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INTEGRATION OF OPERATIONAL PERFORMANCE AND ECO-INDICATORS FOR ASSESSING ENVIRONMENTAL IMPACTS OF MANUFACTURING PROCESSES IN AN AUTOMOTIVE COMPONENT COMPANY

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Abstract: This paper focuses on assessing manufacturing processes in an automotive component company using aspects of availability, performance efficiency, quality rate and sustainability to determine the overall progress achieved by implementing lean and green techniques. This action research aims to improve sustainability and manufacturing process efficiency simultaneously with appropriate corrective actions. Overall Environmental Equipment Effectiveness (OEEE) is calculated as the relationship between overall equipment effectiveness and environmental impact conducted by Domingo and Aguado. It means identifying losses due to sustainability and establishing a complete understanding of machine effectiveness and sustainability aspects of the production process. The manufacturing process consists of cutting, forging, CNC machining, robodrill machining, chamfering, broaching and removing burry, collected from primary (sampling data collection) and secondary data from the internals company. Based on the results, the OEEE value was "poor" in the forging process 55.752%, and the machining process 56.040%, due to low sustainability value. The corrective actions are to change the raw material from S45C to SWCH45K and recycle the waste. After improvements, the OEEE results on the forging process 60.118% and on the machining process 60.278%, can be declared "acceptable" because it meets the requirements of 60% < OEEE <70%.

Keywords: Operational performance, Overall Environmental Equipment Effectiveness, sustainability, Eco-Indicator 99, environmental impact.

Introduction

The concept of lean and green is used by manufacturers in various industries. Lean manufacturing was developed to maximise the product's value through the minimisation of waste, and then the lean manufacturing scheme was developed in response to the changing and highly competitive business environment (Sundar *et al*., 2014). However, companies also face requirements from the government that require all companies to be aware of aspects regarding the environment and its implementation.

Lean manufacturing was developed by Toyota, Japan and it is a systematic approach to identifying and reducing waste (non-value-added activities) through continuous improvement (Dixit *et al*., 2015). Green practices focus on reducing the elimination of harmful substances, wasteful consumption of resources, recycling and minimising health risks throughout the manufacturing process by minimising the entire product lifecycle's environmental footprint (Marhani *et al.,* 2013; Medeiros *et al*., 2014). Green practices go further than lean practices, being concerned not only with waste reduction but also with process efficiency and optimisation of raw material consumption (Abulafaraa *et al.,* 2020). Due to these two assumptions, lean and green practices are achieved through lean and green production (Mollenkopf *et al*., 2010; Gupta & Kumar, 2013).

The OEE value shows the value of the standard for measuring manufacturing productivity, while the OEEE value shows the combination of manufacturing productivity and environmental impact. Overall Equipment Effectiveness (OEE) is the overall level of facility effectiveness obtained by considering availability, performance efficiency, and product quality rate (Davis, 1995). OEE is useful for eliminating various losses by grouping them into three parameters (Gupta & Vardhan, 2016), including availability, performance efficiency, and product quality rate (Dobra & Jósvai, 2021). OEE is a way to measure the performance of production machines in the implementation of the TPM program and it is worth remembering that Total Productive Maintenance (TPM) focuses on implementing eight pillars (Ahuja & Khamba, 2008), among which is the environment (Nakajima, 1998).

One of the principles of green manufacturing is to consume less material and energy, utilise renewable resources and understand processes to reduce environmental waste (Dornfeld, 2014). Sustainable materials produce significantly less waste than other materials, such as plastic, which means less landfill waste, less energy consumption, and less impact on the overall environment (Thompson, 2013). In addition to materials, the processes used such as cutting, forging and machining, can significantly impact the environment. Energy use during processing is considered one of the biggest impacts of machining (Faludi *et al*., 2015). Embodied energy, water, toxins, and other environments are the effects of machine tools. One of the biggest health and environmental concerns for machine tools is the use of cutting fluids, as workers are directly exposed (Ogaldez *et al*., 2012). Machine tools with cooling, lubrication, chip removal, corrosion protection and cleaning tools also cause environmental impacts. Overall Environmental Equipment Effectiveness (OEEE) is an extension of OEE to know in what situation a manufacturing plant is about its environment (Cercós *et al*., 2019). The OEEE is a new parameter that allows companies to integrate sustainability into the business world (Durán *et al*., 2018).

