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Efficiency Measurement on the Effectiveness of Train and Wagon Maintenance: A Data Envelopment Analysis Perspective

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Abstract

Research Aims - This research aimed to analyse the efficiency measurement on the effectiveness of train and wagon maintenance in three Decision Making Units (DMU) of Balai Yasa of Indonesian Railways Company (KAI). It focused on both output and input orientations and the effectiveness of production.

Design - The research methodology was descriptive and quantitative, employing data envelopment analysis (DEA) and overall equipment effectiveness (OEE). The input variables were maintenance costs, spare parts inventory and people operating hours, while the output variable was OEE. A stepwise approach with backward method steps was used to examine the relationship between effectiveness and efficiency.

Findings - The results showed that DMU 2 was efficient, while DMUs 1 and 3 were not yet efficient. This indicated that the more effective an organisation is, the more efficient it is. DMU 2 has the highest effectiveness value at 86.19%, while DMUs 1 and 3 had values of less than 85%, indicating the need for improvement in their production departments.

Theoretical Contribution - A stepwise approach uses a forward method, adding revenue variables that have not been implemented in previous studies.

Managerial Implications in the Southeast Asian Context - Efficacy and revenue have a significant impact on organisational efficiency, which means that if the revenue is high and the organisation is effective, organisational efficiency will be high.

Research Limitation and Implications - This research is limited to DMUs, and its focus is on improving the effectiveness and efficiency of the train and wagon maintenance program in Java. The scope can be expanded to Sumatra and/or a comparison with other Southeast Asian countries by considering the characteristic differences of their operations and economies.

Keywords - data envelopment analysis, overall equipment effectiveness, stepwise approach

INTRODUCTION

The Indonesian Railway Company (Kereta Api Indonesia - KAI) is the largest train operator in Indonesia. Its main functions are the transportation of goods and passengers. It also has a secondary function of asset leasing. KAI carries out periodic maintenance of its train facilities and wagons to improve its productivity. Campbell (1999) defines 'maintenance' as a business process that converts input into usable output and has an impact on companies. Maintenance should be aimed at improving performance capabilities, including quality, benefits, and other concerns. Proper maintenance makes it possible for firms to meet regulatory requirements, including safety, hazard, and environmental standards, in a cost-effective manner. Zhu *et al.* (2002) suggest that maintenance is a business function that supports the main processes in the organisation. These processes provide value to the customer in

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terms of profit, quality, time and service; thus, maintenance can improve a company's business sustainability. Sherwin and Johnson (1995, as cited in Emrouznejad & Yang, 2018) have integrated maintenance as a type of production programme and part of a market-oriented system. It is important to provide feedback on the maintenance system, in order to improve firms' productivity, quality, reliability and design. To reduce total lifecycle costs, and to ensure machines are in the best condition, condition-based preventive maintenance should be carried out periodically. Therefore, preventive maintenance should be optimized, including component and machine updates, inspections, monitoring, repairs, and integration with other business functions, since maintenance may affect performance.

Balai Yasa is a unit of KAI that handles the maintenance overhauls of trains and wagons. In Java, there are three Balai Yasa train and wagon maintenance sites: UPT Balai Yasa Sarana Manggarai, UPT Balai Yasa Sarana Tegal, and UPT Balai Yasa Sarana Surabaya Gubeng. Based on the rail network, these three sites are operationally connected to the railroad and have the same business processes for the maintenance of trains and wagons.

Balai Yasa carries out two types of train and wagon maintenance, known as P24 and P48; these programmes are tasked with trains' and wagons' 24- and 48- month overhaul maintenance. The work programmes and realisation can be seen in Table 1 below;

As Table 1 shows, most of the recorded programmes for the realisation of Balai Yasa's three DMUs are at 98.8% achievement, which includes work repetition among them. This could lead to a gap between programme inaccessibility and realisation, alongside the existence of work repetition, which could disturb Balai Yasa's performance. Maltseva *et al.* (2020) argued that performance measurements can be defined in terms of measurement process efficiency and the effectiveness of actions. Gómez Fernández *et al.* (2018) pointed out that the success of a business depends on the performance of its marketing, financial, and operating or interacting plans during production.

As a result of the aforementioned gap, the performance is disturbed, which can lead to unbalanced effectiveness in the production department. However, the excessive use of resources occurs because every Balai Yasa DMU uses input resources efficiently but not effectively, or vice versa.

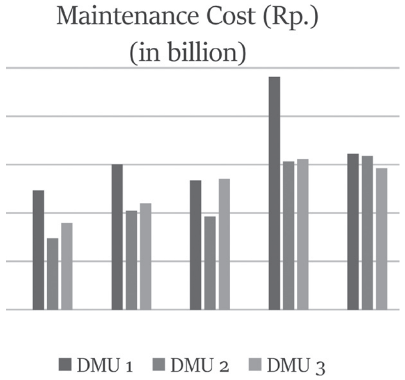
Table 1
Maintenance Programs and Realization

Maintenance Item	Type of Maintenance	DMU 1			DMU 2			DMU 3		
		∑ Prog.	∑ Real	∑ Rework	∑ Prog.	∑ Real	∑ Rework	∑ Prog.	∑ Real	∑ Rework
Train	P24	107	100	2	127	124	0	157	157	3
	P48	112	98	3	44	46	1	74	77	0
Wagon	P24	360	369	5	41	41	0	71	67	5
	P48	360	28	0	370	370	1	305	305	6
∑		615	595	10	582	581	2	607	606	14
% Achievement		96.7%			99.8%			99.8%		

Source: Data Collection

The measurement of an organisation's performance can be obtained either from a resource efficiency or effectiveness standpoint in its production department, since effectiveness and efficiency are related factors (Teresienė, 2018). However, if these measurements refer only to one of these variables – effectiveness and efficiency, they will provide incomplete and unbalanced descriptions of the organisation's performance. Moreover, KAI is a part of BUMN Company (Indonesian State-Owned Enterprise) which is always seeking to make a profit. Thus, performance measurement should be based on both effectiveness and efficiency (Roghanian et al., 2012). However, while efficacy and improvement can be measured by an organisation, the measurement of efficiency is not yet possible. Mouzas (2006) argued that efficiency addresses the necessary conditions or hurdles reflected in a company's operating margins, while effectiveness refers to a company's production ability as reflected in its sustainable income growth. If these factors are ignored, the company will fail to achieve differentiation and innovation, resulting in inefficiency, ineffectiveness, and a lack of profitability (Speklé & Verbeeten, 2014). Moreover, the next gap can be seen in Figure 1 below, where the maintenance costs tend to increase, while the proportion of total production remains the same.

