Assessment of the impact of preventive maintenance strategy on reliability indicators of a rice combine harvester in the Gambia

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Abstract: Maintenance cost of agricultural machines accounts for about 10% to 15% of total production cost and this tends to increase as the machine gets older. To stabilize this already high cost, agricultural machinery maintenance engineers chose Preventive Maintenance (PM) strategy. However, PM may not produce the desired results especially when machines are used under different operating conditions. In this paper, an assessment of the effects of PM strategy on reliability indicators (failure rate, mean time between failures (MTBF), mean time to repair (MTTR) and mechanical availability) of a rice combine harvester Mitsubishi TVR96 working under the operating condition of Pacharr rice fields in the Gambia, was discussed. These reliability indicators have been computed for each month of the harvesting seasons of 3 years (2013, 2014 and 2015). The failure rate of the machine reached an all-time high in December of 2015 with 0.889, and MTBF was between 1.13 hour and 17 hours, MTTR was between 0.86 hour and 5.63 hours and the mechanical availability fluctuated with the highest (94%) recorded in June of 2013 and the lowest (44%) recorded in December of 2015. These unfavourable results prompted us to propose a new PM strategy, condition based maintenance (CBM). The results of this proposed strategy showed an improvement of the various reliability indicators; failure rate dropped between 0.014 and 0.033, MTBF increased to between 30.63 hours and 70.02 hours, MTTR dropped to 0.62-0.79 hour and the mechanical availability increased to 98%-99%. This strategy will be implemented on the machine in 2018, 2019 and 2020 to see if same results will be obtained.

Keywords: assessment, impact, preventive maintenance, reliability indicators, failure, rice combine harvester

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1 Introduction

Agriculture, the backbone of The Gambia economy, accounts for about 29% of the gross domestic product (GDP) and employs about 75% of its 1.8 million inhabitants. Despite this, the country is able to meet only 50% of its food requirements (Ministry of Agriculture, 2010). Rice, the staple food of the country, is cultivated in all six administrative regions and yet it is the single biggest import food crop (between 80,000 and 100,000 tonnes are imported each year) (Ministry of Agriculture, 2010). Successes in the sector are hindered by challenges, most important of which is the used of low inputs (machinery, seeds, fertilizers etc.).

To address this challenge and boost production and productivity, the government in recent years has purchased other agricultural machines, such as rice combine harvesters of small and medium capacities. These fleets of machineries require a sound maintenance strategy to increase their uptime (reliability and availability) and prolong their useful life. Preventive maintenance (PM) is the type of maintenance strategy that is employed to conserve the functions of these agricultural machines. The PM strategy carried out is done according to the manufacturer's recommendations

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and the activities carried out include inspections (checks), cleanings, lubrications, adjustments, calibrations/ alignment, components replacements and repairs. They are carried out on daily, periodic and out-of-season basis. All these activities are clearly stated in an operator's manual which comes with the machine when it is been sold.

PM strategy is known for increasing machines' uptime since components aren't left to reach failure state but are always maintained to prevent failure occurrences. However, this is not always the case especially when machines are operated under an operating context that is totally different from the one in which the testing and evaluation of the machines were carried out.

The idea of this paper is to assess the impact of the PM strategy employed, on reliability indicators of a rice combine harvester Mitsubishi TVR 96 working under the environmental and operational conditions of Pacharr rice fields in the Central River Region (CRR) of The Gambia. The research is centred around three terms that forms the core of the study, i.e. PM, reliability indicators and rice combine harvester.

Maintenance can be broadly defined as the combination of all technical and corresponding administrative actions, including supervision actions, intending to retain an item or system in, or restore it to, a state in which it can perform its required function (IEC50(191), 1990). PM is planned maintenance performed when an item is functioning properly to prevent future failures. Beside PM, there is also corrective maintenance (CM).