This measure was first developed by Domingo and Aguado (2015), however, further study is needed for deeper understanding. Similar studies are also scant. Hence, this paper focuses on the assessment of manufacturing processes in an automotive component company, which is a joint venture factory between Indonesia, Japan, and Taiwan, using aspects of availability, performance efficiency, quality rate and sustainability to determine the overall progress achieved by implementing lean and green techniques. This study aims to improve sustainability and manufacturing process efficiency simultaneously with appropriate corrective actions. Based on previous research, there are various methods can be used to calculate environmental impacts, such as Ecotax (Eldh & Johansson, 2006), Ecotoxicology (Boros & Ostafe, 2020), Eco-Indicator 99 (Goedkoop, 2007) and Ecoinvent (Frischknecht *et al*., 2005), each of which has its unique advantages and disadvantages. This action research uses Eco-indicator 99, where Eco-indicator 99 measures environmental impact calculated by milli points at each step in the production line. Eco-Indicator 99 is a life cycle impact assessment tool developed and helps to make an environmental assessment of a product by calculating eco-indicator scores for materials and processes used (Goedkoop & Spriensma, 2001). The resulting scores indicate areas for product improvements. The Eco-Indicator is split into three sections production of raw materials (e.g., polystyrene), processing, and manufacture (e.g., injection moulding), transportation of product (e.g., shipping), energy in use (e.g., electricity), and consumables in use (e.g., paper) and disposal.

The subsequent structure of this paper is as follows: The materials and methods section presents the research methodology of this paper, followed by the results, discussion of the findings and implications of this study in the next section. The last section presents the conclusions, limitations and directions for future research.

Materials and Methods

This action research uses data collection methods using both primary data (sampling data collection) and secondary data from internal companies. Action research is a process of interactive inquiry or/and transformative change through simultaneous action-taking and data-driven collaborative research, linked together by critical reflection. This method consists of three main phases: the repetitive cycle of planning, action, and fact-finding or measuring the action results (Reason & Bradbury, 2001). The manufacturing process consists of cutting, forging, Computer Numerical Control (CNC) machining, robodrill machining, chamfering, broaching and removing burry. The performance efficiency score is calculated based on regular hours, overtime, planned stop time, unplanned stop time, cycle time, use of company production data, and machines used, along with power efficiency calculation details (Singh *et al.,* 2018). From these data, it is known that the cycle time of each machine is different. Thus, the calculation can produce different levels of performance efficiency. To calculate the total production, it is necessary to group products based on not-good products and products that have passed the inspection process.

Parametric OEEE is to measure the effectiveness of the machine and the OEEE value depends on the initial and final environmental assessment, which can be carried out with a valid method to identify the environmental impact of the process and relate it to environmental aspects. The new metric OEEE presented in this paper is based on the OEE consisting of availability, performance efficiency and rate of quality (Chikwendu, 2020) (see Equation 1).

$$OEE = Availability\ x\ Performance\ Efficency\ x\ Rate\ of\ Quality \quad (1)$$

Loading time is the available time planned per day or month for production operations, while downtime refers to the total production time during which the integrated system is not operating due to equipment failures or setup/adjustment requirements (see Equation 2). Processed amount refers to the number of products processed in a day or month and operating time is the difference between loading time and downtime (see Equation 3). The defect amount is the number of products rejected due to the inability of the product to meet production design, and therefore requires to be reworked or may be regarded as scrap (Equation 4) (Dal *et al*., 2000).