In Figure 1, the resource allocation in the form of maintenance cost for every Balai Yasa is one of the fund allocation placements that comes from the office revenue. The maintenance depends on the budget, spare part availability, and direct operational hours, which are influenced by performance. Moreover, every Balai Yasa is a decision-making unit (DMU) which must utilise efficient resources and an effective maintenance process to achieve better performance. Related to the theory of al-Najjar (2015, as cited in Fraser et al., 2015), the role of efficient maintenance can improve the company's internal effectiveness and improve the company's competitive advantage. The implementation of effective maintenance aims to increase the profitability and competitiveness of the company by increasing the efficiency and sustainability of the production process, which can be achieved through maintaining and improving the quality of all the elements that contribute to a sustainable and cost-effective production process. Fredendall *et al.* (1997, as cited in Velmurugan & Dhingra, 2015) stated that the maintenance process is considered a crucial aspect of a company's ability to successfully compete in the market based on its quality, shipping, and cost. His argument is that investment in maintenance is an investment in the form of performance rather than in the form of cost. Based on the gaps above,



Source: KAI Annual Report

Figure 1
Maintenance Expenses

this research is directed at measuring and analysing the efficiency of train and wagon maintenance effectiveness. Wang (2006) and Jeon *et al.* (2011) evaluated the effectiveness of OEE by measuring the efficiency of OEE through data envelopment analysis (DEA) on its production. The measurement of effectiveness using OEE and efficiency using DEA cannot be separated. As Parida and Kumar (2009) noted, productivity is a combination of measured effectiveness and efficiency, and a productive organisation must be both effective and efficient.

The measurement results can be used to test the relationship between effectiveness and efficiency based on Nakajima's and Al-Najjar's theory that an effective organisation is an efficient organisation. However, Ho and Zhu (2004) stated that an efficient company is not always effective because there is no correlation between these two aspects. Therefore, apart from measuring and analysing the efficiency and effectiveness of train and wagon maintenance, this research also conducted a sensitivity analysis with a stepwise approach to ascertain whether an effective organisation is an efficient organisation, as well as to determine which variables contribute to making an ineffective and inefficient organisation effective and efficient. Moreover, the main focus of this research is directed toward identifying the variables that affect the function of organisational goals. Doing so can enable management to focus on improving the effectiveness of performance and the efficiency of production.

LITERATURE REVIEW

Effectiveness

Performance has been seen as a tool to measure efficiency and effectiveness; specifically, effectiveness can be measured by the extent to which the stakeholders' requirements have been fulfilled, whereas efficiency can be measured by economic resources used to provide stakeholder satisfaction (Neely et al., 2005; Slack & Lewis, 2017). Kumar and Gulati (2010) and the US Department of Energy (1995) defined effectiveness as the characteristic process that shows how far the output process matches the requirements. Williamson (2006) argued that there are three steps to measure effectiveness: availability level, performance level, and quality level. Together, these steps indicate the *Overall Equipment Effectiveness* (OEE) (Nakajima, 1988). Nakajima (1988) defined *Total Productivity Maintenance* (TPM) as the production maintenance implemented by all staff members through small group activities. One of the TPM implementation pillars through the effectiveness index value or OEE is the assessment of effectiveness to maximize output by maintaining ideal operating conditions and equipment/machine performance. Brah and Chong (2004) argued that TPM improves business performance in many aspects, such as operational safety performance and hygiene, employee morale, and customer satisfaction. All of these aspects can lead to significant improvement in the company bottom line.

Efficiency

Charnes *et al.* (1978) argued that Data Envelopment Analysis (DEA) is an effective approach to measure the relative efficiency from Decision Making Units (DMU) with several performance sizes characterized as input and output. Du *et al.* (2014) argued that there have been many DEA studies, including (1) in the bank sector, with input as the total staff and output as the total of counter transactions and financial service products for sale; (2) in the patrol sector or in road maintenance crews, with input as the maintenance and construction budget and output as the number of trail miles served and the repaired accident sites; (3) in the franchise sector, with input as the number of staff and technological resources and output as the number of product units sold; (4) in the university or university department sector, with input as the number of teaching staff and research and output as the research quality produced and the number of students being taught; and (5) in Research and Development (LITBANG) projects of an organisation, with input as financial resources and technical expertise and output as benefits from the project success. Sun (2004) implements the maintenance efficiency calculations in the Taiwanese army with the input orientation, including the total vehicles, weapons, armoured vehicles, facilities, cost of spare parts, and total available working hours, while the output is the vehicle repair total, weapon repair, armoured vehicle repair, facility repair, and the total number of personnel trained for each month.

Farrell (1957) applies the measurement of relative efficiency to the system of multi input and multi output. Efficiency consists of two categories, price efficiency and technical efficiency, which are then combined into the efficiency of economic systems. Farrell and Fieldhouse (1962) stated that technical efficiency is the structural efficiency which measures the extent to which an industry follows the performance of its best firms and the extent to which firms have optimal sizes. They did a development that emphasized efficiency with a certain weight for efficient units, which are used as a comparison for inefficient units with predetermined coefficients through observations based on industrial samples.