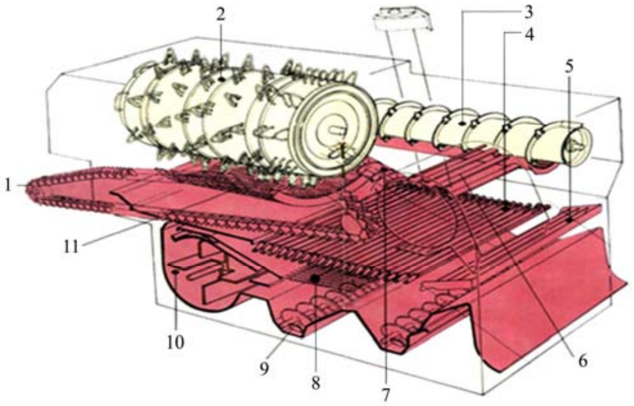
Reliability indicators measures the level of reliability of a machine. They include failure rate, mean time between failures (MTBF), maintainability measure, mean time to repair, (MTTR) and mechanical availability (A).

Rice combine harvester is a self-propelled, trailed or mounted agricultural machine that is used to harvest rice. The machine derives its name from its action of combining, reaping, threshing and winnowing into a single process (Constable and Somerville, 2003). Rice combine harvesters are classified according to different types, notable of which is the classification according to the type of feeding. This classification divides the combine into straight-through feed combines and heed-feed combines.

2 Material and methods

2.1 Object of study

The object of this study was a head-feed rice combine harvester of the make Mitsubishi TVR96 (Figure 1). It was brought in the Gambia by the Taiwanese agricultural technical mission in 2009. The machine consists of a vertical cutter header in front, conveying and feeding unit consisting of intermediate feeding chain, threshing or separation unit, cleaning unit, handling unit, displacement unit and engine.



1. Feeder chain 2. Threshing cylinder 3. Re-threshing cylinder 4. Chaffer 5. Straw walker 6. Dust sucking fan 7. Tailing return auger 8. Sieve 9. Grain auger 10. Winnowing fan 11. Concave

Figure 1 Internal view of the rice combine harvester (Noomhorm and Chen, 2010)

Rice harvesting process started with reaping when the rice stalks are cut and delivered to the threshing cylinder by components of vertical cutter header. The paddy was later threshed, sieved and winnowed to separate the grains from the straw by threshing and separating components. The clean grains were conveyed to the grain tank by grain augers where they are later discharged into sacks or medium of transport by unloading auger.

The rice combine harvester had a productivity of 1.5 ha per hour, a working period of 6 hours per day and 6 working days per week.

2.2 PM strategy carried out on the machine

PM strategy employed on this rice combine harvester was clock-based and the tasks carried out included inspections (checks), cleanings, lubrications, adjustments, calibrations/alignment, components replacements and repairs. They were carried out on daily, periodic (at 100, 200, 300, 400, 500, 800, 1400 and after 1400 hours of operation) and out-of-season basis, as per manufacturer's recommendations. These maintenance activities were done by a team consisting of agricultural engineers, mechanics and an operator from Sapu Agricultural Station Mechanical Workshop. A checklist stating the task/activities that needed to be carried out was used. Information relating to machine working hours, preventive maintenance tasks carried out, components failures, number and time of components failures, and machine downtime were recorded

2.3 Study site

The study site, Pacharr rice fields are situated about 290 km east of Banjul, capital of The Gambia (Figure 2). They are located on latitude 13°30" North and longitude 14°60" West. It can be found on the map in Figure 2 below.

Note: the black shaded ellipse represents the location of Pacharr rice fields.

Figure 2 Map of The Gambia showing the location of Pacharr rice fields

These rice fields were established in the mid-1950s when the Colonial Development Corporation introduced a rice development project. Somehow, this project came to an end by the end of the decade. The fields were later revived in August 1967 after the Republic of China (ROC) on Taiwan signed an agreement on technical cooperation with the Government of the Gambia (GoTG) and a 38-member Taiwanese Agricultural Technical Mission (ATM) was dispatched to The Gambia (Hsieh, 2001).

The region in which the site is found has a wet and dry tropical climate. The soil is composed of compact sediments consisting largely of quartz grains (Hall and Mpande, 1994), and the size of rice fields varies from 0.4 to 10 hectares. The river Gambia in this part of the country is entirely fresh water and this why irrigation schemes are setup in the area. Rice cultivation in this region is done twice a year and so is harvesting too (May–July and October–December).

