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Method for Determining the Number of Maintenance Personnel

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Abstract—Reducing the number of workers (downsizing) is a strategic step for companies to increase their competitiveness. With downsizing, worker productivity is expected to increase; therefore, the company's financial performance can improve. For the quantitative accuracy of downsizing to be achieved, it is necessary to measure the workload of the related work. Measuring the workload on maintenance work is difficult because of the varying nature of the work activities (e.g., frequency, duration, complexity). This study aims to develop a method for calculating the number of workers working in maintenance. The developed method is based on a combination of time study and RAM (Reliability, Availability, Maintainability) methods. The number of maintenance workers is determined by calculating the Full-time equivalent value (the ratio between the actual total working hours and the maximum scheduled working hours). A full-time equivalent value greater than one indicates a workload that is too large (over-utilized), and a full-time equivalent value of less than one indicates a workload that is too small (underutilized). The method developed was then tested in a case study on maintenance work at a mining company. The results show that the proposed method can be used as input for decision-makers in determining the number of workers on maintenance work.

***Keywords*—**Maintenance, Worker, Probability, Reliability, Availability, Maintainability

I. Introduction

Downsizing is one of the strategic steps for companies in dealing with declining economic conditions or increasing the company's competitiveness (Brauer & Zimmermann, 2019). The downsizing measure aims to increase worker productivity and improve financial performance by reducing labor costs and workforce size.

Downsizing can also contribute to an improvement of the firm's long-term value and growth. On the study of 3,149 US publicly traded manufacturing firms, Alnahedh & Alrashdan (2021) found a positive relationship between corporate downsizing and a firm's long-term value with no moderation effect of the proximity to bankruptcy.

However, downsizing may have drawbacks such as a reduction in skilled workers and low morale of employees. The satisfaction and commitment of existing employees can also be degraded, which can result in lower performance (Mujtaba & Senathip, 2020). Downsizing not only impacts to the workers who are laid off, but also those who remain, where they experience a wide range of harmful secondary effects (i.e., poor work conditions), which are associated with a wide variety of adverse outcomes (Frone & Blais, 2020). Similarly, Ahammer, et al. (2021) shows that downsizing has significant impact on mental and physical health of the employees who remain, and these conditions might impact on the non-negligible costs for company. For this reason, some companies prefer to have a cutting pay policy for payroll cost reduction than downsizing policy. Companies that has a history of downsizing consider to be less favorable for job-seeker in comparison to company that have a history of pay cuts (Yoon, 2022).

Downsizing must ensure that the rationalization is carried out correctly from a qualitative standpoint (i.e., reducing incompetent human resources) and from a quantitative standpoint (i.e., reducing appropriate human resources). To ensure the rationalization's quantitative accuracy, it is necessary to measure the workload of the type of work to be carried out by the rationalization. Several studies have been conducted to determine the optimal number of workers. The optimal number of workers in Surakarta's cosmetic industry has been performed using workload analysis (Dewi & Alghofari, 2020). The optimal number of salesmen in Makassar has been determined by using a full-time equivalent approach (Ahmad, et al, 2021). Akhundov, et al. (2022) formulated mathematical models based on scheduling problem to determine optimal number of workers at a restaurant chain based in Baku, Azerbaijan, which showed that applying this model can reduce overstaffing levels by approximately 40% and labor costs by 20% while keeping the same service standards. Minimizing the number of workers in a paced mixed-model assembly line were also conducted by Delorme, et al. (2019) by using Integer Linear Programming model.

All the studies above are conducted for routine work (e.g., production) where measuring workload can be done quickly because the variation in work activities (e.g., frequency, duration, complexity) is insignificant. However, measuring workload becomes difficult for non-

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routine work (e.g., maintenance) due to the significant variation in work activities.

Maintenance could be defined as an integrated activity of all possible technical and administrative actions, including planning, supervising, monitoring and controlling to ensure that an asset, a machine, or an equipment in their original functional state in which they can perform the intended functions. It also includes protective and corrective actions to keep the plant operational system in intended conditions or to maintain the acceptable manufacturing conditions (Erbiyik. 2022). Maintenance types could be divided into two main parts namely Planned Maintenance and Unplanned Maintenance. In general, planned maintenance can be treated as routine work and can be scheduled. For unplanned maintenance, the nature of event is random, therefore must be considered as a stochastic process. But both types of maintenance share a common characteristic that even for the same asset, the maintenance works varies from time to time. This variation is due to complication and scope of activities for each maintenance demand.

