Maintenance Cost Reduction of Paddy Seed Production Machinery by Implementing Preventive Maintenance System

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Abstract. Production of paddy seed in seed industry involves several different functions and operations of seed production machinery. Maintenance of those machinery has a fundamental role in the production system through its impact on productivity as well as cost management. This paper will discuss the case study on analysis of possible cost reduction on maintenance of paddy seed production machinery through changes from the current practiced corrective maintenance system into preventive maintenance system. The study was mainly based on twenty four years of company's maintenance records of its seed production machinery which covered the failures history and actions undertaken. The methods were including the identification of critical components using Equipment Criticality Rating (ECR) and optimization of replacement schedule of critical components. The results indicated that eleven (11) components out of total 294 components in 8 specific machines have been identified as having considerable criticality rating and the changes from corrective maintenance system into preventive maintenance system may reduce about 39.4% of direct machinery maintenance cost.

1. Introduction
Seed is the foundation of any rice crop. In rice production, seed must be grown, harvested, and processed correctly for best yield and quality results. Certified paddy seed use is highly recommended. However, Indonesian certified rice seed production can only fulfil half of the total domestic needs of the seeds. According to BPS, seed requirements in 2015 reaching 374 thousand tons while the total seed production only reached 184 thousand tons. The factor that causes the lack of certified seeds production, among others, is the poor condition of seed production machinery. Machinery condition greatly affects the quality of the seeds produced. Maintenance of those machinery has a fundamental role in the production system through its impact on productivity as well as cost management. Therefore, machinery maintenance activities need to be undertaken to maintain the condition of the machinery in its optimal state.

Prahmawati, Pertiwi, and Hermawan [1] investigated the machinery maintenance system in the largest seed production industry in Indonesia, namely PT SHS. The company produces approximately 20% of the domestic seed needs. Seed production activities sometimes were stopped due to engine failure. Systematic efforts to overcome engine disruption need to be done through improvement of machinery maintenance system.

In general, there are two machinery maintenance approaches, namely corrective (or reactive) machinery maintenance and preventive machinery maintenance. Corrective maintenance is maintenance which is carried out after the occurrence of failure to restore the failed equipment, machine, or facilities to an operational condition. On the other hand, preventive maintenance is the care and servicing by qualified personnel to maintain equipment, machine and facilities in satisfactory operating condition by providing systematic inspection, detection, and correction of incipient failures either before they occur or before they develop into major defects. The machinery maintenance activities in PT SHS is carried out correctly. Impacts of corrective maintenance include unscheduled downtime resulting in damage to seed products, cessation of operations under certain conditions of damage, idled labour time, and an
increasing in machine start-up costs. To improve the situation, implementation of preventive maintenance is highly recommended. However, the implementation of a preventive maintenance can be time consuming and costly. This paper will discuss the case study on analysis of possible cost reduction on maintenance of paddy seed production machinery through changes from the current practiced corrective maintenance system into preventive maintenance system.

2. Method

Production of paddy seed in seed industry involves several different functions and operations of seed production machinery. In PT SHS, the machinery consist of a set of machines such as intake, chain conveyor, buckets elevators, pre-cleaners, hopper, dryer, lockers bin, air screen separators, sealer, bet conveyor, cyclone and silo as shown in figure 1.

![Figure 1. Paddy seed production machinery in PT SHS.](image)

Given the complexity of the machinery, the analysis is limited to the critical machines and/or components of the machinery system. Hence the analysis was carried out in three steps, namely 1) determining the equipment criticality rating, 2) optimizing the replacement schedule of components with respect to the existing routine maintenance schedule, and 3) calculating the direct maintenance costs.

Suryadi and Setyanta [2] proposed a combination model of serial and parallel criteria to assess Equipment Criticality Rating or ECR as shown in figure 2. The principle used is if equipment is not functioning, how big it will affect to company as a whole. The method has been adopted by Cahyati, Pramudya, Pertiwi and Herodian [3] in the study of machinery maintenance in sugarcane industry. It was found that the method was very helpful in determining the critical machines and/or components in the factory that enabled the researchers to be more focus on determining maintenance strategy. Results of ECR assessment was also in line with the real conditions in the field.
The assessment of ECR in paddy seed production machinery was undertaken by adopting only the parallel part of the criteria (in the ellipse) as the machinery are clearly comply to government regulation and are not used for public service. The weight of the criteria was determined by using pairwise comparison [4] made by resource persons in PT. SHS. Table 1 exhibits the formulas and weights involved in the assessment. At the end the ECR values were classified as very critical (ECR1: ECR > 60), critical (ECR2: 40 < ECR ≤ 60), slightly (less) critical (ECR3: 20 < ECR ≤ 40) and not critical (ECR4: ECR ≤ 20) to describe the level of machine criticality. From each of machines identified as very critical and critical the optimum schedule for replacement of critical components were then determined.