$$Availability = (loading\ time - down\ time)/loading\ time\ x\ 100\% \quad (2)$$

$$Performance\ Efficiency = (processed\ amount\ x\ cycle\ time)/ \\ operating\ timex\ 100\% \quad (3)$$

$$Rate\ of\ Quality = (processed\ amount - defect\ amount)/processed\ amountx\ 100\% \quad (4)$$

OEEE is calculated as the relationship between the OEE and a sustainability parameter, identifying losses due to sustainability and establishing a complete understanding of the production press regarding availability, performance, quality and sustainability (Domingo & Aguado, 2015) (Equation 5).

$$\text{OEEE} = OEE\ x\ Sustainability \quad (5)$$

$$Sustainability = 1 - (Environmental\ impact\ of\ the\ workstation/ \\ total\ environmental\ impact\ of\ initial\ state\ production) \quad (6)$$

The following is the ideal standard of overall environmental equipment effectiveness, as seen in Table 1. This table is a further interpretation of OEEE, where the minimum value to be categorised as acceptable is 60%.

Table 1: Interpretation of the ranges for Overall Environmental Equipment Effectiveness

OEEE	Result
OEEE < 60%	Poor
60% < OEEE < 70%	Acceptable
70% < OEEE < 85%	Good
85% < OEEE	Excellent

One of the factors that must be faced to achieve sustainable development is how to repair environmental damage without compromising the need for economic development and social justice (Brundtland Report, 1987). Based on this, sustainability considers ecological, economic and social aspects. In this case, measuring overall equipment effectiveness focuses on environmental sustainability, which prioritises environmental aspects. While the environment calculation uses the eco-indicator 99 as a life cycle impact assessment tool developed by PRé Consultants B.V. (Lees, 2012), which is a number that states the total burden on the environment of a product or process (Goedkoop & Spriensma, 2001) (Equation 6). Standard Eco-indicator 99 values are available for materials (the indicators for production processes are based on 1 kg of material), production processes (treatment and processing of various materials expressed for each treatment in the unit appropriate to the particular process (square metres of rolled sheet or a kilo of extruded plastic), transport processes (these are mostly expressed in the unit tonne-kilo-metre), energy generation processes (units are given for electricity and heat), disposal scenarios (these are per kilo of material, subdivided into types of material and waste processing methods) (Domingo & Aguado, 2015).

The OEEE method was used to calculate machine effectiveness and sustainability aspects. Then, the lowest OEEE value will be found on the machine. Thus, it is necessary to have appropriate recommended actions or an effective way to improve operational performance to reduce negative environmental or social (worker) impacts simultaneously.

Results and Discussion

The value of operational performance: availability, performance efficiency and rate of quality as well as the value of OEE can be seen in Table 2.

The following is a breakdown of the environmental factors (Ministry of Housing, 2000; Goedkoop & Spriensma, 2001).

Material

The indicator for the production process is based on 1 kg of the material. At this stage, the material used in each product component is assessed by multiplying the weight of each component (Wci) by the material indicator (Im). The data needed is the weight of each unit before machining and the total product to be produced (Goedkoop & Spriensma, 2001). In addition, the type of material in the production process is also needed. This calculation is carried out to determine the impact of the material to be processed on the sustainability aspect. The indicator used for each material is 110 (In milli points per kg), with details of block material containing 93% primary iron, 5% scrap, and 1% alloy material. The material used is a hot roll bar S45C with the following material composition following Japanese Industrial Standard (JIS) standards. The reason for taking low alloy steel data is that because the material consists of a maximum of 2.845% alloying elements, this material is similar to low alloy steel. The following is the value of the Production of Ferro Metals indicator in Table 3.