Effectiveness and Efficiency Calculation

Nakajima (1988) stated that the application of the total productivity maintenance (TPM) is used to erase the six big lost aspects in production floor, including; Equipment Failure, Setup and Adjustments, Idling and Minor Stops, Reduced Speed, Process Defects and Reduced Yield. The results of the effectiveness measurement on an effectiveness index (OEE) show how effectively the organisation carries out its production process. Fraser *et al.* (2011) argued the TPM approach is more suitable for holistically integrated improvement of the system of the whole organisation, compared to Reliability Centred Maintenance (RCM) and Condition Based Maintenance (CBM). TPM refers to maintenance focused on reliability, while RCM refers to maintenance based on the condition. TPM not only focuses on how to optimize the productivity of work tools but also how to increase the productivity of workers through the mastery of tools and materials (Dewi & Rinawati, 2015). TPM is more comprehensive, with the practical philosophy of its technique implementation and tools, while RCM and CBM are specific models that can create a part of the company's total integrated maintenance system including TPM. Thus, the effective index is later used for measuring the efficiency of train and wagon maintenance to find out whether the effective treatment is considered as efficient maintenance or not.

Therefore, it is expected that the resource allocation policies can be implemented appropriately.

Relevant research using the DEA methodology is primarily located in four sectors, consisting of the banking sector, health treatment sector, farming sector and transportation sector. DEA is used to measure the efficiency of the entire rail system and does not require a multilateral price index for output or input (Parida et al., 2015). Other methods of measuring efficiency as total factor productivity (TFP) and estimation of the parametric cost function require a multilateral price index for output or input.

The calculation of efficiency in the maintenance of the Balai Yasa train and wagon system requires input resources in the form of production costs, personal operating hours and inventory in the output effectiveness index (OEE). The *Constant Return to Scale* (CCR) method assumes that every DMU of Balai Yasa has the same competency and condition of optimal operation (Hooi & Leong, 2017). The CCR method utilises linear fractional programming theory with output-oriented formulation transformations, as below:

$$Max\ Ø \tag{1}$$

Limitation:

$$\Sigma_{j=1}^{n} \quad \lambda_j y_{rj} - Øy_{rk} \geq 0\ ; \qquad r=1,\ldots,s$$

$$X_{ik} - \Sigma_{j=1}^{n} \quad \lambda_j x_{ij} \geq 0\ ; \qquad i=1,\ldots,\mathrm{m}$$

$$\Sigma_{j=1}^{n} \quad \lambda_j \leq 1\ ;$$

$$\lambda_j \geq 0\ ; \qquad j \in 1,\ldots,\mathrm{n}$$

Description:

CCR method compares the maintenance efficiency of Balai Yasa (Ø) as much as *n*. Each Ø uses *m input* type to produce *s* type of output. $x_{ij} > 0$ is the number of *inputs* used by Balai Yasa *j*, $y_{rj} > 0$ is the number of *outputs* produced by Balai Yasa *j*, and λ_j is the weight of each Balai Yasa *j*.

Stepwise Analysis Approach

The analysis of primary data was processed using DEA Solver and Microsoft Excel. From the results of the data processing, a sensitivity analysis was carried out using a stepwise approach. Wagner and Shimshak (2017, as cited in Emrouznejad & Yang, 2018) argued that CCR or VRR method with input or output based can be used to analyse the sensitivity in both backward and forward method. A stepwise approach can be used with various DEA models. Variable or constant returns scales can be used in the input- or output-oriented model. Sensitivity analysis is used to ascertain the sensitivity of each factor if there is a change in the value of the factor causing changes in the relative efficiency value. Sensitivity analysis is done by changing, removing or adding parameters to the variables. This analysis is used to determine a variable efficiency level at which DMU will increase its efficiency or change the inefficiency to efficiency or vice versa. Based on the data, there are 2 DMUs that are not effective and 1 DMU that is effective. Therefore, it is necessary to analyse the resource efficiency of the 3 DMUs, as well as the improvement measures that have been taken or are currently in progress to improve the future performance of the ineffective DMUs. Until today, it is not yet known whether the maintenance of the train and wagon has been done properly or not.

Banker *et al.* (1984) expanded the CCR model which is now known as the assumption of *Return to Scale Characterizations* (VRS) that every measured unit will make a change in various output levels (increasing, constant or decreasing) and the assumption that the production scale can affect the efficiency. The VRS method differs from the CCR method, which indicated that the production scale does not influence the DMU efficiency in Balai Yasa. The VRS method indicates that the comparison of input and output can influence productivity in Balai Yasa. The VRS method identified imperfect conditions in the Balai Yasa DMU due to limited costs, capacity and other factors. It can be seen that the Balai Yasa DMU is not optimally operational. Banker *et al.* (1984) uses the term "efficiency postulate" which is converted to "inefficiency postulate" to indicate that inefficient production is always possible in the form of more input and less output, or vice versa. Furthermore, Lampe and Hilgers (2015) developed the postulate *convexity*, in which $\lambda_j \geq 0$ is non-negative scale becomes $\Sigma_{j=1}^{n} \lambda_j = 1$; the form of output-oriented VRS formulation transformation can be seen in the following:

$$Max\ Ø \quad (2)$$

Limitation:

$$\Sigma_{j=1}^{n} \lambda_j y_{rj} - Ø y_{rk} \geq 0 ; \quad r=1,\ldots,s$$
$$X_{ik} - \Sigma_{j=1}^{n} \lambda_j x_{ij} \geq 0 ; \quad i=1,\ldots,m$$
$$\Sigma_{j=1}^{n} \lambda_j = 1 ;$$
$$\lambda_j \geq 0 ; \quad j \in 1,\ldots,n$$

Data Envelopment Analysis (DEA) is a linear program application that compares a number of service units of the same type based on their input (resources) and output. The operation unit of the organisation has multiple inputs in the form of total staff, salary, operational hours, cost and others, while the multiple outputs can be defined in the form of *revenue, market share*, *growth rate* and others. The result of the DEA model solution indicates whether a particular unit is less productive or inefficient compared to other units.

