight has an effect on downtime.

The data further revealed that cycle time has a coefficient of 0.001 at a probability value of 0.674. Hence, it is significant. This indicates that, for each unit increase in cycle time, there is a corresponding increase of 0.002 h in downtime when all other independent variables are held constant.

The data further reveals that quantity/shift has a coefficient of 0.004, and it is significant at a probability value of 0.019. This indicates that downtime increases by 0.004 h when the amount/shift increases by 1 kg when all other independent variables are held constant.

Coefficient of determination (R^2) = 1. This indicates that all variations in the dependent variable are as a result of the independent variables. That is, 100% variation in downtime is as a result of changes in uptime, weight, quantity/shift and cycle time.

5. Conclusion

The optimization of production downtime in a plastic manufacturing firm was carried out in this study. In the course of this research, different methods were adopted: a case study was conducted on Innoson, set of structured questionnaires was presented to the staff working in the plant and oral interviews were conducted. The choice of a plastic firm is motivated by inseparable nature of raw material, process and product qualities variables which influence productivity improvements in plastic manufacturing. The data collected from the respondents were analysed, optimisation model was solved using MATLAB in which the uptime was maximised. Multiple regression analysis using statistical package for social sciences (SPSS) was also used to analyse how downtime affect cycle time, weight, production capacity. Overall equipment effectiveness (OEE) of the company was also evaluated. The study observed a trend in OEE with changes in pit-stop or inspection time and it reveals that cycle time is a critical parameter for improvement in the plant's uptime and overall productivity. For example, Table 2 also indicates how downtime increases as the number of shift hours increase with the calculation of OEE. The study has shown that it is possible to evaluate downtime and once downtime is known it can be reduced.

In conclusion, the research work contributes to body of knowledge that pit stop contributes 25.64% of planned downtime duration. Pit stop has more diminishing impact on productivity when its frequency is high, say 24 h, than once on weekly basis. This is proved in Table 3 where there is a significant difference in numbers of chairs produced at existing 24 h pit-stop and when pit-stop is once a week. The differences in Table 3 represent accurable extra revenue to the organization if the above proposed weekly pit stop scheme is implemented. Hence, this study reveals that higher frequency of downtime can cause a significant reduction in productivity compared with a single event of downtime. From the optimization model, uptime was maximised by 332 min per shift operation thereby reducing downtime. In the light of these findings, the study recommends a routine downtime audit of the production process to manufacturing firms as a continuous improvement strategy. In a nutshell, the results have been able to reveal the extent reduced machine downtime can affect

productivity performance. As a part of the measures to leverage on the pit stop, a recommendation of weekly, rather than 24 h planned down time is proposed. However, three pillars, namely avaialability, performance and quality, pindown using OEE to reduce machine downtime and unless adequate control is maintained over them, avoidable increment in downtime would still occur. Hence, the study suggests path of continuous improvement of a production process is the right path for achievement of manufacturing sustainability while reducing downtime and increasing profitability.

Author details
S.C. Nwanya[1]
E-mails: snwanya@yahoo.com, stephen.nwanya@unn.edu.ng
J.I. Udofia[1]
E-mail: joyfuludofia@yahoo.com
O.O. Ajayi[2]
E-mail: oluseyi.ajayi@covenantuniversity.edu.ng
[1] Department of Mechanical Engineering, University of Nigeria, Nsukka, Nigeria.
[2] Department of Mechanical Engineering, Covenant University, Ota, Nigeria.

Citation information
Cite this article as: Optimization of machine downtime in the plastic manufacturing, S.C. Nwanya, J.I. Udofia & O.O. Ajayi, *Cogent Engineering* (2017), 4: 1335444.

Cover image
Source: Authors.

References
Al-Chalabi, H. S., Lundberg, J., Wijaya, A., & Ghodrati, B. (2014). Downtime analysis of drilling machines and suggestions for improvements. *Journal of Quality in Maintenance Engineering, 20*, 306–332. doi:10.1108/JQME-11-2012-0038.

Alsyouf, I. (2007). The role of maintenance in improving companies' productivity and profitability. *International Journal of Production Economics, 105*, 70–78. https://doi.org/10.1016/j.ijpe.2004.06.057

Anand, R. (2010). *Monitor and optimize machine efficiency with OEE dashboards* (SAE Technical Paper 2010-01-0398). doi:10.4271/2010-01-0398. Retrieved November 2, 2017, from www.papers.sae.org/2010-01-0398

AMT. (2011). *Production equipment availability: A measurement guideline* (4th ed., pp. 1–33). McLean, VA: Author.

Dhillon, B. S., & Liu, Y. (2006). Human error in maintenance: A review. *Journal of Quality in Maintenance Engineering, 12*, 21–36. https://doi.org/10.1108/13552510610654510

Fadeyi, J. A., Oguoma, O. N., & Ogbonnaya, E. A. (2013). Sanitary towel production plant optimization using reliability model. *Nigerian Journal of Technology, 32*, 101–108.