2.4 Primary data obtained during the observation period and used in the study

Primary data collected during the harvesting seasons of 2013, 2014 and 2015 have been used in the study and these comprised of the number of areas harvested, number of working hours, number of components failures and that of downtime. This information was used to determine the failure rates (λ), MTBF, MTTR, and mechanical availability of the combine harvester. During the period under review, the machine had an accumulated work of 2200 ha, a working time of 1466 hours (Table 1). It suffered 205 component failures (Table 2) and had been on downtime for 442 hours (Table 3).

Table 1 Total working hours of the combine harvester

Month Years	Dry season harvest			Rainy season harvest		
	May	June	July	October	November	December
2013	-	102 h	131 h	102 h	114 h	51 h
2014	60 h	105 h	48 h	84 h	135 h	54 h
2015	87 h	138 h	42 h	78 h	90 h	45 h
Total per column	147 h	345 h	221 h	264 h	339 h	150 h
Cumulative total	1466 h					

Note: there was no harvesting in May of 2013 due to the presence of high level of water in the fields; h represent the unit in hour.

Table 2 Number of failures of the combine harvester

Month Years	Dry season harvest			Rainy season harvest		
	May	June	July	October	November	December
2013	-	7	11	6	13	4
2014	5	8	6	12	11	8
2015	11	12	10	17	24	40
Total per column	16	27	27	35	48	52
Cumulative total	205					

Note: there was no harvesting in May of 2013 due to the presence of high level of water in the fields.

Table 3 Total number of downtimes of the combine harvester

Month Years	Dry season harvest			Rainy season harvest		
	May	June	July	October	November	December
2013	-	6 h	13 h	30 h	42 h	21 h
2014	12 h	45 h	18 h	18 h	15 h	18 h
2015	21 h	18 h	18 h	30 h	60 h	57 h
Total per column	33 h	69 h	49 h	78 h	117 h	96 h
Cumulative total				442 h		

Note: there was no harvesting in May of 2013 due to the presence of high level of water in the fields, h represent the unit in hour.

There were two harvesting seasons each year. The first one was the dry season harvest from May to July, and the second was the rainy season harvest from October to December (Tables 1, 2 and 3).

2.5 Reliability indicators

To evaluate the effect of PM strategy on reliability indicators of the rice combine harvester, the following indicators were used: failure rate, MTBF, MTTR (maintainability measure) and mechanical availability.

2.5.1 Failure rate

This is the frequency with which a component of the rice combine harvester fails to perform its required function(s). Failure rate is expressed mathematically as shown in the Equation (1) below (Shirmohammadi, 2002).

$$\lambda = \frac{N}{H} \tag{1}$$

where, λ is the failure rate; N is the number of failures in a given time, and H is the total working hour.

2.5.2 MTBF

This is the average predicted elapsed time between inherent failures of the combine harvester or its component (s) during operation. It is expressed mathematically as shown in the Equation (2) below (Billinton and Allan, 1992).

$$MTBF = \frac{H}{N}\text{(hour)} \tag{2}$$

where, $MTBF$ is the mean time between failures (in hours); H is the total working hour, and N is the number of failures in a given time.

2.5.3 MTTR

This is the average time required to troubleshoot and repair failed components and return them to normal functional state. It is a maintainability parameter and it is used to calculate the mechanical availability of a machine. This is why we mentioned it under the reliability indicators. It is expressed mathematically as shown in the Equation (3) below (Billinton and Allan, 1992).

$$MTTR = \frac{C}{T_{CM}}\text{(hour)} \tag{3}$$

where, $MTTR$ is the mean time to repair (in hours); C is the corrective maintenance (CM) downtime, and T_{CM} is the total CM actions (same as the number of failures in our case).

2.5.4 Mechanical availability

This refers to the probability that the machine will carry out its functions of cutting, separating and cleaning as required when required during the period of harvesting. It can be mathematically expressed as shown in the Equation (4) below (Hall and Daneshmend, 2010).

$$A = \frac{MTBF}{MTBF + MTTR} \times 100(\%) \tag{4}$$

where, A is the mechanical availability.