The efficiency calculation using the DEA, CRS and DEA VRS method will obtain technical efficiency (TE) and scale efficiency (SE) values. According to Park and De (2015), scale efficiency is measured from the aggregate efficiency ratio which is evaluated to know the orientation of the expected direction for the efficiency evaluation model. The scale efficiency (SE) can be obtained by dividing the calculation results of technical efficiency Constant Returns to Scale (CCR) with technical efficiency Variable Returns to Scale (VRS) characterisation; if the obtained proportion value is 1, the DEA model is characterised by CCR, whereas if the value is less than 1, then the DEA model is characterized by VRS. The calculation of efficiency using the DEA methods of Constant Returns to Scale (CCR) and Variable Returns to Scale (VRS) was applied to the formulation equation above using the DEA Solver application.

RESEARCH METHOD

A descriptive quantitative method was used in this research. The object consists of three Balai Yasa DMU which are engaged in the maintenance of train and wagon facilities. As a continuous improvement from the maintenance department at UPB Balai Yasa, *KAI* has implemented the ISO 9001: 2015 system. The data is collected through pProduction and performance data were collected for the *KAI* report period of 2016-2019. The techniques of data calculation and analysis focus on effectiveness and efficiency, and the calculations are performed using the DEA Solver software.

Data and Variables

Output Variable

In this research, output variables on train and wagon maintenance, which are used to calculate the efficiency with the DEA model, consist of total productivity maintenance (TPM) and revenue. Effectiveness can be used to measure output organisation. One of the measurements can be made based on the Overall Equipment Effectiveness (OEE) method of the TPM pillar from Nakajima. For the revenue, Oum and Yu argued that the output size basically shows an output level consumed by users and the value that users assign to the organisation (Parida et al., 2015). If the government did not implement control through trains, including frequency and other service levels, using revenue measurement to calculate the managerial efficiency is the best way to do so. Economic efficiency as measured by revenue output reflects the combined effect of managerial efficiency and constraints imposed by the government. Jeon *et al.* (2011) and Wang (2006) argue that TPM is a tool that only measures effectiveness, not efficiency, even though efficiency is crucial for enhancing performance. In this study, DEA is used to evaluate the efficiency score when the utility function considers many attributes.

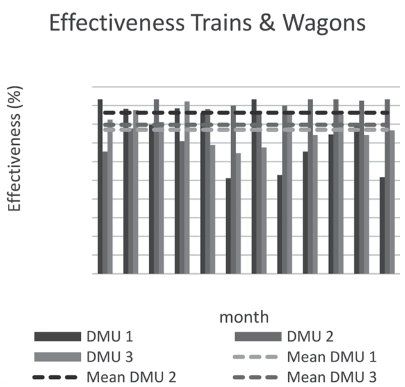
Input Variable

The input variables on train and wagon maintenance, which used to calculate the efficiency using the DEA model, consist of people operating hours (*Jam Operasional Orang*/JO), inventory, and costs. For people operating hours variable is defined by experience, training and competence aspect (Stewart, 1997). In Balai Yasa, workers must attend training and receive a certificate of maintenance. If they pass the training, the worker can be employed in the maintenance system. The measurement of workforce here uses the people's operational hours, which are inputted into the maintenance system in the form of completion hours. Related to the theory of Brah and Chong (2015, as cited in Netland, 2016) human resources focus on how the company aligns its human resource practices with its strategic direction. Inventory purchasing can be used as the material input size. According to the Stewart (1997), the supply business model is where the buyer provides certain information to the supplier of the product, who is fully responsible for maintaining the agreement of materials, usually at the buyer's consumption location. Baseline inventory is defined as the lower supply level owned by a certain SKU (Stock Keeping Unit) during the late 12 months. The inventory of Balai Yasa is used as input based on the span of time of inventory turnover for each month or once per year.

The other input variable is cost, cost defined as an example of any financial input to an operation which enables it to produce products and services (Slack & Lewis, 2017). Conventionally, financial input can be divided into 3 categories: operating expenses, capital expenditures and working capital. The expense is very influential on operating strategies that may affect the company performance (Negrão et al., 2016). Negrão *et al.* (2016) argued that the strategy of planning implementation of the company through the cost of buyer's requirements, suppliers and other stakeholders is crucial for the success of the company's performance. The use of input and output variable data on train and wagon maintenance is shown in Table 2;

RESULTS AND DISCUSSION

This study was done in three Balai Yasa DMU in 2019: *Balai Yasa Manggarai* (DMU 1), *Balai Yasa Tegal* (DMU 2), and *Balai Yasa Surabaya* (DMU 3). The calculation of train and wagon maintenance is carried out in output and input variables, which can be seen in the following figures.



