



PROCESS CAPACITY IMPROVEMENT BY EQUIPMENT AND OPERATIONS CONTROL RATIOS IN DE-HUSKING LINES OF SMALL-SCALE RICE PROCESSING FACTORIES

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ARTICLE HISTORY:

Received: 20 November, 2023.

Revised: 04 May, 2024.

Accepted: 07 May, 2024.

Published: 12 June, 2024.

KEYWORDS:

Rice processing, Control ratios, Process capacity, Operations effectiveness, Equipment availability, Process improvement.

ARTICLE INCLUDES:

Peer review

DATA AVAILABILITY:

On request from author(s)

EDITORS:

Chidozie Charles Nnaji

FUNDING:

None

Abstract

Inadequate knowledge of equipment and operations control ratios which contribute largely to low process capacity in the de-husking lines of small-scale rice processing factories is one of the critical challenges to improving rice processing in Sub-Saharan African countries, particularly Nigeria where capacity deficit leads to rice importation. This study seeks to empirically investigate equipment and operations control ratios in de-husking lines of small-scale factories in order to explore their potential and improve process capacity. The objectives are to determine the equipment and operations effectiveness, identify the root causes of inefficiency, and prioritize improvement efforts in the de-husking lines. The study was carried out in 10 selected factories of a milling cluster where production data for 2017-2022 was collected to complement data obtained through direct observation during processing hours and structured interviews. Microsoft Excel and Scilab software were used for data analysis based on existing models and other mathematical models developed for this study. Fluctuations observed in the process capacities of the de-husking lines from 2017-2022 indicated variabilities in equipment availability and performance. The overall equipment effectiveness (OEE) was generally below 50% which indicates production losses caused by frequent downtime and reduced speed of the machines. The overall operations effectiveness (OOE) were below 40%, and that implies the de-husking lines do not respond well to unscheduled downtime or unexpected tasks to reduce downtime for process capacity improvement. Tracing other potential to be unlocked to improve process capacity with the existing machines in the de-husking lines; the total effective equipment performance (TEEP) values were found below 25%, leaving 75% potential to be unlocked. Reliability modelling before machine installation, preventive maintenance, extended work scheduling, continuous training of workforce to reduce delays in equipment repairs are some of the measures to increase machine availability and improve process capacity in de-husking lines of small-scale rice processing factories.

1.0 INTRODUCTION

Rice processing is one of the leading industries in the world for food security and sustainability but had struggled over the years to be one of the significant industries for economic growth in Nigeria. Rice is processed in Nigeria for family consumption and commercial purposes by rice processing factories and clusters of varying capacities located around the rice producing states, towns and communities [1], but they are yet to process enough quantities to meet up domestic demands. Capacity deficit is evidently shown by comparing the yearly production and consumption quantities. Rice Industry review report by KPMG[2] presented average annual production,

HOW TO CITE:

Achebe, C. N., Nwanya, S. C., and Enibe, S. O. "Process Capacity Improvement by Equipment and Operations Control Ratios in De-Husking Lines of Small-Scale Rice Processing Factories", *Nigerian Journal of Technology*, 2024; 43(2), pp. 253 – 260; <https://doi.org/10.4314/njt.v43i2.8>

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consumption, self-sufficiency and deficiency at 3,985 million metric tons (MMT), 7,121MMT, 56% and 46% respectively. Quality-wise, poor processing contributes indirectly to capacity deficit because consumers reject rice characterized by high percentage of impurities like husk and stones as well as under size/broken grains. Quality reduces the market values [3,4].

Various attempts over the years to improve capacity and quality of rice processed in Nigeria have not yielded the desired results. Among the attempts, the government and stakeholders envisioned that rice importation can be overcome through policy regulations and building of integrated rice mills. According to National Rice Development Strategy II, 2020-2030 report of Nigeria Federal Ministry of Agriculture and Rural Development [5], by the end of 2019, there were over 70 fully integrated rice mills (IRM) in Nigeria at different stages of installation and operation, with a minimum of 10,000MT per annum, but after installations, none was producing at up to 70% of the installed capacity. Capital intensiveness, very high maintenance cost and inadequacy of quality paddy are the identified challenges of integrated rice mills. These challenges have contributed to underutilization of the capacities of the IRMs, and so they operate several months per year with fractions of their milling capacities, leaving Nigeria rice industry to be dominated by small-scale rice processing factories with challenges of low capacity and quality. Rice processing rate in Nigeria is 65% for integrated rice mills [IRM], and 55-60% for small-scale mills which represent 60-70% of Nigeria's total milling capacity [6]. These statistics call for further research approaches and attention on improving the process capacity of small-scale rice processing factories characterised by de-husking machines with process rate of 0.5tonnes per hour of milled rice or 1.3tonnes per hour of input paddy.

