Jurnal SIstem Teknik Industri (JSTI) Vol. 23, No. 1, 2021 | 111 – 120

talenta PUBLISHER

JSTI
Jurnal Sistem Teknik Industri

Preventive Maintenance Scheduling on Belt Conveyor Using Failure Mode Effect and Criticality Analysis

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Abstract. PT. X is a services and manufacturing company. PT. Y is one of some of industrial companies use the services of PT. X, is one of the biggest chemical fertilizer producer in Southeast Asia. PT Y uses 66 belt-conveyors for distributing the material. In order to arrange maintenance schedule, used preventive maintenance calculations using Failure Mode Effect and Critically Analysis method (FMECA). Preventive maintenance is used to schedule the maintenance of the conveyor belt's components (belt and primary cleaner). Data analysis obtained a critical belt values are $2.521x10^{-3}$ and $1.863x10^{-3}$, respectively, on the primary cleaner component. Furthermore, effective maintenance and evaluation time intervals which obtained for belt components is indicating operation time with 92% reliability level or about 215 hours.

Keyword: Maintenance, Scheduling, Failure Mode Effect Criticality and Analysis (FMECA), Critical Components, Cleaner

Abstrak. *PT. X adalah sebuah perusahaan di bidang jasa dan manufaktur. PT. Y adalah perusahaan pengguna jasa dari PT. X, sebuah perusahaan penghasil pupuk kimia terbesar se-Asia Tenggara. PT. Y menggunakan belt conveyor dalam mendistribusikan material. PT. Y mempercayakan perawatan 66 belt conveyor kepada PT. X. Penyusunan jadwal pemeliharaan/perawatan dilakukan dengan perhitungan preventive maintenance memakai metode failure mode effect and criticality analysis (FMECA). Penjadwalan pemeliharaan/perawatan komponen belt conveyor (belt dan primmary cleaner) menggunakan konsep preventive maintenance. Pengolahan data menghasilkan nilai critical belt sebesar* $2,521x10^{-3}$ *dan* $1,863x10^{-3}$ *pada komponen primmary cleaner. Interval waktu perawatan dan level keandalan yang efektif menunjukkan waktu operasi dengan reliability 92% atau sekitar 215 jam.*

Kata Kunci: Penjadwalan, Maintenance, Failure Mode Effect Criticality and Analysis (FMECA), Komponen Kritis, Cleaner.

Received 06 October 2020 | Revised 15 January 2021 | Accepted 26 January 2021

1. Introduction

A company must get the process efficiently and effectively, and resulting in the highest profit. Maintenance is a supporting factor in increasing the productivity of a company, especially those

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https://doi.org/10.32734/jsti.v23i1.4368

Journal Homepage: http://talenta.usu.ac.id/jsti

engaged in manufacturing. The availability of a good machine maintenance system can increase quality and productivity, by minimizing downtime and maximizing effectiveness [3][4].

PT. X is a company engaged in services and manufacturing. One of the member of PT. X, is PT. Y, which is the largest chemical fertilizer factory in Southeast Asia. PT. Y uses several transportation methode, for delivering the material from the ship at the port to the storage area. One of the transportation tool is the belt conveyor.

Routine maintenance that is carried out aims to reduce the frequency of damage to the belt conveyor, which is applied to 66 conveyor belts, namely 2 times a month. The material transported from the ship to the factory, package in bulks, are sulfur and phosphate. Damage or failure of the conveyor causes PT. Y will be penalized for demurrage or the length of time using the container exceeds the provisions.

In this article, we arrange the preventive maintenance schedule using the concept of failure mode effect and criticality analysis (FMECA) on the belt conveyor, as the object of this research. El-Dogdog [2] states that FMECA can be applied in designing of the reliability center maintenance concept. On all belt conveyor, is in a production line with a high level of utilities, for screening the sulfur. The belt conveyor needs to get special treatment to avoid any downtime.

2. Literature Review

2.1. Preventive Maintenance

Preventive maintenance is a systematic, economical way of keeping production equipment running and extending its service life. Preventive maintenance aims to obtain a optimum maintenance level for all production equipment in order to obtain the highest quality [5][6].

Preventive maintenance is also means as maintenance throughout the range or duration, paying attention to other things to minimize the opportunity for other components to exceed the provisions. Preventive maintenance is carried out when the failure rate increases, as shown in the bathtub graph, and the formula is:

$$C(Tp) = \frac{cf \text{ x } \left(1\text{-}R(Tp)\right)+Cp \text{ x } R(Tp)}{Tp \text{ x } R(Tp)+M(Tp) \text{x } (1\text{-}R(Tp))} \tag{1}$$

This cutting region is often called the wear out area. to calculate the total cost per unit of time, is used:

$$M(Tp) = \int_0^{Tp} \frac{t\, f(t)dt}{(1\text{-}R(Tp))} \tag{2}$$

C(Tp) = total cost
Cp = preventive maintenance cost
Cf = corrective maintenance cost

Tp = interval between preventive maintenance
R(Tp) = reliability level
M(Tp) = Maintainability

Determining the amount of preventive maintenance by:

$$nT < t < (n+1)\,T;\ n = 0,1,2 \quad (3)$$

Rm(t) = reliability level.
R(t)n = The probability of the n value of the maintenance interval
R(t-nT) = The probability of the t until nT value of the maintenance interval.