Source: own study

Figure 2
Data Effectiveness

Variable	Unit	Criteria	Information
Total Productive Maintenance (TPM)	OEE/month	Output 1	Maintenance Effectiveness Value per Month x100% (Effectiveness Index in %)
Revenue	Rp/month	Output 2	Average Monthly Income (in thousands)
Inventory	Balance Value (Rp)/month	Input 3	Inventory turnover per Month (in thousands)
Personal Operational Hours (JO)	Average Hours/month	Input 2	Average Number of Hours of Operation per Month
Maintenance Cost (c)	Average *Cost* (Rp)/month	Input 1	Average Monthly Maintenance Costs (in thousands)

Source: own study

Table 2
List of DEA variables

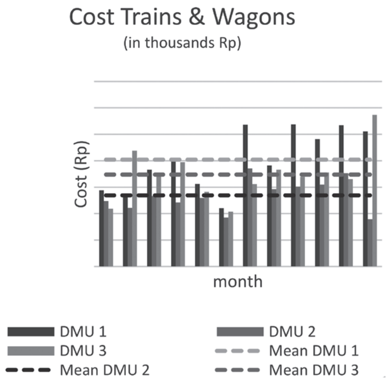


Figure 3
Data Cost

Source: own study

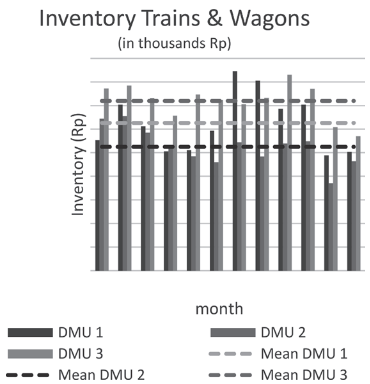


Figure 4
Data Inventory

Source: own study

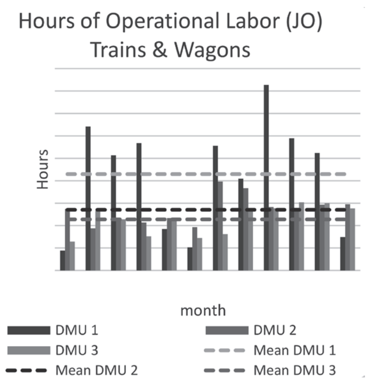


Figure 5
Data Hours of Operation Labor

Source: own study

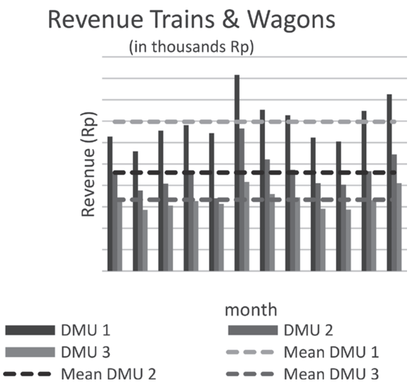


Figure 6
Data Revenue

Source: own study

Efficiency Measurement

This calculation was done to test the relation between effectiveness and efficiency by using the method of DEA, CCR and VRS. The efficiency measurement can be seen in Table 3 and 4.

The calculation results of DEA in tables 3 and 4 show that DMU 1 has a Scale Efficiency value of 0.838 < 1, which is marked with the calculation of return to scale variable (VRS). DMU 1 reached a VS value of 0.8940 or 89.40%, which means it is not efficient, while DMU 2 and DMU 3 reached efficiency of 1 or 100%. It can be seen that there is improvement in DMU 1, especially in OEE output which previously 77.06% became 86.19%. Thus, DMU 1 can be said to be effective since it reduces cost by 33.415%, JO 37.049%, and inventory by 16.158%. However, although DMU 3 has been found to be efficient, the effectiveness should be improved to the minimum international standard value of 85%. DMU 3 indicates that not every ineffective DMU is inefficient. DMU 3 has ineffective results with lower input and higher output variables compared to DMU 1. Therefore, we conclude that DMU 3 is more efficient than DMU 1.

The improvement of variables has been suggested by other researchers, such as Wang (2006), who stated that there were 5 factories with an OEE value of 97.02% and efficiency value of 55.90%. This means these 5 factories were effective but not efficient. However, Wang (2006) did not complete a sensitivity analysis on all variables. Therefore, a sensitivity analysis was done in this current research to assess whether an effective organisation is an efficient organisation and to identify which variables affect the sensitivity with regard to train and wagon maintenance.

Table 3
Efficiency Value

	Input				Efficiency DEA		
	Cost	JO	Inventory	Effectiveness (OEE)	CCR	VRS	Scale Efficiency
1	20.200.478	42.947	31.303.858	77,06	0,7496	0,8941	0,838
2	13.450.259	27.035	26.245.459	86,19	1	1	1
3	17.378.246	22.754	35.975.924	79,71	1	1	1

Source: own study

Table 4
Efficiency *Improvement (Slack)*

Variable	Item	DMU 1	DMU 2	DMU 3
	Data	20.200.478	13.450.259	17.378.246
Cost	Projection	13.450.394	13.450.259	17.378.246
	Diff. (%)	-33	0	0
	Data	42.947	27.035	22.754
JO	Projection	27.036	27.035	22.754
	Diff. (%)	-37	0	0
	Data	31.303.858	26.245.459	35.975.924
Inventory	Projection	26.245.721	26.245.459	35.975.924
	Diff. (%)	-16	0	0
	Data	77	86	80
OEE	Projection	86	86	80
	Diff. (%)	11,8	0	0

Source: own study

Sensitivity Analysis (Stepwise Approach – Backward Method)

According to Wagner and Shimshak (2007) sensitivity analysis, using either a backward or forward method, can be used with CCR or VRS with input and output orientation, as long as the model is used consistently. They argued that the backward method is used for input or output orientation on returns to scale variables, by comparing the average scores of effectiveness and efficiency. The smallest differences in variables that have the least effect on efficiency can be excluded one by one from the DEA model. The calculation of DEA VRS in Table 5 produced the weight value of each input and output variable.

It can be seen in Table 5 that the cost variable has a low value of 0.258, or 0.086 when averaged against 3 DMUs. If the weight value is close to 0, which indicates that the variables activity have proportion in achieving small efficiency level, thus it is necessary to implement DEA calculation to find out which is the most efficient by removing several variables that have small effects on efficiency using the following steps:

Step 1: The cost variable was erased because the lower weight value is 0.086. It implements the DEA VRS calculation by the JO input variable and inventory with the output variable of (OEE) effectiveness index. The result is shown in Table 6 with the result that only DMU 2 is efficient, and there is no change after the cost is removed; thus, the cost variable has no influence on DMU efficiency.