Optimization of the components replacement schedule was carried out by combining approaches suggested by Jardine and Tsang [5] with respect to the existing routine maintenance schedule, i.e. optimization of replacement time interval (tr) that minimize total cost per unit time C(tr), optimization of replacement time interval (tp) that minimize total cost C(tp), optimization of replacement interval (tp) between preventive replacements to minimize total downtime per unit time, and optimization of preventive replacement age (tp) to minimize total downtime per unit time. The optimum times to replace the components were determined as the weighted values of the four optimum replacement times. Figure 3 shows the approaches while table 2 indicates formulas and weights involved in the optimization process.

The direct maintenance costs were calculated for both, corrective and suggested preventive maintenance system, to be compared. They were involving number of required components, component prices (IDR), production loss (IDR) due to unscheduled down time, wages of idle paid labour (IDR), wages of overhauling for each scheduled downtime (IDR), and additional start-up cost (IDR) due to unscheduled down time. All prices were based on year 2016 market prices.
Table 1. Formulas and weights involved in the ECR assessment.

| Criteria                      | Weight | Formula                                                                 |
|-------------------------------|--------|------------------------------------------------------------------------|
| Safety                        | 0.251  | Rating on safety risk: 20, 40, 60, 80, 100                              |
| Effect on Production          | 0.201  | $EfP = \frac{PL}{SC} \times 100$                                      |
| Reliability                   | 0.167  | $URF = \left[ 1 - \left( \frac{MDT - (SDT + USDT)}{MDT - SDT} \right) \right] \times 100$ |
| Spare Availability            | 0.143  | $SAF = \left( 1 - \frac{SUC}{RUC} \right) \times 100$                |
| Frequency of Failure          | 0.126  | $FoF = \left[ \frac{NoF}{NoY} \right] \times 100$                   |
| Applicability of Monitoring Technique | 0.112 | Rating on applicability of monitoring technique: 0, 10, 25, 50, 100   |

Note:
- PL: production loss
- SUC: standby unit capacity
- SC: sustainable capacity of equipment
- RUC: running unit capacity
- MDT: machinery working time
- NoF: number of machine failure
- SDT: scheduled downtime
- NoY: time span of all failures occurrences (year)
- USDT: unscheduled downtime

Figure 3. Combination of approaches for optimizing component replacement schedule.
Table 2. Formulas and weights involved in the optimization of component replacement schedule

| Parameter      | Weight | Formula                                                                 |
|----------------|--------|------------------------------------------------------------------------|
| tr of C(tr)    | 0.315  | \( C(t_r) = \frac{1}{t_r} \int_{0}^{t_r} \left[ FC - VC \times e^{-kt} \right] dt + Cr \) (5) |
| tp of C(tp)    | 0.262  | \( C(t_p) = \frac{CP \times R(t_p) + CF \times [1 - R(t_p)]}{tp \times R(t_p) + \int_{-\infty}^{t_p} tf(t)dt} \) (6) |
| tp of D1(tp)   | 0.226  | \( D1(t_p) = \frac{H(t_p)Tf + Tp}{tp + \left( \frac{Tp}{8670} \right)} \) (7) |
| tp of D2(tp)   | 0.197  | \( D2(t_p) = \frac{TpR(t_p) + Tf[1 - R(t_p)]}{(tp + Tp)R(t_p) + [M(tp) + Tf][1 - R(t_p)]} \) (8) |

Note:
- FC: fixed cost
- VC: variable cost
- R(tp): reliability function in interval tp
- k: constant, rate of deterioration
- H(tp): expected number of failures in interval tp
- Cr: component replacement cost
- Cp: cost of preventive maintenance
- Cf: cost of failure
- Tf: mean time for annual replacement due to failure
- M(tp): mean time to failure

3. Results and Discussion
Currently the company carries out reactive maintenance system, in which repair and replacement of machine components was undertaken after the occurrence of machine breakdown. Routine maintenance were undertaken every four-month (trimester) during off season, i.e. after the completion of harvest season. Activities during routine maintenance were including overall checking, replacement of broken components, and factory cleaning.

The records of maintenance history from 1992-2016 (twenty four years) indicated a number of machine breakdown and the handling activities carried out to repair or to replace machine component. There were several components that experience recurring breakdown every year such as bearings, cables, v-belts, bucket elevators, chain, and gear. In addition, breakdown also occurred in the bottom of the hoper funnel and the box dryer floor plate so it must be replaced frequently. Impact of breakdown varies greatly depending on which machine components were breakdown. It may cause physical damage to seeds, unpredictable machine downtime, and even may lead to cessation of overall operation. The downtime occurrences during 18 years were 72 times of four monthly routine downtime and 34 times of unscheduled downtime that occurs when the machine is operating. The duration of downtime was varied depending on the availability of spare parts and time to repair. Figure 4 shows the distribution of unscheduled breakdown times.