2.2. Reability

The reliability is the probability that the equipment will work properly, functioning over time (t) or even more. The reliability level is expressed by [1]:

$$R(t)=1-F(t)= \int_t^{\sim} f(t)dt \quad (4)$$

f(t) = probability density function
R(t) = probability the equipment perform at interval t
F(t) = probability the equipment do not perform at interval t

The probability density function of 2-parameters Weibull is [1]:

$$f(t) = \frac{\beta}{\eta}\left(\frac{t}{\eta}\right)^{\beta-1} \exp\left[-\left(\frac{t}{\eta}\right)^{\beta}\right] \quad (5)$$

$$f(T) \geq 0,\ \eta > 0,\ t \geq 0,\ \beta > 0 \quad (6)$$

η = Eta (scale parameter)
β = Beta (shape parameter)

The meantime between failure (MTBF) is:

$$MTBF = \gamma + \Gamma\left(\frac{1}{\beta}+1\right) \quad (7)$$

γ = Gamma (location parameter)

The probability density function of 3-parameters Weibull is:

$$f(t) = \frac{\beta}{\eta}\left(\frac{t-\gamma}{\eta}\right)^{\beta-1} \exp\left[-\left(\frac{t-\gamma}{\eta}\right)^{\beta}\right] \quad (8)$$

$$r(x) = \int_0^x y^{x-1} - e^{-y}\, dy \quad (9)$$

2.3. Failure mode Effect & Criticality Analysis (FMECA)

Rausand stated that FMECA is a methode for identifying and analyze [7]:

1. Possible damage
2. Other effects of damage, using monitoring the severity and probability level.

FMECA consists of two steps of analysis, namely Failure Mode and Effect Analysis (FMEA), which consists of four stages: system determination, system function block diagrams, identification of the mode of damage and identification of the consequences. The Criticality Analysis (CA) stages include the calculation of the criticality value and the calculation of the failure rate [8].

Table 1 Criticality

CRITICALITY		Risk or Hazard
Degree of criticality	Value	
Minor	0-30	Acceptable
Medium	31-60	Tolerable
High	61-180	
Very High	181-252	Unacceptable
Critical	253-324	
Very critical	>324	

Table 2 Occurrence Rating

Rating	Probability of occurrence	Failure probability
10	Very High (VH)	> 1 in 2
9	High (H)	1 in 3
8		1 in 8
7		1 in 20
6	Moderate (M)	1 in 80
5		1 in 400
4		1 in 8000
3	Low (L)	1 in 15000
2		1 in 150000
1		< 1 in 150000

Table 3 Severity Rating

Rank	Verbal Criteria
1	Negligible severity
2	Mild severity
3	
4	Mild severity
5	
6	

7 8	High severity
9 10	Catastrophic: potential safety problem

Table 4 Detection Rating

Rank	Verbal Criteria	Failure probability
1	Almost Certain	1 in 1000000
2	Very High	1 in 20000
3	High	1 in 4000
4	Moderate High	1 in 1000
5	Moderate	1 in 400
6	Low	1 in 80
7	Very Low	1 in 40
8	Remote	1 in 20
9	Very Remote	1 in 8
10	Absolute Uncertain	1 in 2

3. Literature Review

3.1. Data Collecting

Primary research data were obtained directly from original sources, by interviewing a person or any community. The purpose is to answer the research questions and doing an observation. Secondary research data is obtained indirectly or through intermediary media. The required data are:

1. Breakdown time of the belt conveyor.
2. List of the belt conveyor components.
3. Repairing-Time duration.
4. The Critical component of the belt conveyor.

3.2. Failure Effect Identification

Identification of the failure effect aims to determine the components, i.e. the object of this research, and looking for the causes, impacts, and forms of failure that occur in the belt conveyor components.

3.3. Determine the Critical Component

At this stage, the RPN value is obtained by multiplying S x O x D. The next step is FMECA analysis. The component with the largest RPN value is the critical component.

3.4. Preventive Maintenance Scheduling

After collecting data on critical components of the conveyor belt, the average time between damage of the components is calculated. This process is carried out with a distribution approach from the damage data obtained. Maintenance schedules are prepared by taking into account the desired level of reliability.