Step 2: The JO variable is erased since it has the smallest value of 0.7666 or 0.255 when averaged against three DMUs which means it has proportion in achieving a small level of efficiency. The DEA VRS calculation was performed with only one input variable, inventory, and the output variable of effectiveness (OEE). Emrouznejad and Yang (2018) argued that the backward method is done until there is only one input and one output left.

The result is shown in Table 6, where DMU 2 is the only efficient variable. This indicates that the more effective the DMU, the more efficiency will be implemented, according to Nakajima's theory. If organisational effectiveness is more than 85%, the organisation is operating both efficiently and effectively.

Stepwise Approach – Forward Method

In order to make an effective DMU become efficient in train and wagon maintenance, a stepwise approach with the forward method by adding the input and output variables on every DMUs is applied. The purpose of DMU is to know the variable

Table 5
Weight (λ) Data 3 *Inputs* and 1 *Output*

DMU	Weight Input			Weight Output
	v(1) Cost	v (2) JO	v(3) Inventory	u(1) Effectiveness (OEE)
DMU 1	0	0	0	1
DMU 2	0	0	1	1
DMU 3	0,2580	0,74197	0	1

Source: own study

condition and what value of the variable must be achieved. Thus, DMU can be efficient (Emrouznejad & Yang, 2018). A stepwise approach is implemented because DMU is not efficient (see Table 4). In Table 4, the terms of output effectiveness have not been analysed on the impact of the effectiveness output variable that has been generated, which is called revenue (Parida et al., 2015). Revenue can be seen as the organisational performance resulting from the effectiveness and efficiency of organisation. Speklé and Verbeeten (2014) claimed that effectiveness is the company's ability to produce sustainable income growth. As for the additional output variable can be done with the forward method by adding revenue variable.

Thus, this research indicated that the input variables are cost, JO, inventory and the amount condition determined by the generated revenue. The calculation result of DEA with the added output revenue variable in Table 7 obtained the result that the DMU becomes efficient. The calculation results are as follows;

In Table 7, the DEA calculation result shows that every DMU indicates a value of 100% or is considered efficient; this means that the entire process of implementing train and wagon maintenance has been efficient;

Variable in Analysis	Start	Step 1	Step 2
Variable Input	Cost		
	JO	JO	
	Inventory	Inventory	Inventory
Variable Output	OEE	OEE	OEE
DMU 1	0,894	0,894	0,894
DMU 2	1	1	1
DMU 3	1	1	0,925
Efficient DMU's	2	2	1
Efficiency Changes	0,086	0,255	

Source: own study

Table 6
Backward method

DMU	Input			Output		Efficiency			
	Cost	JO	Inventory	Effectiveness	Revenue	DEA CCR	DEA VRS	Scale Efficiency	Slack
1	20.200.478	42.947	31.303.858	77,06	348.599.072	1	1	1	0
2	13.450.259	27.035	26.245.459	86,19	229.886.614	1	1	1	0
3	17.378.246	22.754	35.975.924	79,71	166.514.252	1	1	1	0

Source: own study

Table 7
Increased *Multi Input* and *Output* Efficiency

Variable in Analysis	Start	Step 1
Variable Input	Cost	Cost
	JO	JO
	Inventory	Inventory
Variable Output	OEE	OEE
		Revenue
DMU 1	0,894	1
DMU 2	1	1
DMU 3	1	1
Efficient DMU's	2	3

Source: own study

Table 8
Forward Method

From the input and output weight analysis in Table 8, it is obtained the weight of every input and output variables which have influence on the efficiency calculation as follows;

Table 9 shows that the weight value of input variables with the most influential variable toward efficiency is inventory which is seen in DMU 2. This indicates that every DMU should follow and reach the efficient input value to reduce the input surplus. Meanwhile, the cost input variable has an average weight of 0.086 or close to 0. The value of weight activity that is similar to 0 indicates that the variable activity has no proportion in efficiency level, and if it is bigger than 0 then it influences the efficiency level due to its contribution.

For the weight value of the output variable, OEE is efficient. Every DMU should be able to reach output effectiveness as much as in DMU 2 (86.19%) with an efficiency result of 1 or 100%. This means that the more the organisation is effective, the more efficient it will be. For the highest output revenue obtained by DMU 1 indicates that each DMU should be able to achieve output revenue like DMU 1; this means that the higher is the output of the organisation, the more possible it is for the organisation to achieve its goals.

The efficiency calculation is done by eliminating or adding variables through a stepwise approach using the backward method. In the backward method, the elimination occurs on variables that have the smallest value (or close to 0), in which the variable is carried out until the maximum iteration for 1 input and 1 output. Thus, it can be concluded that the fewer variables are used, the smaller the number of efficient DMU. For the next iteration, the forward method is used by adding the variables that are considered influential on organisation performance. As in Table 9 above, only DMU 2 is efficient. However, after using the forward method, every DMU is efficient. Therefore, it can be concluded that the more variables are added and the bigger the output variables, the more efficient a DMU will be.