Maintenance activities are very important for the business process of the company. When the production facilities or machines suddenly experiences an unexpected failure, the entire operational process will be disrupted and ultimately reduce productivity. Choosing the right type of maintenance is not an easy task, as it involves multiple criteria and consideration and will impact significantly on the sustainability of the company (Hamasha, et al., 2023).

The industry is generally experiencing problems related to the increase in the cost of maintenance work. Every year, the budget allocated to the maintenance department has increased (Azizova, 2024). Based on the data from the discrete manufacturing of U.S. manufacturers, Thomas & Weiss (2020) shows that in 2016 the costs and losses due to maintenance were estimated to be $57.3 billion. Depending on the type of industry, in the USA, maintenance-related costs account for 15 to 70 percent of the value of goods produced (Thomas, 2018), where personnel-related costs are the most significant cost component of care work within self-care departments; it reaches 70-80 percent of the total cost of care (Dong, Zhao, & Wang, 2022).

Due to the complexity of maintenance tasks, maintenance workers often must perform a variety of tasks frequently under unusual circumstances which requires decision-making accompanied by excessive cognitive and physical demands. These circumstances are including working at a running process, under a time pressure, in an awkward posture, lifting heavy weights, and working on machineries with different components, which require an understanding of unique methods and processes for each task (Alhaag, et al., 2022). Maintenance workers typically experience more serious and frequent accidents than production workers (Baç & Ekmekçi, 2021).

It is known that cognitive and physical load, if it cannot be managed properly, could contribute to work stress and decrease work performance accordingly. Three studies on maintenance workers shows that most of maintenance workers experience work stress and have significant impact on their work performance (Utari, et al., 2021), physical workload has a correlation with work stress (Aulia, et al., 2021), and cognitive workload significantly effects on mental and physical stress (Abdul-Samad, et al., 2022).

An analysis of the overall workload and personnel capacity must be carried out to rationalize workers in maintenance work. An analysis of the needs for the capacity of maintenance personnel includes quantitative needs (i.e., the number of staff needed), qualitative needs (i.e., competence and ability of staff), as well as time requirements (i.e., within a certain period). Regarding quantitative needs, there is a challenge in determining the number of employees in maintenance work considering the uncertainty of maintenance work activities (e.g., frequency, duration). Therefore, this research aims to develop a method for determining the number of employees in maintenance jobs.

II. METHOD

A. Overview of the Proposed Method

This study developed a method for determining the number of employees in maintenance work based on a combination of time study and RAM (Reliability, Availability, Maintainability) methods. Figure 1 shows the general description of this method.

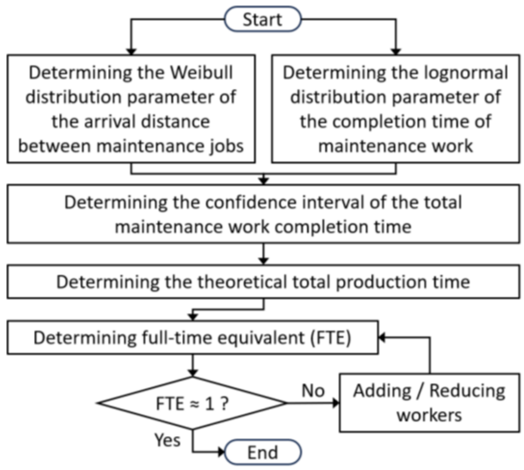

Figure 1. Flowchart of the Proposed Method

The proposed method begins by determining the Weibull distribution parameter of the arrival distance between maintenance jobs and the lognormal distribution parameter of the completion time of maintenance work. Next, determine the confidence interval of the total maintenance work completion time. Then, the theoretical total production time data is determined to calculate the adequate working time of workers by considering the allowance factor. Finally, maintenance work's full-time equivalent (FTE) value is calculated. FTE is selected for the calculation as it is the most adapted method for determining number of workers regardless of the type of industry (Wijaya, et al., 2024; Edi, et al., 2024; Rahman, et al., 2023; Kustanti, et al., 2023). If the FTE value is close to one, then the number of workers is appropriate; if not, adding or reducing workers is necessary.