Review of extant literature revealed previous significant research efforts on improving the value chain activities in rice processing. Saniso et al. [7] proposed a new method of producing parboiled rice with no requirement of steam and fewer processing steps, and that is by first soaking the paddy in hot air and then using microwave-assisted hot air fluidized bed dryer (MWFB) for drying. A Safer and more efficient rice parboiling (improved boiler) designed by Chakrovorty et al. [8] for local rice parboiling factory in Bangladesh was able to save appreciable amount of energy and water. Also, parboiling energy, improvement and its requirements were extensively discussed by some authors [9-11]. Sun drying is the

predominant method of drying for small-scale rice processing in developing and low income countries. Investigating the best practice for paddy drying in Vietnam, Cambodia, Philippines, and Myanmar, Nguyen et al. [12] discovered that reversible airflow flatbed dryer could be the best option in terms of cost-benefit, labour operation, and energy efficiency. In a related research, Mondal et al. [13] developed energy efficient mixed flow dryer for small-scale batch drying. Selection of best dryer for parboiled paddy was studied by Taghinezhad et al. [14] through mathematical modelling using various methods and they found that best drying conditions is related to the lowest dryer specific energy consumption.

Other drying options had been proposed in research findings to overcome the challenges of sun-drying and extreme weather [15-17]. Research efforts had led to the replacement of steel roller husker and Teflon rollers with rubber roller husker in de-husking machines[18,19]. De-husking efficiency using rubber rolls is about 85% -90%, while steel rolls offer efficiency of about 53%-55%[20,21]. Some technology improvement on capacity and efficiency had been made on locally made destoners by researchers[22,23]. Low stone removal efficiency and low air flow channel which affects the aerodynamic lifting of the rice grains of the existing destoners were also addressed.

The existence of any published work on the use of operations management functions in addressing capacity and quality deficits of Nigeria rice industry is not known to the authors.

Operations management functions in small-scale rice processing factories should ensure equipment and operations effectiveness at all times for continuous capacity improvement. Wolniak [24] distinguished seven functions of operations management to include planning, scheduling, controlling, quality control, and inventory control and emphasised that in each of these functions, operations managers should take many decisions affecting organisational effectiveness [25]. Contemporary research in management by Jagadeesh [26] noted that capacity planning is one of the major decisions in operations management and is considered critical to the success of business operations. By proper capacity planning, it is possible to decide the strategies related to capacity expansion and creating capacity cushion to absorb fluctuations [27].

This study seeks to empirically investigate equipment and operations control ratios in the de-husking lines of the small-scale factories in order to explore their



potential and improve process capacity. Equipment and operations control ratios are shop floor parameters such as machine availability, performance and product quality that are used in obtaining equipment and operations effectiveness. The objectives of this study are to determine the equipment and operations effectiveness in order to identify the root causes of inefficiency and prioritize improvement efforts in small scale rice processing factories. Detailed specific study was undertaken on selected 10 small-scale rice processing factories confidentially identified as F1-F10 from Omor Milling clusters in Anambra State, Nigeria.

2.0 METHODOLOGY

Data for process rate, process capacity, equipment availability, performance and product quality was needed for this study. Therefore, mixed method approach which involves quantitative and qualitative method approaches of data collection was used to obtain numerical and non-numerical data. The study was carried out in 10 selected factories of Omor milling cluster where production data for 2017-2022 was collected to complement data obtained through direct observation during processing hours and structured interview. Following mathematical models developed for this study and existing equations, Microsoft Excel and Scilab were used for data analysis to obtain performance metrics of the de-husking lines: process capacity, equipment and operations control ratios, overall equipment effectiveness (OEE), overall operations effectiveness (OOE) and total effective equipment performance (TEEP). From these metrics, challenges critical to improving process capacity and potential of the de-husking lines were identified and recommendations offered for improvement.