MANAGERIAL IMPLICATIONS IN THE SOUTH EAST ASIAN CONTEXT

Based on the results of the effectiveness calculation, Balai Yasa showed a mean value of the OEE index of 81%, which is close to the International Standard of 85%. Japan Institute of Plant Maintenance (JIPM) has been established as the standard benchmark; if OEE cannot reach 85%, the production will be considered to have opportunities for improvement. The efficiency of Balai Yasa is greatly influenced by the input variable with the biggest integrity, which is the inventory variable. This indicates that the bigger the variable integrity, the more it influences the proportion of efficiency. The measurement of effectiveness and efficiency is suggested to

Table 9
Weight (λ) data *multi input and output*

DMU	Weight Input			Weight Output	
	v(1) *Cost	v (2) *JO	v( ) *Inventory	u(1) *Revenue	u(2) *OEE
1	0	0	0,999	0,61	0,39
2	0	0	1	0	1
3	0,258	0,742	0	0	0,999

Source: own study

be implemented to train and wagon depots or to medium care units in Java island. However, the train and wagon maintenance in depots is not complete as in Balai Yasa. The effectiveness and efficiency measurement is also suitable for locomotive and rail maintenance. This research uses sensitivity analysis using a stepwise approach by Wagner and Shimshak (2007) to prove that an effective organisation is an efficient organisation. As the findings showed, DMU 2 is an effective and efficient organisation, whereas DMU 1 and DMU 3 are ineffective and inefficient organisations; in other words, if the organisation is effective, the organisational efficiency will be higher.

In addition, this study uses the stepwise approach to determine which variables have a major influence on the efficiency of train and wagon maintenance. The results show that the inventory input variable and the output effectiveness variable have the greatest weight compared to other variables in influencing organisational efficiency.

THEORETICAL IMPLICATIONS

This research encourages each Balai Yasa as a decision-making unit (DMU) to focus on increasing the effectiveness and efficiency of the maintenance program. Balai Yasa should implement an improvement of both effectiveness and efficiency aspects to avoid work repetition, enhance rapidity and availability, and define the resources allocation target. The measurement of output-oriented efficiency indicated that the bigger the output, the more effective the organisation is.

This research also uses a stepwise approach using a forward method, by adding revenue variables which have not been implemented in prior studies. It is limited to the DMUs, and its focus is to improve the effectiveness and efficiency of the train and wagon maintenance program in Java. The scope can be expanded to Sumatra and/or compared to Southeast Asian countries by considering the characteristic differentiation of the economic field.

CONCLUSION

It can be concluded that in the case of train and wagon maintenance, the fewer variables are used, the smaller is the number of effective DMUs. For the next iteration, a forward method is achieved by adding variables that are believed to affect the organisational performance. Thus, an effective organisation can be obtained. The forward method concludes, with regard to train and wagon maintenance, that are more variables added are and the output variables are larger, the higher will be the efficiency of the DMU. This research also shows a different conclusion from the literature in terms of efficiency calculation. It shows that DMU 3 is not being effective in the maintenance process but effective in using input. In other words, the input resources have been implemented as much as possible in the optimisation compared to the other DMUs.

References

Banker, R. D., Charnes, A., & Cooper, W. W. (1984). Some models for estimating technical and scale inefficiencies in data envelopment analysis. *Management Science*, *30*(9), 1078–1092.

Brah, S. A., & Chong, W. K. (2004). Relationship between total productive maintenance and performance. *International Journal of Production Research*, *42*(12), 2383–2401. https://doi.org/10.1080/00207540410001661418

Campbell, J. D. (1999). Reliability: Past, present, future (Establishing the historical and theoretical framework of RCM). In J. D. Campbell (Ed.), *The reliability handbook: From downtime to uptime - in no time!* (pp. 5). Burlington: Clifford/Elliot Ltd.

Charnes, A., Cooper, W. W., & Rhodes, E. (1978). Measuring the efficiency of decision making units. *European Journal of Operational Research*, *2*(6), 429–444. https://doi.org/10.1016/0377-2217(78)90138-8

Dewi, N. C., & Rinawati, D. I. (2015). Analisis penerapan total productive maintenance (TPM) dengan perhitungan overall equipment effectiveness (OEE) dan six big losses mesin cavitec PT. Essentra Surabaya. *Industrial Engineering Online Journal*, *4*(4), 1–17.

Du, J., Cook, W. D., Liang, L., & Zhu, J. (2014). Fixed cost and resource allocation based on DEA cross-efficiency. *European Journal of Operational Research*, *235*(1), 206–214. https://doi.org/10.1016/j.ejor.2013.10.002

Emrouznejad, A., & Yang, G. (2018). A survey and analysis of the first 40 years of scholarly literature in DEA: 1978–2016. *Socio-Economic Planning Sciences*, *61*, 4–8. https://doi.org/10.1016/j.seps.2017.01.008

Farrell, M. J. (1957). The measurement of productive efficiency. *Journal of the Royal Statistical Society: Series A (General)*, *120*(3), 253–290. https://doi.org/10.2307/2343100

Farrell, M. J., & Fieldhouse, M. (1962). Estimating efficient production functions under increasing returns to scale. *Journal of the Royal Statistical Society: Series A (General)*, *125*(2), 252–267. https://doi.org/10.2307/2982329

Fraser, K., Hvolby, H.-H., & Tseng, T.-L. (Bill). (2015). Maintenance management models: A study of the published literature to identify empirical evidence. *International Journal of Quality & Reliability Management*, *32*(6), 635–664. https://doi.org/10.1108/IJQRM-11-2013-0185

Fraser, K., Hvolby, H. H., & Watanabe, C. (2011). A review of the three most popular maintenance systems: How well is the energy sector represented?. *International Journal of Global Energy Issues*, *35*(2-4), 287–309. https://doi.org/10.1504/IJGEI.2011.045024

Gómez Fernández, J. F., Crespo Márquez, A., & López-Campos, M. A. (2018). Customer-oriented risk assessment in network utilities. In *Advanced Maintenance Modelling for Asset Management* (pp. 263–290). Springer International Publishing. https://doi.org/10.1007/978-3-319-58045-6_11

Ho, C. T., & Zhu, D. S. (2004). Performance measurement of Taiwan's commercial banks. *International Journal of Productivity and Performance Management*, *53*(5), 425–434. https://doi.org/10.1108/17410400410545897