Fitchett, D. (2016). *What is the true downtime cost?* Downtime Central Business Industrial Network. Retrieved May 20, 2016, from www.downtimecentral.com/V2/what_is_tdc_shtml

Fox, J. P., Brammel, J. R., & Valagadda, P. K. D. V. (2008). Determination of the financial impact of machine downtime on the post large letters sorting process. *Journal of Achievement in Materials and Manufacturing Engineering, 31*, 732–738.

Fujishima, M., Mori, M., Nishimura, K., & Ohno, K. (2017). Study on quality improvement of machine tools. *Procedia CIRP, 59*, 156–159. https://doi.org/10.1016/j.procir.2016.09.029

Habtoor, N. (2015). The relationship between human factors and organizational performance in Yemeni industrial companies. *European Scientific Journal, 2*, 17–29.

Hechtman, T. (2011a, February 8). *Making OEE implementations a success*. Folsom, CA: Inductive Automation. 800.266.7798. Retrieved May 20, 2016, from www.inductiveautomation.com

Hechtman, T. (2011b, October 26). *How to reduce downtime and raise overall equipment efficiency*. Folsom, CA: Inductive Automation. 800.266.7798. Retrieved May 20, 2016, from www.inductiveautomation.com

Iannone, R., & Nenni, M. E. (2015). Operations management : Managing OEE to optimize factory performance. *In Tech publishers, Chapter 2*. Retrieved April 30, 2017, from http://dx.doi.org/10.5772/55322

Jeroen, K., & Rooij, M. (2006a). *Downtime reduction, A profitable road to SUCCESS: Part 2–The downtime reduction philosophy and how to gain the necessary data*. Retrieved from http://www.s-s-systems.nl/fileadmin/introduction/downloads/Articles/Downtime.

Jeroen, K., & Rooij, M. (2006b). *Downtime reduction: A profitable road to success*. Retrieved from http://www.pulpandpapercanada.com/innovation

Lam, Y., & Zhang, Y. (2004). A shock model for the maintenance problem of a repairable system. *Computers and Operations Research, 31*, 1807–1820. https://doi.org/10.1016/S0305-0548(03)00121-7

Lewis, B. T. (1999). *Facility manager's operation and maintenance handbook*. McGraw-Hill, NY: R. R. Donelley and Sons Company.

Nwanya, S. C., Achebe, C. N., Ajayi, O. O., & Mgbemene, C. N. (2016). Process variability analysis in make-to-order production systems. *Cogent Engineering, 3*, 1269382. doi:10.1080/23311916.2016.1269382.

Palmer, R. D. (1999). *Maintenance planning and scheduling handbook*. McGraw-Hill, NY: R. R. Donelley and Sons Company.

Prombanpong, S., Kaewyu, J., Thanadulthaveedech, N., & Matwangsang, M. (2013). A buffer design for mitigation downtime effect in an automated transfer line. *International Journal of Innovation, Management and Technology, 4*, 155.

Riggs, J. L. (1987). *Production systems: Planning, analysis, and control* (4th ed.). Hoboken, NJ: John Wiley & Sons.

Shagluf, A., Longstaff, A. P., & Fletcher, S. (2014). *Maintenance strategies to reduce downtime due to machine positional errors*. Coimbra: FCTUC. ISBN 978-972-8954-42-0. Retrieved May 5, 2016, from http://dx.doi.org/10.14195/978-972-8954-42-0_25 https://doi.org/10.14195/978-972-8954-42-0

Shagluf, A., Longstaff, A. P., Fletcher, S., Denton, P., & Myers, A. (2013). *Predictive calibration-based tolerance boundaries for arresting deterioration of machine tool accuracy*. Presented at the manufacturing the future conference 2013, manufacturing at Cranfield University.

cogent ·· engineering

Sivaselvam, E., & Gajendran, S. (2014). Improvement of overall equipment effectiveness in a plastic injection moulding industry. *IOSR Journal of Mechanical and Civil Engineering, 5/53*, 12–16.

Subramaniam, S. K., Husin, S. H., Yusop, Y., & Hamidon, A. H. (2013). *Machine efficiency and manpower utilization on production lines*. Proceedings of the 8th WSEAS international conference on electronics, hardware, wireless and optical communications (pp. 70–75). ISBN 978-960-474-053-6.

Cogent Engineering (ISSN: 2331-1916) is published by Cogent OA, part of Taylor & Francis Group.

Publishing with Cogent OA ensures:

- Immediate, universal access to your article on publication
- High visibility and discoverability via the Cogent OA website as well as Taylor & Francis Online
- Download and citation statistics for your article
- Rapid online publication
- Input from, and dialog with, expert editors and editorial boards
- Retention of full copyright of your article
- Guaranteed legacy preservation of your article
- Discounts and waivers for authors in developing regions

Submit your manuscript to a Cogent OA journal at www.CogentOA.com