Table 2: Overall Equipment Effectiveness Value

Description	Cutting	Forging	Machining CNC	Robodrill	Chamfer	Broaching	Remove Burry
Normal hours (hour)	66 hours 50 minutes	300 hours	2066 hours	1873 hours	417 hours	417 hours	417 hours
Normal hours (second)	240,600	1,080,000	7,437,600	6,742,800	1,501,200	1,501,200	1,501,200
Overtime hours (second)	0	0	0	0	0	0	0
Plan stop time (second)	14,700	7,800	102,600	376,200	0	50,400	0
Unplan stop time (second)	0	90,000	199,800	25,200	0	25,200	0
Operation time (second)	225,900	982,200	7,135,200	6,341,400	1,501,200	1,425,600	1,501,200
Availability	93.890%	90.944%	95.934%	94.047%	100.000%	94.964%	100.000%
Good product (unit)	76,610	76,406	74,634	73,817	73,793	73,664	73,664
Not a good product (unit)	0	204	1,772	817	24	129	0
Total production (unit)	76,610	76,610	76,406	74,634	73,817	73,793	73,664
Cycle time	2.3	11	80	66	18	16	15
Performance	78.000%	85.798%	85.667%	77.678%	88.510%	82.820%	73.605%
Rate of quality	100.000%	99.734%	97.681%	98.905%	99.967%	99.825%	100.000%
OEE	73.235%	77.821%	80.278%	72.254%	88.481%	78.512%	73.605%

Table 3: Score of Ferro Metals Production Indicator

Description	Cutting	Forging			Machining CNC		Robodrill	Chamfer	Broaching	Remove burry
		Induction	Forming	Trimming	Machining OP10	Machining OP20				
Weight (kg)/unit before the process	0.262	0.262	0.262	0.262	0.256	0.222	0.162	0.150	0.150	0.150
Good product (unit)	76,610	76,610	76,610	76,406	75,185	74,634	73,817	73,793	73,664	73,664
Not a good product (unit)	0	0	0	204	1,221	551	817	24	129	0
Total	76,610	76,610	76,610	76,610	76,406	75,185	74,634	73,817	73,793	73,664
Material production	S45c	S45c	S45c	S45c	S45c	S45c	S45c	S45c	S45c	S45c
Indicator (millipoints/kg)	110	110	110	110	110	110	110	110	110	110
Score (millipoints)	2,207,900.200	2,207,900.200	2,207,900.200	2,207,900.200	2,151,592.960	1,836,017.700	1,329,977.880	1,217,980.500	1,217,584.500	1,215,456.000

Manufacturing Process

At this stage, an assessment of the process used to make each component of the product is carried out by multiplying the weight of each component (Wci) by the indicator of each process (Ip) (Goedkoop & Spriensma, 2001). The data needed is material weight data (kg/unit) before processing, which will be multiplied by dm^3 and total production data (units) specifically for cutting machines, it will be calculated based on mm^2/cutting surface. The following is the value of the processing of metals indicator which can be seen in Table 4.

In the calculation process, it is known that the indicator is kg/dm^3, so the density of S45C is 7.85 kg/dm^3 (Voestalpine One Step Ahead, 2021). The trimming process is considered to have an indicator value of 23 in the machine pressing for material, namely S45C. For broaching machines, the machining process uses milling, turning, and drilling indicators because these indicators are similar to the broaching machine process, namely punching holes in material like a drilling machine. Therefore, the drilling machine indicator is the most appropriate indicator to use. Meanwhile, in the remove burry process using a hand grinder, an indicator is obtained with a zero value because it does not significantly affect sustainability. This is because it does not cause any scrap in the remove burry process, so hand grinding is considered very environmentally friendly.

Electricity

Energy indicators refer to extraction, fuel production, energy conversion and power generation. Eco-indicators for high-voltage electricity have been defined, which are intended for industrial processes and low-voltage electricity, especially for household and small-scale industrial electricity consumption (Goedkoop & Spriensma, 2001). The data needed is the current and voltage strength during a certain period. The electric current and voltage consist of each process taken by sampling as much as 10 data. The existing machine at this company is a machine with 3-phase electricity with a voltage of 380 V. Three-phase electricity is an electrical network that uses three-phase wires (R, S, T) and one neutral wire (N). Tests are carried out for each phase and each machine. This is because the electric current's magnitude and voltage are not fixed, so sampling is needed in data collection. Sampling was conducted to test for adequacy, normality and reliability, and based on the test, the data was sufficient, normal and reliable. The electricity indicator value can be seen in Table 5.