Hooi, L. W., & Leong, T. Y. (2017). Total productive maintenance and manufacturing performance improvement. *Journal of Quality in Maintenance Engineering*, *23*(1), 2–21. https://doi.org/10.1108/JQME-07-2015-0033

Jeon, J., Kim, C., & Lee, H. (2011). Measuring efficiency of total productive maintenance (TPM): A three-stage data envelopment analysis (DEA) approach. *Total Quality Management & Business Excellence*, *22*(8), 911–924. https://doi.org/10.1080/14783363.2011.593865

Kumar, S., & Gulati, R. (2010). Measuring efficiency, effectiveness and performance of Indian public sector banks. *International Journal of Productivity and Performance Management*, *59*(1), 51–74. https://doi.org/10.1108/17410401011006112

Lampe, H. W., & Hilgers, D. (2015). Trajectories of efficiency measurement: A bibliometric analysis of DEA and SFA. *European Journal of Operational Research*, *240*(1), 1–21. https://doi.org/10.1016/j.ejor.2014.04.041

Maltseva, V., Na, J., Kim, G., & Ha, H.-K. (2020). Efficiency analysis of russian rail freight transportation companies with super slack-based measurement data envelopment analysis. *Journal of International Logistics and Trade*, *18*(2), 77–89. https://doi.org/10.24006/jilt.2020.18.2.077

Mouzas, S. (2006). Efficiency versus effectiveness in business networks. *Journal of Business Research*, *59*(10–11), 1124–1132. https://doi.org/10.1016/j.jbusres.2006.09.018

Nakajima, S. (1988). *Introduction to TPM: Total productive maintenance*. Productivity Pers.

Neely, A., Gregory, M., & Platts, K. (2005). Performance measurement system design: A literature review and research agenda. In *International Journal of Operations and Production Management*, *25*(12), 1228-1263. https://doi.org/10.1108/01443570510633639

Negrão, L. L. L., Godinho Filho, M., & Marodin, G. (2016). Lean practices and their effect on performance: A literature review. *Production Planning & Control*, *28*(1), 33-56. https://doi.org/10.1080/09537287.2016.1231853

Netland, T. H. (2016). Critical success factors for implementing lean production: The effect of contingencies. *International Journal of Production Research*, *54*(8), 2433–2448. https://doi.org/10.1080/00207543.2015.1096976

Parida, A., & Kumar, U. (2009). Maintenance productivity and performance measurement. In M. Ben-Daya, S. O. Duffuaa, A. Raouf, J. Knezevic, & D. Ait-Kadi (Eds.), *Handbook of maintenance management and engineering* (pp. 17–41). Springer. https://doi.org/10.1007/978-1-84882-472-0_2

Parida, A., Kumar, U., Galar, D., & Stenström, C. (2015). Performance measurement and management for maintenance: a literature review. *Journal of Quality in Maintenance Engineering*, *21*(1), 2–33. https://doi.org/10.1108/JQME-10-2013-0067

Park, R., & De, P. (2015). An alternative approach to efficiency measurement of seaports. In H. E. Haralambides (Ed.), *Port management* (pp. 273–292). London: Palgrave Macmillan UK. https://doi.org/10.1057/9781137475770_13

Roghanian, P., Rasli, A., & Gheysari, H. (2012). Productivity through effectiveness and efficiency in the banking industry. *Procedia - Social and Behavioral Sciences*, *40*, 550–556. https://doi.org/10.1016/j.sbspro.2012.03.229

Slack, N., & Lewis, M. (2017). Operations strategy (5th ed.). Harlow: Pearson Education

Speklé, R. F., & Verbeeten, F. H. M. (2014). The use of performance measurement systems in the public sector: Effects on performance. *Management Accounting Research*, *25*(2), 131–146. https://doi.org/10.1016/j.mar.2013.07.004

Stewart, G. (1997). Supply-chain operations reference model (SCOR): The first cross-industry framework for integrated supply-chain management. *Logistics Information Management*, *10*(2), 62–67. https://doi.org/10.1108/09576059710815716

Sun, S. (2004). Assessing joint maintenance shops in the Taiwanese Army using data envelopment analysis. *Journal of Operations Management*, *22*(3), 233–245. https://doi.org/10.1016/j.jom.2004.01.003

Teresienė, D. (2018). Performance measurement issues in central banks. *Entrepreneurship and Sustainability Issues*, *6*(1), 176–189. https://doi.org/10.9770/jesi.2018.6.1(12)

US Department of Energy. (1995). *How to measure performance: A handbook of techniques and tools.* Oak Ridge Associated Universities.

Velmurugan, R. S., & Dhingra, T. (2015). Maintenance strategy selection and its impact in maintenance function: A conceptual framework. *International Journal of Operations & Production Management*, *35*(12), 1622–1661. https://doi.org/10.1108/IJOPM-01-2014-0028

Wagner, J. M., & Shimshak, D. G. (2007). Stepwise selection of variables in data envelopment analysis: Procedures and managerial perspectives. *European Journal of Operational Research*, *180*(1), 57–67. https://doi.org/10.1016/j.ejor.2006.02.048

Wang, F.-K. (2006). Evaluating the efficiency of implementing total productive maintenance. *Total Quality Management & Business Excellence*, *17*(5), 655–667. https://doi.org/10.1080/14783360600588232

Williamson, R. M. (2006). *Using overall equipement effectiveness: The metric and the measures*. Columbus, NC: Strategic Work Systems Inc. https://swspitcrew.com/wp-content/uploads/2018/01/OEE.pdf

Zhu, G., Gelders, L., & Pintelon, L. (2002). Object/objective-oriented maintenance management. *Journal of Quality in Maintenance Engineering*, *8*(4), 306–318. https://doi.org/10.1108/13552510210448513