2.6 Formulation of a new PM strategy

In order to formulate a PM strategy that conforms to the operational context, we first determined the PM requirement of the rice combine under the operating conditions of the Pacharr rice fields.

The new PM strategy that we have proposed was Condition Based Maintenance (CBM). CBM relied on the actual health of the machine to determine when and what maintenance was required. Therefore, instead of having a predetermined time and interval to perform the PM tasks, we will perform them whenever the conditions of the machine warrant them. The daily maintenance of the machine will allow us to detect or discover anomalies that will require us to carry out the tests of monitoring of the necessary conditions.

In this step, we first defined our operational context (environmental and operational) and then we determined the PM strategy (based on age, clock, condition or opportunity) that could suit these conditions. From this, we chose CBM for being the PM system that suits our condition.

Afterwards, we decided what resources (people, spare parts and tools) were needed to fulfill those requirements. At the stage, we should decide who must do each task and what spare parts and tools are required to do each.

At the end, we decided what systems were needed to manage the resources. A system that we will employ to manage the resources will be to assigned the role of personal performance monitor to the agricultural engineer and to have a store keeper who will take an inventory of all the tools and spare parts.

Monitoring tasks (Table 4) we will implement included a set of tasks within the limits of our organization's capacity, in terms of human, material and financial resources.

Table 4 Maintenance checklist for condition monitoring of rice combine harvester subsystems

No.	Monitoring type	Rice combine harvester subsystems								
		Header	Feeding	Threshing	Cleaning	Handling	Engine	Displacement	Hydraulic	Electrical
a	Temperature measurement						x			x
b	Oil analysis						x		x	
c	Visual inspection	x	x	x	x	x	x	x	x	X
d	Vibration monitoring	x		x			x	x	x	X
e	Corrosion monitoring	x	x	x				x		X
f	Electrical testing									X
g	Performance monitoring	x	x	x	x	x				

Note: x represent check carried out.

2.7 Primary data used to predict the reliability

The new productivity of the machine is expected to be between 1.40 ha h^{-1} and 1.49 ha h^{-1} as the machine will be older during the harvest seasons of years 2018, 2019 and 2020. The amount of working day and working hour will be the same as in the previous PM strategy; 6 days per week and 6 hours per day respectively. The total working area of the machine will also be the same 2200 ha, because we will make a comparison of the impacts of CBM and the current PM strategy on the reliability indicators of the rice combine. With the above data, the total working time is expected at 1500.16 hours, a bit high than the previous one (1466) because of the expected decrease in productivity of the machine (Table 5). The number of components failures is expected be 32 failures (Table 6) and the number of hours of downtime expected to be 22.10 hours (Table 7). These expected low numbers of failure and downtime are attributed to the fact that in CBM, maintenance tasks are carried out at the time when they are necessary.

Table 5 Total working or operating hours of the rice combine harvester

Month Year	Dry season harvest			Rainy season harvest		
	May	June	July	October	November	December
2018	59.18 h	144.22 h	34 h	108.84 h	132.65 h	30.63 h
2019	42.19 h	132 h	48 h	72.02 h	144 h	59.98 h
2020	90.20 h	132.30 h	47.77 h	42.05 h	132 h	48 h
Total per column	191.57 h	408.52 h	129.77 h	222.91 h	408.65 h	138.61 h
Cumulative total			1500.16 h			

Note: h represent the unit in hour.

Table 6 Number of failures of the rice combine harvester

Month Year	Dry season harvest			Rainy season harvest		
	May	June	July	October	November	December
2018	1	3	1	2	3	1
2019	1	3	1	1	3	1
2020	2	3	1	1	3	1
Total per column	4	9	3	4	9	3
Cumulative total			32			

Table 7 Total number of downtimes of the rice combine harvester

Month Year	Dry season harvest			Rainy season harvest		
	May	June	July	October	November	December
2018	0.75 h	2.37 h	0.74 h	1.48 h	2.28 h	0.70 h
2019	0.65 h	2.16 h	0.70 h	0.62 h	1.95 h	0.63 h
2020	1.30 h	1.95 h	0.62 h	0.63 h	1.95 h	0.62 h
Total per column	2.70 h	6.48 h	2.06 h	2.73 h	6.18 h	1.95 h
Cumulative total			22.10 h			