The electrical voltage obtained by the company is 12 kV, then the electricity indicator used can be considered medium voltage (1 kV-24 kV). Based on the OEE calculation, the sustainability calculation must also be made into seven main processes to adjust to the OEE calculation. The calculation of OEEE can be seen in Table 6 and the comparison of the values of each aspect can be seen in Figure 1.

Based on the comparison data shown in Table 6, the lowest OEEE value is found in the forging machine at 55.752%, this is because the sustainability value of the forging machine is 71.641% which is caused by the large indicator of the material used, namely for low alloy steel of 110 milli points, resulting in score indicator material 2,207,900.200 milli points. The OEEE value on the CNC machine is 56.040% because the sustainability value on the CNC machine is 69.808% with the same problems as the forging machine. Therefore, we know that the root of the problem of both forging machines and CNC machines is the material aspect. The material indicators used have a significant impact on the sustainability aspect. Therefore, making a work instruction by recycling the S45C material would be better. In addition, the company can change the type of material to steel type SWCH45K, which is medium carbon steel with a composition that is not much different from before. In addition, an alternative to the environmental impact that can be reduced is to recycle steel scrap from S45C material. The following improvements are to increase the sustainability measure or parameter.

Table 4: Score of Metals Processing Indicator

Description	Cutting	Forging			Machining CNC		Robodrill	Chamfer	Broaching	Remove burry
		Induction	Forming	Trimming	Machining OP10	Machining OP20				
Manufacturing process	Cutting shearing	Induction	Pressing machine	Trimming machine	CNC lathe machine	CNC lathe machine	CNC drilling machine	Drilling machine	Broaching machine	Hand grins
Indicator (millipoints)	0.00006	0	23	23	800	800	800	800	800	0
Data	mm^2/cutting surface	Mega joule	kg/dm^3	kg/dm^3	kg/dm^3	kg/dm^3	kg/dm^3	kg/dm^3	kg/dm3	0
Measurements	28	0	0.033375796	0.033375796	0.032611465	0.028280255	0.020636943	0.01910828	0.01910828	0
Total production	76,610	76,610	76,610	76,610	76,406	75,185	74,634	73,817	73,793	73,664
Score	128.705	0.000	58,809.154	58,809.154	1,993,369.274	1,701,000.764	1,232,174.064	1,128,412.739	1,128,045.860	0.000

Table 5: Score of Electricity Indicator

Description	Cutting	Forging			Machining CNC		Robodrill	Chamfer	Broaching	Remove burry
		Induction	Forming	Trimming	Machining OP10	Machining OP20				
Power (kilowatt)	11.497	80.775	20.881	10.782	3.111	3.162	4.142	0.715	4.128	3.082
Time	66 hours 50 minutes	300 hours	300 hours	300 hours	2066 hours	2066 hours	1873 hours	417 hours	417 hours	417 hours
Energy (kilowatt hour)	768.383	24,232.555	6,264.280	3,234.743	6,427.479	6,533.320	7,758.602	298.324	1,721.208	1,285.008
Indicator (millipoints/ KWH)	22	22	22	22	22	22	22	22	22	22
Score (millipoints)	16,904.424	533,116.206	137,814.157	71,164.338	141,404.528	143,733.040	170,689.241	6,563.133	37,866.586	28,270.175

Table 6: Overall Environmental Equipment Effectiveness

Description	Cutting	Forging	Machining CNC	Robodrill	Chamfer	Broaching	Remove Burry
Availability	93.890%	90.944%	95.934%	94.047%	100.000%	94.964%	100.000%
Performance efficiency	78.000%	85.798%	85.667%	77.678%	88.510%	82.820%	73.605%
Rate of quality	100.000%	99.734%	97.681%	98.905%	99.967%	99.825%	100.000%
OEE	73.235%	77.821%	80.278%	72.254%	88.481%	78.512%	73.605%
Sustainability	91.569%	71.641%	69.808%	89.644%	91.083%	90.968%	95.287%
OEEE	67.060%	55.752%	56.040%	64.771%	80.591%	71.421%	70.136%