2.1 Mathematical Models

2.1.1 Process capacity

Process capacity (P_c) is the quantity of paddy processed or milled rice obtained in a given factory as a system per day. Equation (1) presents process capacity for the production line.

$$P_c = P_r \cdot S_A \quad (1)$$

where; P_c is Process capacity (kg), S_A is planned production time (12hrs), P_r is process rate for a production line (kg/hr).

2.1.2 Conversion factors of paddy to milled rice

Conversion of quantity of paddy to milled rice in kilogram is necessary for process capacity evaluations at de-husking lines. It was obtained during the factories' survey that a batch of 1200kg of dried paddy yields an average of 460kg of milled rice and a batch

of 60kg yields 23kg of milled rice, therefore as expressed in Equation (2),

$$\text{Milled rice} = \frac{460}{1200} Q_p = 0.3833Q_p \quad (2)$$

$$\text{Or Milled rice} = \frac{23}{60} Q_p = 0.3833Q_p$$

Milled rice is measured in kg or metric tonnes, Q_p = quantity of paddy (kg).

0.3833 = conversion factor for paddy to milled rice.

2.1.3 Existing machines and optimum requirements

Optimum machine or workforce requirement is the least number of machines or workforce a production line must have to meet average demand. Equation (3) presents optimum machine requirements for the production line.

$$M_o = \frac{DT + S_t}{N} \quad (3)$$

Where, M_o is optimum machine requirement, $DT + S_t$ is total time required for processing per week (hr), D is factory week = 6 days, S_t is total set up time per week (hr), T is processing time for average arrival (hr), N is total time each resources is available per week ($6 \times 12 = 72$ hrs).

2.1.4 Equipment and operations effectiveness

The metrics for equipment and operations effectiveness include overall equipment effectiveness (OEE), overall operations effectiveness (OOE), total effective equipment performance (TEEP) while the equipment and operations control ratios are machine availability, performance and product quality. *Overall Equipment Effectiveness (OEE)* measures the current equipment performance of a production line without taking unscheduled downtime into account during the planned production time. *Overall Operations Effectiveness (OOE)* estimates how the production lines are handling unexpected downtime or tasks during production. It takes both scheduled and unscheduled downtimes into account during planned production time. *Total Effective Equipment Performance (TEEP)* was used to discover how much potential is existing in a production line to increase production output with existing machines [28]. Each of the three metrics was evaluated with Equation (4), however the availability for each metric differs [29,30].

$$E_x = \text{Availability}_x \times \text{Performance} \times \text{Quality} \times 100 \quad (4)$$

where, E is the effectiveness and x is OEE, OOE or TEEP.

2.1.5 Equipment and operations control ratios

Equipment and operations control ratios are key to obtaining equipment and operations effectiveness. According to Clements et al. [31], *equipment*



availability defines the percentage of time that machines are available for potential production compared with the planned production time which is designed to exclude the effects of performance and quality. *Equipment performance* compares the actual production to the maximum throughput and therefore accounts for speed loss or factors that makes machine run at less than the maximum possible speed during operation. It excludes the effects of availability and product quality. *Product quality* is the percentage of the milled rice that pass the quality inspection [32, 33].

2.1.5.1 Availability for overall equipment effectiveness

Availability for overall equipment effectiveness (OEE) is as expressed in Equation (5).

$$Availability_{(OEE)} = \frac{Potential\ production\ time}{Planned\ Production\ time} = \frac{S_A - \sum K_i}{S_A} \quad (5)$$

where, S_A is planned production time (hr), K is scheduled downtime within planned production time (hr), $S_A - \sum K_i$ is potential production time (hr).

2.1.5.2 Availability for overall operations effectiveness

Availability for overall operations effectiveness (OEE) takes both scheduled and unscheduled downtime within planned production time into account. This is expressed in Equation (6).

$$Availability_{(OEE)} = \frac{Actual\ production\ time}{Planned\ Production\ time} = \frac{S_A - \sum K_i - \sum U_i}{S_A} \quad (6)$$

Where, S_A is planned production time (hr), K is scheduled downtime within planned production time (hr), U is unscheduled downtime within planned production time (hr), $S_A - \sum K_i - \sum U_i$ is actual production time (hr).