Note: h represent the unit in hour

3 Results and discussion

The results obtained from the various analysis are presented and discussed below. Each figure consists of both results obtained during the study period when PM strategy based on manufacturer's recommendations (2013, 2014 and 2015) and afterwards when PM strategy based on the proposed CBM (2018, 2019 and 2020) were applied on the rice combine harvester.

3.1 Failure rates

The calculation of the failure rates of the rice combine harvester during the study period and that of the proposed CBM, using Equation (1) and the primary data in Tables

1 and 2 and Tables 5 and 6 respectively, allowed us to plot Figure 3 below.

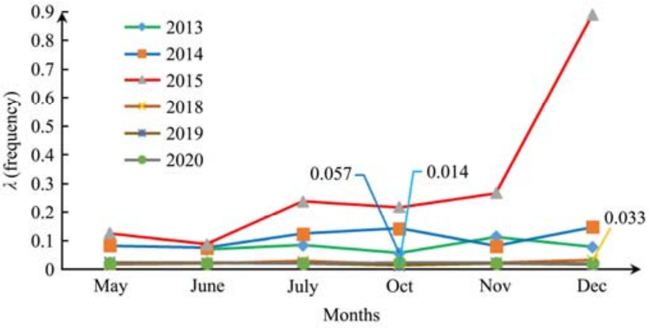


Figure 3 Failure rates of the rice combine harvester

PM strategy based on manufacturer's recommendations: Figure 3 above showed that the failure rates of the machine were generally low during dry season harvesting periods but high during rainy season harvesting periods. This is sure because the machine did more work during the rainy season harvest than during the dry season harvest and the prevailing operational and environmental conditions during the former were more favorable than during the latter. It can also be observed that failure rates increased as the machine gets older with 2013 having the lowest rate 0.57 and 2015 having the highest rate 0.889.

PM strategy based on the proposed CBM: Failure rates under this PM strategy were predicted to be very low during the two harvesting seasons with highest and lowest failure rates expected to occur in December 2018 with 0.033 and October 2019 with 0.014, respectively. The latter will be recorded as the highest failure rate, because during the rainy season harvest of that year, the machine should be harvested 450 ha and these will lead to fatigued components. The month of October will record the lowest failure rate as the proposed CBM system is expected to improve the condition of the machine by this time.

3.2 MTBF

The calculation of the MTBF of the rice combine harvester during the study period and that of the proposed CBM, using Equation (2) and the primary data in Tables 1 and 2 and Tables 5 and 6 respectively, allowed us to plot Figure 4 below.

PM strategy based on manufacturer's recommendations: Generally, MTBF showed a decreasing trend from 2013 going towards 2015 with the highest recorded in October of 2013 (17 hours) and the lowest in December of 2015 (1.13 hours) (Figure 4). This phenomenon can be largely attributed to shortage of spare part (stock ran out) due to the fact that these parts could be purchased locally and also due to the old age of the machine.

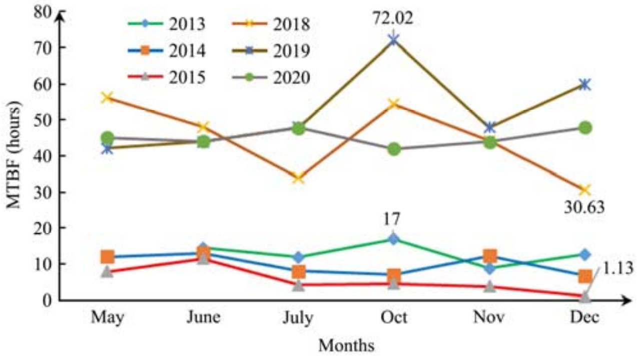


Figure 4 MTBF of the rice combine harvester

PM strategy based on the proposed CBM: According to Figure 4 above, the highest and lowest MTBF are to be recorded in October 2019 with 72.02 hours and December 2018 with 30.63 hours of uptime, respectively. These is explained by the fact that less and more breakdowns are expected to occur during these months, respectively.