4. Result and Discussion

4.1. Risk Priority Number (RPN) of the Belt Conveyor Component

By doing some observations [9], the RPN value for each component is obtained as follows:

Table 5 RPN Value of the Belt Conveyor Component

No.	Component	RPN
1	Pulley	24
2	Tension Roll	24
3	Stop End	12
4	Hopper inlet	24
5	Cut Hopper Inlet	24
6	Skirtboard	24
7	Rubber Seal	36
8	Impact Roll	36
9	Carry Roll	48
10	Hopper Outlet	18
11	Primmary Cleaner	60
12	Head Pulley	36
13	Secondary Cleaner	40
14	Snub Head Pulley	24
15	Bend 1 Pulley	24
16	Counter Weight	27
17	Take Up	24
18	Bend pulley	24
19	Inverse Roll	18
20	Tilting Roll	18
21	Return Roll	18
22	V-scrapper	36
23	Snub Tail Pulley	18
24	Belt	96

4.2. Determine the Critical Component

According to the FMEA analysis, which resulting the RPN value, it can be seen that the belt component and primmary cleaner have the highest value. The calculation of the critical value of the components as seen in the table below.

Table 6 Critical Component Data

Component	Failure mode critical (Cm)
Belt	$2{,}521x10^{-3}$
Primmary Cleaner	$1{,}863x10^{-3}$

4.3. Mean Time Between Failure (MTBF)

We used the records of belt conveyor breakdowns on interval of December 2018 to July 2019.

Table 7 Records of Belt Conveyor Breakdown

No.	Down	Up	Maintenance Time (hours)	MTBF (hours)	Operation time (hours)
1	1/3/19 10:32	1/3/19 15:02	4,50	0	20,23
2	1/4/19 11:16	1/4/19 16:01	4,75	24,98	65,32
3	1/7/19 9:20	1/7/19 14:30	5,17	70,48	264,08
4	1/18/19 14:35	1/18/19 19:50	5,25	269,33	328,95
5	2/1/19 12:47	2/1/19 17:47	5,00	333,95	69,05
6	2/4/19 14:50	2/4/19 19:35	4,75	73,80	597,60
7	3/1/19 17:11	3/1/19 22:26	5,25	602,85	230,85
8	3/11/19 13:17	3/11/19 18:07	4,83	235,68	235,63
9	3/27/19 7:45	3/27/19 12:45	5,00	240,63	187,58
10	4/4/19 8:20	4/4/19 13:00	4,67	192,25	68,58
11	4/7/19 9:35	4/7/19 14:05	4,50	73,08	95,42
12	4/11/19 13:30	4/11/19 18:15	4,75	100,17	15,75
13	4/12/19 10:00	4/12/19 15:20	5,33	21,08	426,25
14	4/30/19 9:35	4/30/19 14:10	4,58	430,83	309,00
15	5/13/19 11:10	5/13/19 16:00	4,83	313,83	26,67
16	5/14/19 18:40	5/14/19 23:10	4,50	31,17	59,78
17	5/17/19 10:57	5/17/19 15:57	5,00	64,78	135,22
18	5/23/19 7:10	5/23/19 12:10	5,00	140,22	141,92
19	5/29/19 10:05	5/29/19 15:15	5,17	147,08	305,08
20	6/11/19 8:20	6/11/19 13:35	5,25	310,33	553,42
21	7/4/19 15:00	7/4/19 19:40	4,67	558,08	260,00
22	7/15/19 14:40	7/15/19 19:25	4,75	264,75	60,83
23	7/18/19 8:15	7/18/19 13:25	5,17	66,00	0,00

4.4. Determination of Reliability Parameters of the Belt Component

After we got the MTBF and repairing time, the reliability parameters are determine using Weibull++6. There are three test parameters to determine the type of distribution, namely Average Good Fitness (AvGOF), Average of Plot (AvPlot), and Likelihood Function Ratio (LKV).

Table 8 The Probability Distribution of the MTBF of the Belt Component

Distribution	AvGOF	AvPLOT	LKV	Rank
Exponential 1	12,169	4,619	-139,38	4
Exponential 2	6,057	4,202	-137,02	2
Normal	10,835	5,656	-143,39	6
Lognormal	15,467	4,494	-139,27	5
Weibull 2	7,825	3,711	-138,56	3
Weibull 3	1,154	3,366	-138,11	1

Based on the results of the distribution ranking in Table 8, the distribution of the MTBF of the belt components is Weibull 3 parameters. The paramaters are β = 0,9798, γ = 206,697, and η = 12,644. Using these data, we got the average of the MTBF of the belt component is about 220 hours.

4.5. Determination of Maintainability Parameters of the Belt Component

Based on the maintainance time on table 7, we determine the maintainability distribution using Weibull++6. The result as shown in table below.