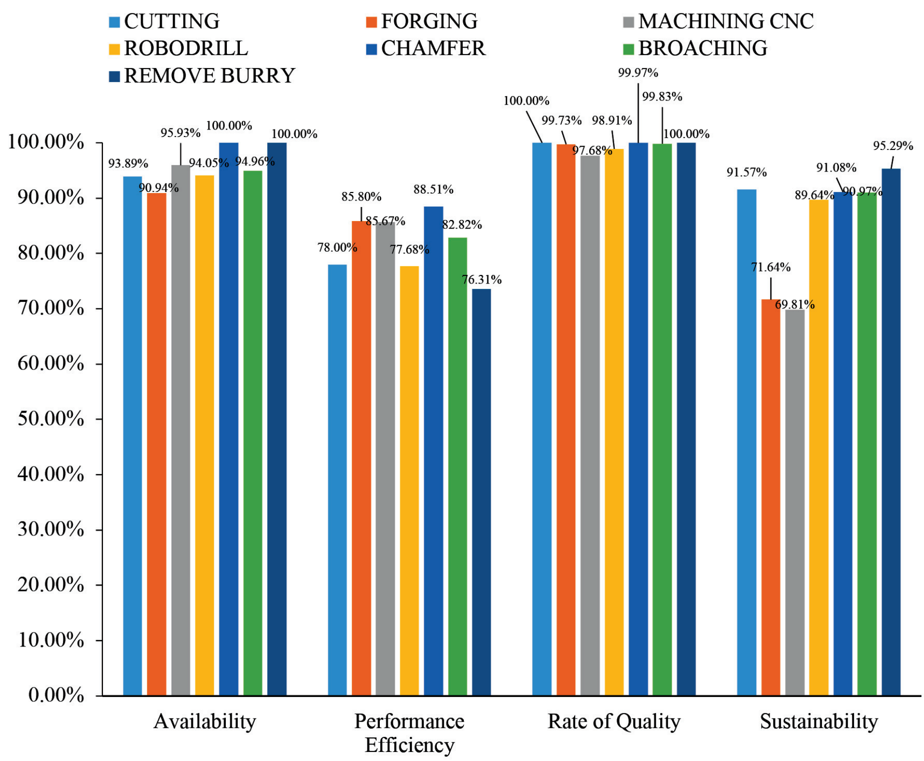

Figure 1: Comparison Value of Availability, Performance Efficiency, Rate of Quality and Sustainability

Material

Based on the results described previously, it is necessary to review the value of the material indicator for S45C medium carbon steel so that the material needs to be replaced with similar, but more environmentally friendly, materials such as SWCH45K. The following is a detailed calculation of the SWCH45K material which can be seen in Table 7. The reason for using SWCH45K steel is that it is a medium carbon steel with a smaller chemical composition percentage, so the environmental impact is also smaller.

Table 7: Improvement Value of Production of Ferrous Metals Indicator

Description	Cutting	Forging			Machining CNC		Robodrill	Chamfer	Broaching	Remove Burry
		Induction	Forming	Trimming	Machining OP10	Machining OP20				
Weight (kg)/ unit before the process	0.262	0.262	0.262	0.262	0.256	0.222	0.162	0.150	0.150	0.150
Good product (unit)	76,610	76,610	76,610	76,406	75,185	74,634	73,817	73,793	73,664	73,664
Not a good product (unit)	0	0	0	204	1,221	551	817	24	129	0
Total production	76,610	76,610	76,610	76,610	76,406	75,185	74,634	73,817	73,793	73,664
Material	Swch45k	Swch45k	Swch45k	Swch45k	Swch45k	Swch45k	Swch45k	Swch45k	Swch45k	Swch45k
Indicator (milipoints/kg)	86	86	86	86	86	86	86	86	86	86
Score (milipoints)	1,726,176.520	1,726,176.520	1,726,176.520	1,726,176.520	1,682,154.496	1,435,432.020	1,039,800.888	952,239.300	951,929.700	950,265.600