3.3 MTTR

The calculation of the MTTR of the rice combine harvester during the study period and that of the proposed CBM, using Equation (3) and the primary data in Tables 2 and 3 and Tables 6 and 7 respectively, allowed us to plot the Figure 5 below.

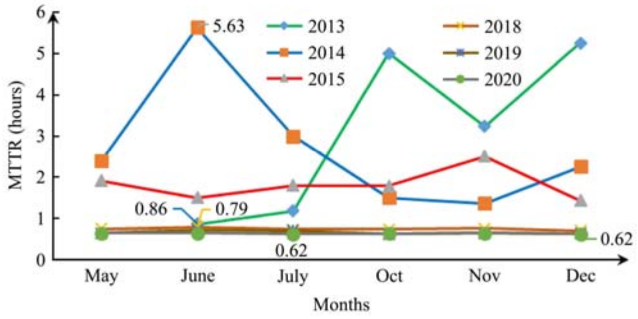


Figure 5 MTTR of the rice combine harvester

PM strategy based on manufacturer's recommendations: The highest MTTR was recorded in June of 2014 with 5.63 hours and the lowest was recorded in the same month but of the year 2013, with 0.86 hour (Figure 5). These values were largely influenced by the nature and complexity of the failure and the availability of spare part for part replacement tasks.

PM strategy based on the proposed CBM: As can be seen (Figure 5), MTTR of the machine is expected to decline as the years of the trial goes by with highest registered in 2018 (between 0.7 and 0.79) and lowest registered in 2020 (between 0.62 and 0.65). These can be largely attributed to the fact that the implementation of the new PM strategy is expected to improve as the years goes, thereby preventing the occurrence of catastrophic failures that will take longer to repair.

3.4 Mechanical availability (A)

The calculation of mechanical availability of the rice combine harvester during the study period and that of the proposed CBM, using Equation (4) and the values of Figures 4 and 5 allowed us to plot Figure 6 below.

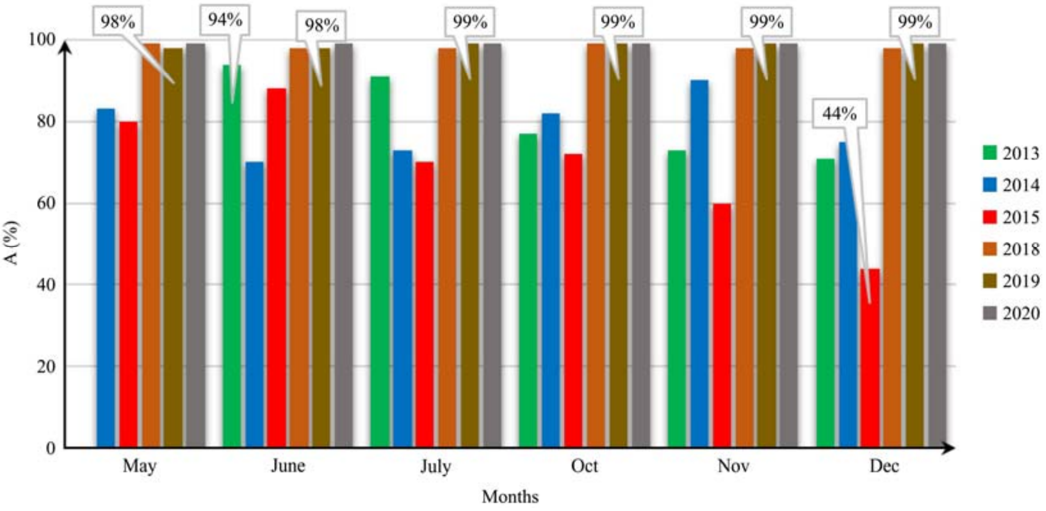


Figure 6 Mechanical availability of the rice combine harvester

PM strategy based on manufacturer's recommendations: According to Figure 6 above the mechanical availability of the machine fluctuated between high and low from one month to the other within the same harvest season and from one harvest season to the other. The highest availability (94%) was recorded in June of 2013 and the lowest (44%) was recorded in December of 2015. This great disparity between the highest and the lowest availability can be attributed to the presence of the Taiwanese agricultural technical mission which had a large stock of spare parts and therefore were able to keep the machine functioning even though its components breaks frequently. The mission left The Gambia in late 2013 and the stock of spare ran out by 2015.