B. Interval Estimation of Total maintenance work completion time

In this method, the arrival distance between maintenance jobs is assumed to follow the Weibull distribution, and the completion time of maintenance work is considered to follow the lognormal distribution. The assumptions are since most maintenance work completion times conform to the lognormal distribution, and most machine failures conform to the Weibull distribution (Abernethy, 2004).

The probability density function (pdf) of the Weibull distribution is given by (1):

$$g(y)=\frac{\beta}{\eta}\left(\frac{y}{\eta}\right)^{\beta-1}\exp\left[-\left(\frac{y}{\eta}\right)^{\beta}\right], \quad y > 0 \qquad (1)$$

where $\beta > 0$ is the shape parameter, and $\eta > 0$ is the scale parameter of the distribution. The mean arrival distance between maintenance jobs (MTP) is given by (2):

$$MTP = \mu_y = \eta\Gamma\left(\frac{1}{\beta}+1\right) \qquad (2)$$

The probability density function (pdf) of the lognormal distribution is given by (3):

$$f(x)=\frac{1}{x\sigma\sqrt{2\pi}}\exp\left[-\frac{1}{2}\left(\frac{\ln(x)-\mu}{\sigma}\right)^2\right], \quad x > 0 \qquad (3)$$

where μ and σ are the mean and standard deviation of the natural logarithm of the variables. The mean time to repair (MTR) is given by (4):

$$MTR = \mu_x = \exp\left(\mu+\frac{\sigma^2}{2}\right) \qquad (4)$$

The total maintenance work completion time (TTR) can be determined by (5):

$$TTR = \frac{MTR}{MTP}\,TTP, \quad x > 0 \qquad (5)$$

where TTP is the total production time. For the arrival distance between maintenance work with the Weibull distribution and the completion time of maintenance work with a lognormal distribution, then equation (5) can be rewritten as (6):

$$TTR = \frac{\mu_x}{\mu_y}\,TTP \qquad (6)$$

The confidence interval of the total maintenance work completion time can be determined by solving the confidence interval for $\mu x/\mu y$. Confidence intervals can be determined using the approximate method or the exact method. The approximation method determines the confidence interval roughly to get the "at least confidence interval" type. In the exact method, the confidence interval is determined simultaneously to make the results more accurate. In this study, the confidence interval of $\mu x/\mu y$ was determined by adopting the exact method from Wijaya (2012). The estimation for the average value of the total maintenance work completion time (TTRM) can be determined by (7) and the lower and upper limits of the total maintenance work completion time (TTRUL and TTRLL) can be determined by (8) and (9) respectively:

$$TTR_M = \left(\frac{\exp\left(\mu+\frac{\sigma^2}{2}\right)}{\eta\Gamma\left(\frac{1}{\beta}+1\right)}\right)\cdot TTP \qquad (7)$$

$$TTR_{LL} = \left(a\cdot\frac{\exp\left(\frac{\sigma^2}{2}\right)G}{\Gamma\left(\frac{1}{\beta}+1\right)2\eta^{1-\beta}\sum_{i=1}^{m}y_i^{\beta}}\right)\cdot TTP \qquad (8)$$

$$TTR_{UL} = \left(b\cdot\frac{\exp\left(\frac{\sigma^2}{2}\right)G}{\Gamma\left(\frac{1}{\beta}+1\right)2\eta^{1-\beta}\sum_{i=1}^{m}y_i^{\beta}}\right)\cdot TTP \qquad (9)$$

Where (7-9) :
σ = standard deviation of the lognormal distribution
G = geometric mean of the lognormal distribution
η = scale parameter of the Weibull distribution
β = shape parameter of the Weibull distribution
y = arrival distance between maintenance jobs
a = constant for the lower bound
b = constant for the upper limit