Recycling of Waste

The recycling of waste indicator is the process of recycling the waste in the form of not good products and the rest of the scrap from machining. A solid recycling process recycles waste. In addition, smelting can also be carried out using an electric furnace. The following is a detailed calculation of the recycling of waste indicator which can be seen in Table 8. The value taken is -70, suggesting that recycling does not avoid primary steel production. Thus, with recycling, steel must still be produced to meet the production needs.

Based on the existing results, the OEEE value for the previous forging machine was 55.752% and for CNC machining 56.040% with international OEEE standards < 60%, it was categorised as bad (Domingo & Aguado, 2015). Therefore, an improvement was made in the form of changing materials and conducting recycling of the waste with the results of OEEE on forging machines of 60.118% and on CNC machining of 60.278%, the OEEE value can be said to be acceptable because it meets the requirements of 60% < OEEE < 70% (Domingo & Aguado, 2015). This is better than before the improvement. The OEEE value after the improvement can be seen in Table 9.

The comparison of OEEE values before and after improvements in the entire production process can be seen in Figure 2. Operators must carry out work instructions first, putting scrap and not good products into the smelting furnace (Riaz & Atiqah, 2014) with a smelting furnace temperature of 1520°C-1570°C. The melting point of S45C is 1520°C (Singh, 2016). The billet will come from the water-cooled mould and run on the conveyor. The billet will be placed in the raw material warehouse through the conveyor. Billets are semi-finished steel made from scrap steel, which is melted at a certain temperature and poured into a certain size mould (Ministry of the Environment, 2012). The raw materials were placed according to the colour and type of material. Colour paint was given accordingly to facilitate the grouping of raw materials. The location of the material is

Table 8: Improvement Score Indicator Recycling of Waste

Description	Cutting	Forging			Machining CNC		Robodrill	Chamfer	Broaching	Remove Burry
		Induction	Forming	Trimming	Machining OP10	Machining OP20				
Leftover scrap (kg)/ unit	0	0	0	0.006	0.034	0.060	0.012	0	0	0
Good product (unit)	76,610	76,610	76,610	76,406	75,185	74,634	73,817	73,793	73,664	73,664
Not a good product (unit)	0	0	0	204	1,221	551	817	24	129	0
Total production	76,610	76,610	76,610	76,610	76,406	75,185	74,634	73,817	73,793	73,664
Material	S45C	S45C	S45C	S45C	S45C	S45C	S45C	S45C	S45C	S45C
Indicator (millipoints/kg)	-70	-70	-70	-70	-70	-70	-70	-70	-70	-70
Score (millipoints)	0.000	0.000	0.000	-35,917.560	-203,726.600	-324,339.540	-71,957.340	-252.000	-1,354.500	0.000

Table 9: The OEEE Value After Improvement

Description	Cutting	Forging	Machining CNC	Robodrill	Chamfer	Broaching	Remove Burry
Availability	93.890%	90.944%	95.934%	94.047%	100.000%	94.964%	100.000%
Performance efficiency	54.261%	85.798%	85.667%	77.678%	88.510%	82.820%	73.605%
Rate of quality	100.000%	99.734%	97.681%	98.905%	99.967%	99.825%	100.000%
OEE	73.235%	77.821%	80.278%	72.254%	88.481%	78.512%	73.605%
Sustainability	93.394%	77.252%	75.087%	91.014%	92.091%	91.980%	96.292%
OEEE	68.397%	60.118%	60.278%	65.761%	81.483%	72.215%	70.876%

distinguished by size and type of material to match customer requirements. The material can be judged OK if all types of checks have been carried out, with the results of the check being OK and giving the status of OK on the raw material label. We can make a Corrective Action Request (CAR) if abnormal/out-of-standard checking results are found (Chino *et al*., 2002; American Standard Testing and Material Steel, 2015). The SWCH45K material test results show a carbon composition of 0.45%, the same as the S45C material. However, these two materials have different compositions so S45C will be replaced with SWCH45K.