The company severely limits the number of spare parts. This policy leads to problem if parts from broken components are not available since it may cause the stopping of production process for a certain period. Stopping the production process may cause prolonged production process, damage to the seed produced, as well as additional startup costs. For example there is damage to the bearing on the bucket elevator which causes the drying operation to stop, while the seeds are located the dryer has reached 15% moisture content and has to be stopped drying. The bearing replacement process takes 2-3 hours so the seed being dried has to be delayed. The water content of the seed will be increased again the presence of water vapor absorbed back into the seed. As a result, drying will last longer resulting in costs additional electricity. Another impact of the cessation of engine operation is the idle time of laborers, especially those of production staff. Therefore, the maintenance costs that occur consist of the
cost of replacing the components coupled with the cost of paid idle laborers and cost of production loss due to engine breakdown during the process.

![Figure 4](image.png)

**Figure 4.** The distribution of unscheduled breakdown times.

Assessment on criticality ratings of the involved machines resulted in table 3. There were no machine categorized into very critical. Four machines were categorized into critical, i.e. chain conveyor, dryer, sealer, and belt conveyor, from which chain conveyor had the highest criticality rating. With this results, further analysis was extended into those categorized as slightly critical machines. Based on maintenance and spare parts replacement record, optimization of replacement schedule on eleven (11) out of 294 spare parts frequently broke down in the critical and slightly critical machines was undertaken. The optimum time for replacing the components varies, ranging from 9 months to 3 years. It is very uneconomical to implement the replacement schedule exactly as the optimization results since it will cause very frequent scheduled machinery breakdown time. Therefore, by taking the longest time for replacement, i.e. 3 years as the preventive maintenance cycle, the replacement schedules were rounded-up or rounded-down into the closest on going four-month routine maintenance schedule. The results are shown in table 4.

| Machine Description        | Safety (0.251) | PF (0.201) | URF (0.167) | SAF (0.143) | FoF (0.126) | ACMT (0.112) | ECR Score | Category          |
|----------------------------|----------------|------------|-------------|-------------|-------------|--------------|-----------|-------------------|
| Seed Intake                | 20             | 0          | 0           | 10          | 10          | 0            | 7.71      | Not Critical      |
| Chain Conveyor             | 40             | 60         | 30          | 60          | 80          | 80           | 54.73     | Critical          |
| Bucket Elevator            | 20             | 10         | 20          | 40          | 60          | 50           | 29.25     | Slightly Critical |
| Pre-Cleaner                | 20             | 30         | 20          | 10          | 40          | 20           | 23.10     | Slightly Critical |
| Hopper with weighing scale | 20             | 0          | 10          | 10          | 10          | 20           | 11.62     | Not Critical      |
| Dryer                      | 40             | 80         | 30          | 30          | 50          | 50           | 47.32     | Critical          |
| Locker Bin                 | 20             | 15         | 40          | 40          | 30          | 20           | 26.45     | Slightly Critical |
| Air screen separator       | 20             | 10         | 20          | 10          | 50          | 40           | 22.58     | Slightly Critical |
| Sealer                     | 40             | 60         | 40          | 60          | 50          | 20           | 45.90     | Critical          |
| Belt Conveyor              | 40             | 60         | 30          | 30          | 50          | 50           | 43.30     | Critical          |
| Cyclone                    | 20             | 30         | 20          | 10          | 40          | 20           | 23.10     | Slightly Critical |
| Silo                       | 20             | 0          | 10          | 10          | 70          | 0            | 16.94     | Not Critical      |
Table 4. Result of components replacement scheduling.

| Machine              | Spare Parts     | tr of C(tr) | tp of C(tp) | tp of D1(tp) | Tp of D2(tp) | Optimum Replacement Time (Year) | Replacement Schedule* |
|----------------------|-----------------|-------------|-------------|--------------|--------------|--------------------------------|----------------------|
| Chain conveyor       | Chain           | 0.33        | 0.5         | 1.07         | 1.87         | 0.85                           | 1, 3, 6              |
| Belt conveyor        | NYY HY Cable    | 4           | 7           | 0.60         | 0.34         | 3.03                           | 1, (+1)              |
| Air screen separator | Bearing 6202    | 1           | 1           | 1.2          | 1.2          | 1.08                           | 1, 4, 7              |
| Cyclone              | Bearing 2211    | 0.83        | 1           | 1.03         | 1.13         | 0.98                           | 1, 4, 7              |
|                     | V belt B118     | 1           | 1           | 1.2          | 1.2          | 1.08                           | 1, 4, 7              |
| Dryer                | Plate screen    | 4           | 4           | 1.05         | 0.60         | 2.66                           | 1, 7                 |
|                     | Burner NYY Cable| 6           | 7           | 1.2          | 0.46         | 4.09                           | 1, (+4)              |
| Sealer               | Heating element | 0.72        | 0.92        | 0.66         | 0.60         | 0.74                           | 1, 3, 6              |
| Bucket Elevator      | Gear elevator Z31| 2           | 3           | 0.73         | 0.53         | 1.69                           | 1, 5, 9              |
| Seed cleaner         | Screen          | 1.10        | 1.50        | 0.87         | 0.83         | 1.10                           | 1, 4, 7              |