2.1.5.3 Availability for total effective equipment performance

Total effective equipment performance (TEEP) considers availability as a function of all available time as expressed in Equation (7). It measures how much a production line could potentially be producing if there are no limits to scheduling.

$$Availability_{(TEEP)} = \frac{Actual\ production\ time}{Available\ time} = \frac{S_A - \sum K_i - \sum U_i}{Available\ time} \quad (7)$$

Where, $S_A - \sum K_i - \sum U_i$ is Actual production time (hr). Available time used in this study for evaluation of TEEP is 24 hrs instead of the planned production time of 12hrs.

2.1.5.4 Equipment performance

Performance measures how well equipment performs when they are available in the factory. It accounts for speed loss or factors that makes rice processing machine run at less than the maximum possible speed

during operation. Performance is as expressed in Equation (8).

$$P = \frac{AP}{M_T} \quad (8)$$

Where, actual production (kg), $AP = P_r \times AP_t$, and maximum throughput, $M_T = P_r \times S_A$, P_r is the process rate (kg/hr) of a production line, AP_t is actual production time (hr) and S_A , is planned production time (12 hours).

2.1.5.5 Product quality

Quality measures percentage of well processed rice in a given sample of job order. Quality factors considered in this study are percentage broken grain, percentage discoloured grain and percentage impurities (dockage); and these factors are dependent on quality function. Samples of 250g of milled rice were collected at each of the de-husking lines of the factories. In the absence of colour sorter and grader, the grains were manually sorted into good, broken, discoloured grains and dockages, and each taken as percentage of the sample. Equation (9) was used to obtain the quality of rice in the factories [29].

$$Q = \frac{number\ of\ good\ grains}{number\ of\ Sample\ grains} = \frac{G_g}{S_g} \quad (9)$$

Q is quality of rice, G_g is good grains, S_g is total number of grains in the sample of 250g, $G_g = S_g - (B_g + D_g + I_d)$, B_g is number of broken grains, D_g is number of discoloured grain, I_d is number of dockages.

3.0 RESULTS AND DISCUSSION

3.1 Annual Process Capacity

Figure 1 presents the annual process capacity of the factories in kg/annum and compares the annual process capacity of the factories from 2017- 2022.

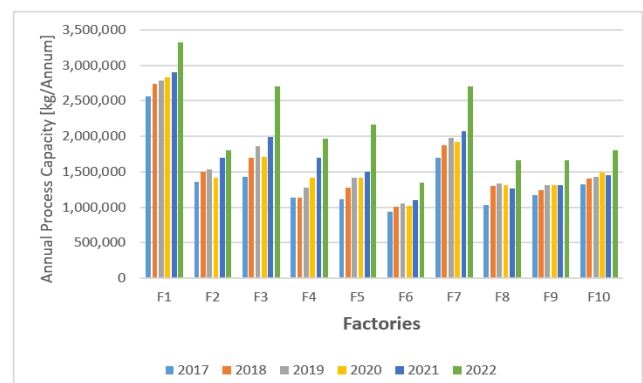


Figure 1: Annual Process Capacity [kg/annum] of the factories (2017-2022)

Process capacity (3,323,077 kg/annum) was highest in F1 in 2022 while the lowest value (937,020 kg/annum) was seen in F6 in 2017. Except for F1, F4 and F5

which showed increase in process capacity from year to year, the process capacities of other factories fluctuated across the six years. The observed fluctuation indicates that there have not been good and sustainable process improvement efforts at the de-husking lines of those seven factories. Again it points at significant variability in equipment availability and performance in those factories.

3.2 Equipment and Operations Effectiveness

Equipment availability is the most significant factor in equipment and operations control ratios, and the values of the three equipment and operations effectiveness metrics are largely influenced by equipment availability. Figures 2 and 3 respectively showed equipment and operations control ratios and overall equipment effectiveness (OEE) obtained.

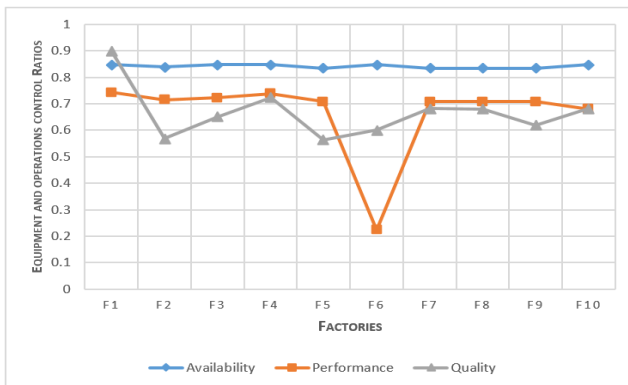


Figure 2: Equipment and Operations Control Ratios for OEE

Figure 2 showed that equipment availability leads the performance and quality, but they all interact to give OEE values.