Conclusions

This action research related to OEEE parametric has been analysed by considering availability, performance efficiency, quality rate and sustainability. The OEE value shows the value of the standard for measuring manufacturing productivity, while the OEEE value shows the combination of operational performance and environmental impact. Based on the investigation results, the "poor" OEEE value in the 05K boss rotor manufacturing process occurred in the cutting process of 46.650%. This is caused by the low value of performance efficiency. The forging process is 55.752%, and the machining process is 56.040% because of the low sustainability value. This research aims to improve sustainability indicators and manufacturing processes simultaneously with appropriate corrective actions. The corrective action from this research is to change the raw material used from S45C to SWCH45K so that it has a lower environmental impact. In addition, the improvement from this study is recycled waste from not good products and remaining raw materials so that those can be remanufactured as raw materials. After improvement, the OEEE value can be declared "acceptable" because it meets the requirements of 60% < OEEE < 70%.

Sustainability is living within the limits of available physical, natural and social resources in ways that allow the living systems in which humans are embedded to thrive in perpetuity. This study further discusses one of the pillars of sustainability, namely environmental sustainability, where the environmental aspect consists of renewable material resources that can be renewed without depleting and destroying natural resources, resulting in less energy consumption and less impact on the overall environment. Environmental sustainability also means that it is done by consuming less material and energy, utilising renewable resources and understanding processes to reduce environmental waste. Energy use during processing is considered one of the biggest impacts of machining. Embodied energy, water, toxins, and other environments are the impact of machine tools. Machine tools with cooling, lubrication, chip removal, corrosion protection and cleaning tools also cause environmental impacts.

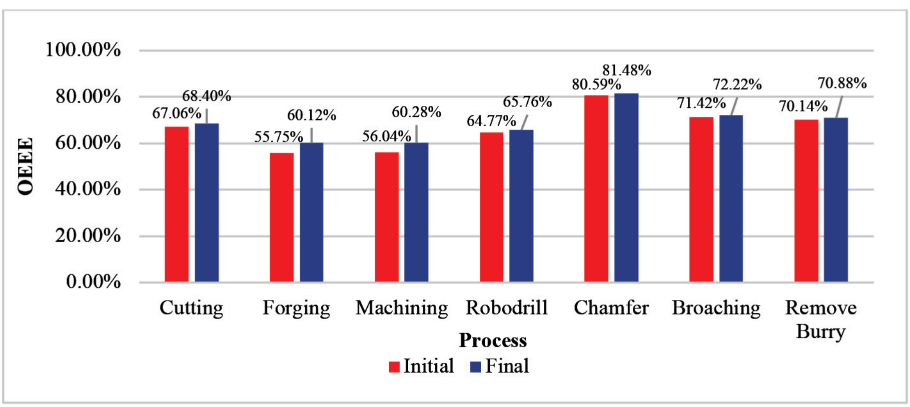

Figure 2: The OEEE Entire Process Production

Based on the three pillars of sustainability, this research discusses environmental impacts indirectly related to economic or social impacts. When an improvement process is carried out to recycle S45C, it will directly impact environmental sustainability and indirectly impact economic sustainability, where the company can reduce purchases of S45C. S45C which has been recycled, can be used to process new products. Likewise, with the environmental impacts on the induction machine, where the huge energy used in the induction machine is heating the S45C, which greatly impacts the environmental sustainability as well as social sustainability like workers who are exposed to heat too often can be exposed to potential heat stress. Although it is stated that there is a relationship between the three pillars of sustainability, future research should determine the sustainability metrics comprehensively to incorporate all these aspects together. Companies must be aware of the principles of green manufacturing on global issues that have been quite crucial in recent years. Environmental impact in the future will affect the world and the welfare of future generations.

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