The effective working time of workers is determined by considering the theoretical production time and allowances for workers. Allowances are made to ensure that the average worker can achieve the expected standard time when working at a normal pace. Allowances are generally divided into four parts, namely relaxation allowances, contingency allowances, policy allowances, and special allowances. Relaxation allowance is an addition to the basic time provided for workers to restore conditions from the physiological and psychological effects of work and to pay attention to personal needs. Relaxation allowance consists of fixed allowances given to workers who do light work in a sitting position and in good working conditions, where the hands, feet, and five senses are used normally (fixed allowance), and additional allowances given when working conditions differ from those of required (variable fatigue allowance). Fixed allowances consist of personal needs allowances, allowances provided to meet personal needs (e.g., taking a drink, going to the restroom), and basic fatigue allowances provided to calculate the energy used in doing work and reduce monotony. A contingency allowance is a relatively small additional time to meet specific work requirements, delays, or rare or irregular

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events (e.g., supervisor interruptions or material irregularities). Policy allowance is an allowance given to ensure sufficient income for workers for a certain level of performance and under certain conditions (e.g., new employees). Finally, special allowance is given for activities that, under normal conditions, are not part of the operating cycle but are essential for satisfactory work performance (e.g., start-up allowance, dismantling allowance).

The number of maintenance workers needed can be determined by calculating the Full time equivalent (FTE) value. FTE is the ratio between the actual total working hours and the maximum scheduled working hours. An FTE value greater than one indicates a workload that is too large (over-utilized). Reducing the value of FTE can be done by providing overtime (overtime regime) and adding human resources. An FTE value of less than one indicates a workload that is too small (underutilized). Increasing the FTE value can be done by providing additional work activities (job enlargement) and reducing human resources (downsizing).

III. Case Study

The proposed method can determine the number of employees in maintenance jobs in any industrial sector as long as the uncertainty of maintenance work activities is considered. A case study in the mining sector illustrates the proposed method's application.

A. Overview of the Case Study

The case study involves maintenance work for mobile equipment in the Kristineberg mining operation held by Boliden Mineral AB. The Kristineberg Mine is in North of Sweden. It has been operating for the last 82 years with a production capacity of around 750,000 tons per year. To date, The Kristineberg Mine has been explored to a depth of 1,400 meters, along a plunge of around 3 kilometers. A more comprehensive description of the company and the mobile equipment can be found in Wijaya (2012). The number of workers who handle mobile equipment maintenance is six people divided into two shifts, and the number of mobile equipment that must be handled is nine units.

B. Results and Discussion of the Case Study

Maintenance work data is historical data for two years, obtained from Maximo, a computerized maintenance management system and the maintenance department's internal reports. Maintenance work data is tested against the validity of the independent and identically distributed (i.i.d.) assumptions prior to being plotted in the related distributions (Weibull distribution and lognormal distribution). The Laplace trend test and autocorrelation test are utilized for testing the assumptions. The parameters of the related distribution are determined by the maximum likelihood estimation (MLE) method and the suitability of the distribution with the Kolmogorov–Smirnov test. All tests were conducted with an alpha significance level (α) of 0.05.

The determination of the confidence interval of the total maintenance work completion time is based on the total theoretical production time in one year. During the data collection period, the company's working hours were 16.5 hours per day, and production was stopped for three weeks per year. Every year, routine shutdown is carried out for maintenance, and based on historical data, the shutdown duration follows a lognormal distribution with an average time of 350 hours. Based on data on working hours, number of working days and effective working weeks per year, theoretical production time, and regular shutdowns, the total theoretical production time in one year is 5,300 hours. The distribution parameters of the arrival distance between maintenance work and the completion time of maintenance work from one mobile equipment unit and the average values and lower and upper limits of the total maintenance work completion time (TTRM, TTRLL, and TTRUL) are shown in Table 1. The constant values for the lower limit (a) and upper limit (b) are obtained from equations (8) and (9) and solved numerically with the MuPAD software.

The worker's effective working time is determined by entering the allowance factor. The concessions given to workers include relaxation allowances, contingency allowances, and special allowances. The policy allowance is not given because the current workers are experienced (e.g., minimum five years working period). All maintenance workers are male, so the basic fatigue allowance is 5%, and the total fixed allowance is 9%. Variable fatigue allowance is determined based on ILO standards, where for working conditions requiring abnormal positions, force, and concentration, the value is 15%. The contingency allowance is set at a maximum value (i.e., 5%) because this type of maintenance work has the potential for delays and interruptions from supervisors. A special allowance is set at 5% for dismantling and start-up activities. So, the total allowance given is 34%.