PM strategy based on the proposed CBM: Based on the results above (Figure 6), the mechanical availability of the machine is expected to be between 98% and 99%. These high values are certain since CBM will prevent many failures from occurring, especially those that will put the machine on downtime for a long period of time.

3.5 Comparison between the reliability indicators

A comparison between the lowest and the highest values of the reliability indicators based on the two PM approaches (based on manufacturer's recommendation and based on the proposed CBM) was showed below (Figure 7).

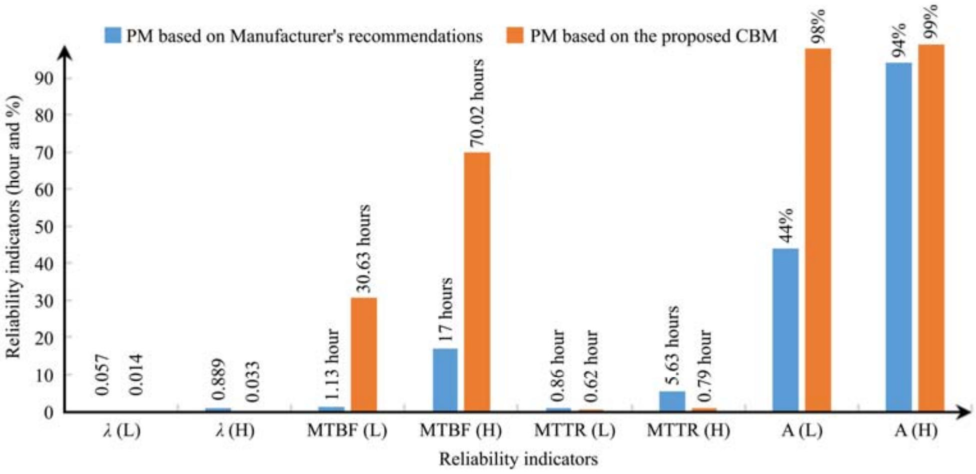


Figure 7 Comparison between the Lowest (L) values and the Highest (H) values of the reliability indicators of the two PM approaches

It can be observed that (Figure 7) the values of reliability indicators for such as failure rates and MTTR were relatively lower under the PM strategy based on the proposed CBM than under the PM based on manufacturer's recommendations. As well MTBF and mechanical availability were higher under the proposed CBM than under the PM based on manufacturer's recommendations. These showed an improvement in all the reliability indicators when CBM was applied. This means that CBM will have a positive impact on the reliability indicators.

4 Conclusions

In order to assess the impact of PM on the reliability of a rice combine harvester working under the operational conditions of Pacharr rice fields in The Gambia, a quantitative approach to data collection was used. Primary data from maintenance reports of the machine which has been recorded during 2013, 2014 and 2015 harvesting seasons were utilized. These included total working hours, total number of failures and total number of downtimes.

The research reveals that the reliability indicators such as failure rate and MTTR are relatively high and MTBF and mechanical availability are low. These seriously affect the ability of the machine to perform it functions and result in high downtimes. Therefore, we can conclude that the PM system employed does not preserve the functions of the machine. This is due to the fact that the PM task used were designed for the operating context of Japan and this is completely different from that of The Gambia.

Due to the above assertion, we proposed the formulation of a PM strategy based on CBM design to suit our operating context. This relies upon actual machine health to determine when and what maintenance is required. The results of the prediction demonstrate an improvement in the reliability indicators of the machine; showing a reduction failure rate and MTTR and an increase in MTBF and mechanical availability. This PM strategy, CBM will be implemented on the machine for three years (2018, 2019 and 2020) to see whether in reality we will obtain the same results.

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