Table 9 The Probability Distribution of the MTBF of the Belt Component

Distribution	AvGOF	AvPLOT	LKV	Rank
Exponential 1	99,999	33,817	-63,308	6
Exponential 2	83,221	11,103	-2,051	5
Normal	13,389	4,832	-1,997	3
Lognormal	13,214	4,778	-1,987	2
Weibull 2	41,418	6,521	-2,702	4
Weibull 3	6,121	4,099	-1,624	1

Based on the results of the distribution ranking in Table 9, the distribution of the MTBF of the belt components is Weibull 3 parameters. The paramaters are β = 2,2034, γ = 0,6877, and η = 4,2963. Using these data, we got the average of the maintainability of the belt component is about 5 hours.

4.6. Determination of Operation Time Parameters of the Belt Component

Based on the down and up time on table 7, we determine the operation time distribution using Weibull++6. The result as shown in table below.

Table 10 The Probability Distribution of Operation Time of the Belt Component

Distribution	AvGOF	AvPLOT	LKV	Rank
Exponential 1	10,730	4,101	-138,85	4
Exponential 2	6,223	4,154	-137,07	3
Normal	18,626	5,661	-143,39	6
Lognormal	17,193	4,624	-139,32	5
Weibull 2	4,106	3,554	-138,34	2
Weibull 3	1,193	3,373	-138,07	1

Based on the results of the distribution ranking in Table 10, the distribution of the Operation time of the belt components is Weibull 3 parameters. The paramaters are β = 0,9508, γ = 204,9817, and η = 8,9987. Using these data, we got the average of the MTBF of the belt component is about 215 hours.

4.7. Determination of the Operating Time

The component reliability is inversely related to the duration of operation time. The calculation of some operating time values resulting a level of reliability, as shown below.

Table 11 Determination of the Operating Time according to the Reliability

No.	Operation time (hours)	Reliability
1	215	0,9232
2	359	0,7851
3	503	0,6662
4	647	0,5739
5	791	0,5023
6	935	0,4458
7	1079	0,4004
8	1223	0,3632
9	1367	0,3322
10	1511	0,3060
11	1655	0,2836
12	1799	0,2642
13	1943	0,2473
14	2087	0,2324
15	2231	0,2192
16	2375	0,2074
17	2519	0,1968
18	2663	0,1872
19	2807	0,1785
20	2951	0,1706
21	3095	0,1633
22	3239	0,1567

Using the data in the table above, we get a plot of the relationship between the duration of operation time and the reliability value, as shown in Figure 1.

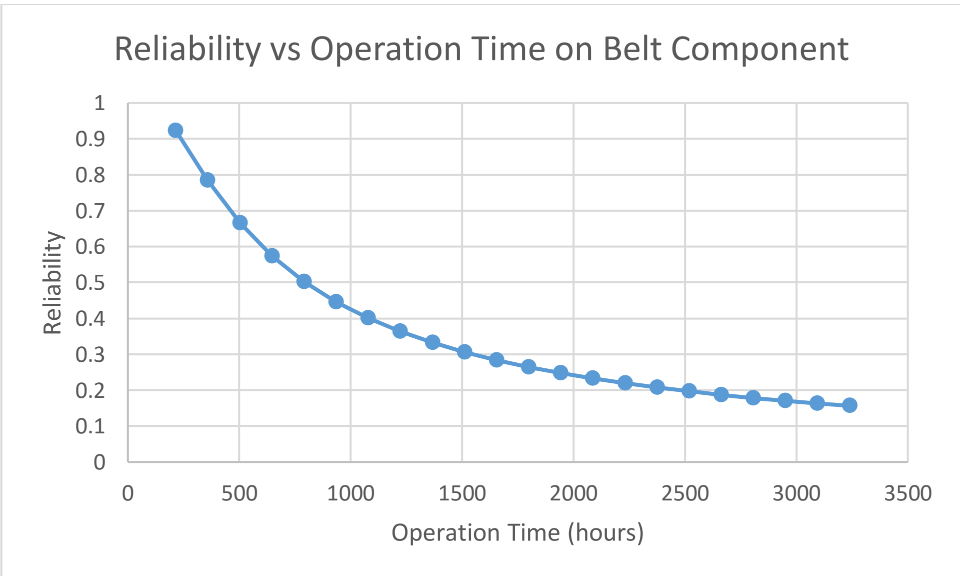

Figure 1 The Relationship between the Duration of Operation Time and the Reliability

4. Conclusion

After performing data processing and analysis, we get the following conclusions. The most critical component of the belt conveyor machine is the primmary cleaner. The belt conveyor have to conduct a maintenance activity after 215 hours operation time. For this condition, the reliability is 92,32 %.

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