The time available for maintenance work is obtained from the effective working time of the worker multiplied by the number of workers working for the job. At the time the data was collected, there were a total of 6 workers divided into two shifts. The effective working time of workers is obtained from the total theoretical production time in one year (5,300 hours) minus the time allocated for allowances (5,300 x 34% = 1,802 hours). So, the total time available for maintenance work is 20,988 hours for six workers. Table 1 shows that the upper limit for the total time for completing maintenance work for one mobile equipment unit is 2,836 hours, so for nine mobile equipment units, it is 23,742 hours. Based on a comparison between the total time for completing maintenance work (23,742 hours) and the total time available (20,988 hours), an FTE value of 0.80 is obtained. It shows that there currently needs to be more maintenance workers. The strategy adopted by the company at this time to cover the shortage of workers is to carry out an overtime system. Adding one worker makes the FTE value 1.03, but adding two workers makes the FTE value 1.18 (underutilized).

It indicates that one person needs to be added ideally, which raises difficulties regarding shift time allocation.

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Based on the type of maintenance work where the time of arrival of work is not specific, then placing one person in one shift is still not the right policy because it allows for over-utilized conditions in one of the shifts. The solution that can be considered is to recruit one worker for each shift but with a contract scheme and limited working time. This contract scheme has been adopted in some food and beverage businesses (e.g., Restaurants), where some workers only work during peak hours (e.g., lunchtime), and in the manufacturing industry, where some workers are only employed when the company has a high demand. However, management should also consider the side effects of this type of contract, such as employee welfare and other social impact in general.

Table 1. The Average Values and Lower and Upper Limits of The Total Maintenance Work Completion Time

Part	Motor	Central Lubrication	Hammer	Boom	Seat	Hoses	Cylinder
MTTF	500.07	193.18	195.64	107.04	923.08	72.10	88.35
MTTR	2.87	4.45	5.65	7.56	17.37	2.46	6.74
MDT	30.52	122.08	153.33	374.79	99.79	181.54	404.88
m_M	10.6	27.4	27.1	49.5	5.7	73.5	60.0
a	3.6	26.3	7.1	50.3	3.7	100.2	67.9
Down time lower limit	5.74	69.84	79.94	243.2	39.8	133.98	233.78
m_{LL}	4.6	20.7	19.6	39.9	3.6	63.4	45.6
TTR_{LL}	1.2	3.4	4.1	6.1	11.0	2.1	5.1
b	20.4	62.5	30.4	105.1	20.3	159.4	120.9
Down time upper limit	32.52	165.97	342.28	508.1	218.3	213.14	416.26
m_{UL}	11.0	32.0	40.5	57.7	8.5	80.0	60.9
TTR_{UL}	3.0	5.2	8.4	8.8	25.7	2.7	6.8
Part	Water System	Transmission	Bearer	Chassis	Cabin	Electric System	Valve
MTTF	165.75	1108.72	300.92	550.48	364.18	163.88	413.48
MTTR	2.71	5.70	4.43	5.63	4.44	2.87	5.79
MDT	86.97	27.25	77.88	54.19	64.61	93.14	74.49
m_M	32.0	4.8	17.6	9.6	14.6	32.3	12.8
a	21.5	3.6	11.4	8.3	3.2	33.3	6.4
Down time lower limit	43.85	12.44	30.05	29.32	10.0	51.79	28.78
m_{LL}	22.8	3.2	10.9	7.1	5.7	24.2	8.0
TTR_{LL}	1.9	3.9	2.8	4.1	1.7	2.1	3.6
B	55.7	20.1	37.6	33.7	24.3	71.1	33.9
Down time upper limit	113.60	69.48	99.12	119.04	77.2	110.58	152.43
m_{UL}	36.7	7.6	19.8	14.3	15.9	35.4	18.4
TTR_{UL}	3.1	9.1	5.0	8.3	4.9	3.1	8.3

III. CONCLUSION

This study developed a method for determining the number of employees needed for maintenance work. The proposed method is based on a combination of time study, RAM (Reliability, Availability, Maintainability) and Full-time equivalent value. The developed method can be used for determining the number of employees in maintenance jobs.

In this study, the method is developed under the assumption that the arrival distance between maintenance jobs is assumed to follow the Weibull distribution, and the completion time of maintenance work is considered to follow the lognormal distribution. Therefore, for the future study it is interesting to improve the method based on other distributions.

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