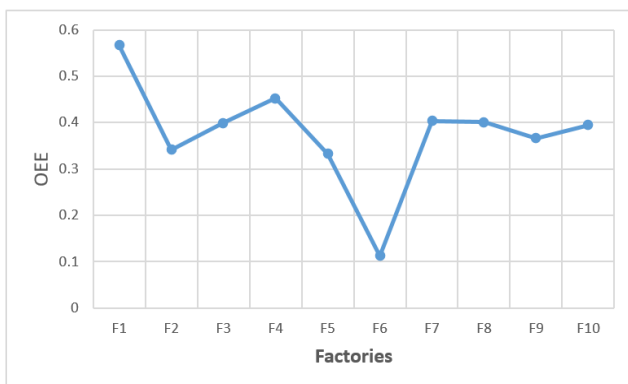


Figure 3: Overall Equipment Effectiveness (OEE)

Table 1 shows the factories has adequate number of machines or capacities to handle the milling operation, and therefore eliminates the effects of equipment inadequacy in the availability results.

Table 1: Existing machines and optimum requirements

Factories	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
M_e	3	2	2	2	2	1	2	2	2	2
M_o	3	2	1	1	1	1	2	1	1	2

The benchmark standards set by Japan Institute of Plant Maintenance (JIPM) which have been widely practiced throughout the world in interpreting OEE values were used in this study [29]. According to JIPM standards, OEE below 50% is considered low. Following the benchmark, Figure 3 showed low OEE for the factories except for F1. The values indicate the reality of current production schedules in the de-husking lines because it measures the amount of planned production time that is actually productive. Therefore, there are production losses caused by machine downtime and reduced speed in the de-husking lines. Since OEE is a current-state metric and its availability takes only the planned production time into account, the results further suggest that machine maintenance in the de-husking lines are mostly reactive to breakdowns which allows production interruptions. The only focus on reactive maintenance is how quickly the machine or system can be returned to service. As long as the machine will function at a minimum acceptable level, maintenance is judged to be effective. This approach to maintenance management is both ineffective and extremely expensive. Above analysis have shown that only OEE cannot be relied on in identifying the root causes of inefficiency in the de-husking lines and improve process capacity.

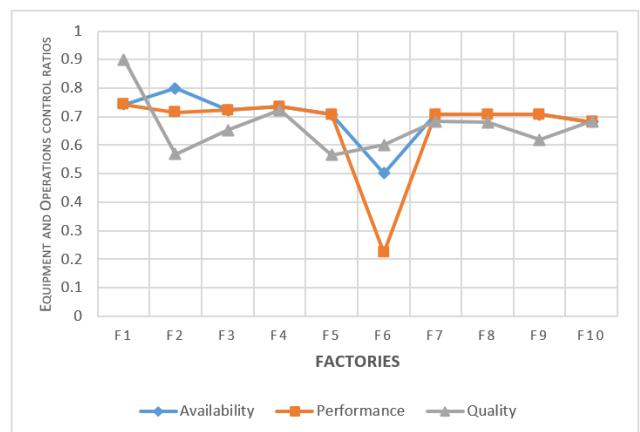


Figure 4: Equipment and Operations Control Ratios for OOE

Other reasons outside machine downtime and speed loses that affects process capacity were traced by evaluating equipment and operations control ratios; and overall operations effectiveness (OOE) as shown in Figures 4 and 5 respectively. Figure 4 showed that machine availability, performance and quality interact



more effectively in determining overall operations effectiveness (OOE).