*) Replacement schedule on 3-year cycle, 4-month routine maintenance schedule; plus sign means next cycle

Having preventive replacement schedule of those ten major components, the direct costs of preventive maintenance system was calculated and it was compared to those of the actual corrective maintenance system. The results are shown in table 5. The table indicated that applying preventive machinery maintenance with periodic replacement of the spare parts may reduce direct maintenance cost to about 59.6% of the existing practiced corrective machinery maintenance. Seeing its nominal value, the cost reduction may be less attractive for the decision makers to change the machinery maintenance approach into preventive machinery maintenance. Inaccurate calculation of yield loss due to unscheduled machinery breakdown highly affected the cost calculation result. However, it should be noted that the nominal value will become greater if some more spare parts/components involved are analysed.

Table 5. Direct cost of corrective maintenance and preventive maintenance (based on 11 spare parts).

| Machine                 | Part/Component  | Unit Price (IDR) | Corrective Maintenance (24 years) | Preventive Maintenance (3-year cycle) |
|-------------------------|-----------------|------------------|-----------------------------------|---------------------------------------|
|                         |                 | Number of Parts  | Direct Cost (IDR)                | Number of Parts  | Direct Cost (IDR) |
| Air Screen Separator    | Bearing 6202    | 28,000           | 26                                | 728,000                             | 3                   | 84,000                  |
| Box Dryer               | Plate Screen    | 45,000           | 6                                 | 270,000                             | 2                   | 90,000                  |
| Box Dryer               | Burner NYY Cable| 180,000          | 5                                 | 900,000                             | 1                   | 180,000                 |
| Box Dryer               | Acer Plate      | 170,000          | 8                                 | 1,360,000                           | 2                   | 340,000                 |
| Belt Conveyor           | NYY HY Cable    | 180,000          | 8                                 | 1,440,000                           | 2                   | 360,000                 |
| Chain Conveyor          | Chain           | 50,000           | 24                                | 1,200,000                           | 3                   | 150,000                 |
| Bucket Elevator         | Gear Elevator Z31| 15,000          | 17                                | 1,513,000                           | 3                   | 45,000                  |
| Sealer                  | Heating element | 15,000           | 84                                | 1,260,000                           | 12                  | 180,000                 |
| Cyclone                 | Bearing 2211    | 30,000           | 26                                | 390,000                             | 3                   | 90,000                  |
| Cyclone                 | V Belt B118     | 55,000           | 18                                | 990,000                             | 3                   | 165,000                 |
| Seed Cleaner            | Screen          | 147,000          | 21                                | 3,087,000                           | 3                   | 441,000                 |
| Paid idle labor         |                 |                  |                                   | 7,236,000                           |                     | -                       |
| Cost of machinery start-up|              |                  |                                   | 1,650,200                           |                     | -                       |
| Production lost due to unscheduled machinery breakdown | |                  |                                   | 6,536,250                           |                     | -                       |

Total direct maintenance cost (24 years) 28,540,450

Average direct maintenance cost (3-year cycle) 3,567,556 2,125,000
4. Conclusions
A case study on analysis of possible cost reduction on maintenance of paddy seed production machinery through changes from the current practiced corrective maintenance system into preventive maintenance system has undertaken with positive results. Based on criteria of component criticality, four (4) out of 12 machinery involved in paddy seed production were rated as critical, i.e. chain conveyor, belt conveyor, dryer, and sealer; four (4) were rated as slightly critical (bucket elevator, pre-cleaner, locker bin, and air screen separator). The rest were not critical. Analysis on eleven (11) components out of 294 involved components in the machinery showed that the optimum time for replacing the components/spare parts varies, ranging from 9 months to 3 years. Applying the preventive machinery maintenance with periodic replacement of the components may reduce maintenance cost to about 59.6% of the existing practiced corrective machinery maintenance. Therefore, preventive machinery maintenance is recommended to be implemented instead of corrective machinery maintenance

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