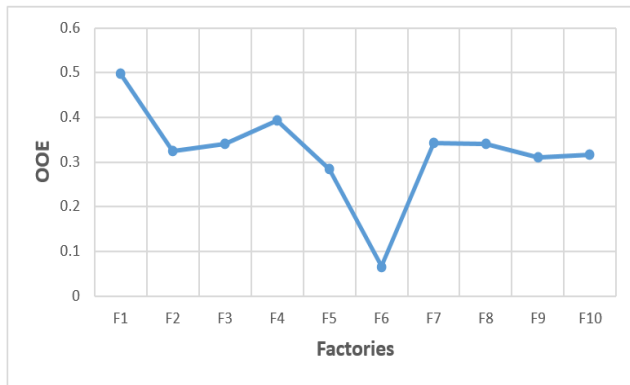


Figure 5: Overall Operations Effectiveness (OOE)

Unscheduled downtime and unexpected tasks are taken into account in equipment and operations control ratios for OOE. The OOE values in Figure 5 were below 50% for all factories, and it showed that the de-husking lines of the factories do not respond well to unscheduled downtime or unexpected tasks to reduce downtime, gain speed and process more. Further, the low OOE values indicate delays in finishing repairs and prevalent idle times, poor approaches to machine maintenance, and inadequate experience on the part of workforce in the de-husking lines, corroborated by the result of workforce assessment carried out in the factories.

Tracing further to know if there are potentials in the de-husking lines to be unlocked for process capacity improvement, scalability with the current equipment, TEEP was evaluated. Figures 6 and 7 show equipment and operations control ratios and TEEP values obtained.



Figure 6: Equipment and Operations Control Ratios for TEEP

Figure 6 shows that availability lags behind performance and quality. General low machine availability is observed across the de-husking lines of

the factories. It also reflected in the TEEP values of Figure 7. TEEP values across the factories are below 25% and such indicate that de-husking lines have 75% of its potentials to be unlocked for more productivity with the current equipment. TEEP values have further shown that with the existing schedules in the factories, there are huge losses in production, and therefore there is need to enhance decision making and improve factories' capacities.

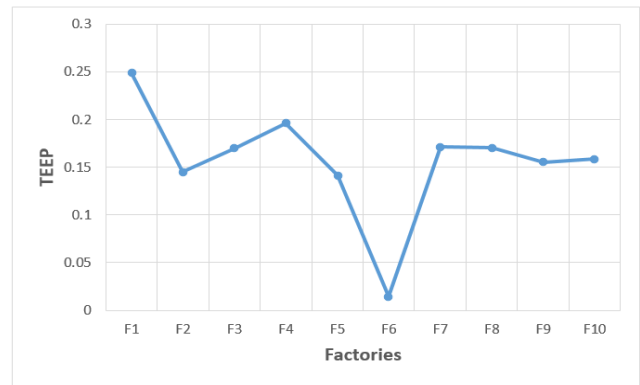


Figure 7: Total Equipment Effectiveness Performance (TEEP)

4.0 CONCLUSION

Process capacity improvement through equipment and operations control ratios have been carried out and the findings will enhance decision making targeted at the improvement of process capacities. Fluctuations was observed in the process capacities of the factories from 2017-2022 and that was the first insight gained from the study of possible variabilities in equipment availability and performance. Through the equipment and operations control ratios, the equipment and operations effectiveness metrics were determined and the root causes of inefficiency identified. The availability in OEE leads performance and quality and the overall equipment effectiveness (OEE) were generally below 50%, and that indicates production losses caused by frequent downtime and reduced speed of the machines.

The values obtained for overall operations equipment (OOE) where the three factors for equipment and operations control ratios interacted more effectively were below 40% which showed the de-husking lines across the factories do not respond well to unscheduled downtime or unexpected tasks to reduce downtime for process capacity improvement. However, tracing if there are potentials of the de-husking lines to be unlocked to improve process capacity with the existing machines through equipment availability, it was found the TEEP values of the factories were below 25% indicating much availability to increase capacity with the existing

equipment. This value implies that 75% potentials of the de-husking line could be unlocked through increased availability.

Based on these findings, preventive rather than reactive maintenance has to be taken seriously in de-husking lines of small-scale rice processing factories to ensure high rate of machine availability, reduce unexpected breakdown and production loss. Machine availability could also be increased by running shifts, production during holidays and preventive maintenance through weekends. There is need for continuous training of workforce in small-scale rice processing factories to reduce delays and prevent idle times that usually arise from finishing repairs, poor approaches to machine maintenance and inadequate experiences. Above all, reliability modelling should be conducted on the machines before installation to reduce unscheduled downtimes. Recommendation for further studies is the failure analysis on the machines to reveal their failure pattern.

5.0 ACKNOWLEDGEMENT

Special thanks to the operations managers and operators of the factories of Omor Milling Clusters in Anambra State, Nigeria, who with their cooperation, real time data was collected during the field survey.

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