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PERFORMANCE ANALYSIS OF GREEN MANUFACTURING USING GREEN SUPPLY CHAIN OPERATION REFERENCE (GREEN SCOR) AND AHP METHODS AT PT. ABC

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ABSTRAK

Pertumbuhan industri manufaktur memberikan dampak positif pada pendapatan negara, namun juga menimbulkan masalah lingkungan akibat limbah produksi. PT. ABC, produsen mur dan baut, menghadapi masalah limbah yang belum diolah dan pemborosan bahan baku dari proses pemotongan, yang menyebabkan permasalahan lingkungan. Penelitian ini bertujuan menilai kinerja green manufacturing dan memberikan rekomendasi perbaikan. Metode yang digunakan adalah model Green SCOR dengan pembobotan *Analytical Hierarchy Process* (AHP). Hasil menunjukkan nilai kinerja akhir perusahaan sebesar 67,53, yang masuk kategori kuning (cukup memuaskan). Namun, empat dari dua belas indikator KPI memerlukan perbaikan, yaitu *yield, recyclable waste, waste disposition, dan waste produced.*

Kata kunci: green manufacturing, green scor, analytical hierarchy process.

ABSTRACT

The growth of the manufacturing industry positively impacts national income but also causes environmental issues due to industrial waste from the production process. PT. ABC, a manufacturer of nuts and bolts, faces problems such as unprocessed waste and material wastage from the cutting process, leading to environmental issues. This study aims to evaluate the green manufacturing performance and provide improvement recommendations based on the measurement results for poor indicators to help the company sustainably grow its business. The study uses the Green SCOR model and the Analytical Hierarchy Process (AHP) weighting method to measure green manufacturing performance. The results show that the company's final performance score is 67.53, indicating a yellow category (fairly satisfactory). However, four out of twelve KPI indicators require improvement, namely yield, recyclable waste, waste disposition, and waste produced.

Keywords: green manufacturing, green scor, analytical hierarchy process.

INTRODUCTION

One of the industries that significantly contributes to a country's economic growth is the manufacturing industry. The positive impacts of the growth of the manufacturing industry include increasing national GDP and providing the largest contribution to employment (Central Bureau of Statistics, 2023). Besides the positive impacts, the manufacturing industry also has negative impacts on the environment. Manufacturing activities can cause environmental pollution and waste contamination (Pujianto et al., 2022). The manufacturing industry must switch to more environmentally friendly methods, known as green manufacturing. Green manufacturing is a type of manufacturing that prioritizes the efficient and sustainable use of resources. It allows aligning manufacturing growth with the preservation of environmental functions and provides benefits to society (Reda, 2018). Green manufacturing refers to a set of actions intended to reduce the environmental impact of manufacturing processes or systems compared to their original state, such as reducing the amount of hazardous waste generated or the use of harmful substances. Green manufacturing is a method of manufacturing that minimizes waste and pollution through the design of products and processes (Muhammad, 2023).

PT. ABC is a manufacturing company that processes steel wire rods into various fastener products such as nuts, bolts, screws, and others. The products can be used for various purposes, such as building towers, power plants, bridges, and more. PT. ABC can produce at least 450 pieces of bolts per day with 8 hours of work managed by 3-4 operators. In the production process, there are issues such as a large amount of unprocessed waste and material wastage from cutting processes, which can cause environmental pollution.

The problems caused by these activities require the measurement of green manufacturing performance to achieve sustainable industry at PT. ABC. According to the "Sustainable Manufacturing Toolkit" issued by the OECD (The Organization for Economic Co-operation and Development), the implementation of green manufacturing can have many benefits for companies. One of these benefits is better financial performance, which can increase sales, improve efficiency and productivity, reduce dependence on hazardous materials, and reduce pollution (Cecilia, 2021).

To assess and monitor green manufacturing performance, an effective analysis method is needed. The method used to measure green manufacturing performance is the Green Supply Chain Operation References (Green SCOR). By using this method, the relationship between the

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company's goals and supply chain management in overall manufacturing activities can be determined by evaluating green manufacturing performance. The supporting method for measuring green manufacturing performance uses the Analytical Hierarchy Process (AHP). The AHP supporting method is used to determine the weighting of each indicator.

METHOD

The research method used is the Green SCOR and AHP methods, through four stages, namely:

Identification of Green Manufacturing

Identifying performance indicators within the company in accordance with the concept of green manufacturing.

Developing KPIs in the Green SCOR Perspective

After identifying green manufacturing performance indicators, the next step is to develop key performance indicators (KPIs) from the Green SCOR perspective.

Data Processing

Data processing in this research uses the AHP method by conducting weighting. Then, normalization tests are performed so that all performance indicators are on the same scale. After that, final performance calculations are carried out to obtain the company's performance score. If there are performance indicator values < 60, improvement suggestions will be provided.

Results and Discussion

The processed data is then analyzed and discussed concerning the existing problems to provide appropriate solutions. The discussion uses the Traffic Light System method to identify indicators that need improvement.

RESULT AND DISCUSSION

KPI Identification

One of the elements supporting environmental sustainability improvement at PT. ABC is the consideration of green SCOR concepts and conditions throughout the supply chain. Reliability, Responsiveness, Flexibility, and Cost are four of the five basic attributes of the green SCOR principle used in this research. The selection of these basic attributes is adjusted to the company's conditions. The following are the KPI indicators :

Table 1. KPI Attributes in Green Manufacturing Performance Analysis at PT. ABC

No	Process	Attribute	Key Performance Indicator
1	Make	Reliability	Yield
2			Water Usage
3			Energy Usage
4			Recyclable Waste
5			Hazardous Material Used
6			Waste Disposition
7		Responsiveness	Waste Produced as % of Product Produced
8			Make Cycle Time
9			Production Schedule
10		Flexibility	Upside Make Flexibility
11		Cost	Production Cost
12			Waste Treatment Installation Cost

Source : Company Interview Results

To determine the relative significance of various KPIs, the "Green Supply Chain Operation Reference (Green SCOR)" is used to perform indicator weighting analysis, and quantitative evaluation of internal KPI consistency is employed. The underlying idea used in the weighting procedure (AHP) is the Analytic Hierarchy Process method. The Green SCOR weighting system consists of two levels; the first level focuses on attributes like reliability, responsiveness, flexibility, and cost, while the second level encompasses twelve KPIs listed in the table.

Table 2. Level 1 Questionnaire Results

Criteria	Reliability	Responsiveness	Flexibility	Cost
Reliability	1,00	4,00	3,00	5,00
Responsiveness	0,25	1,00	3,00	3,00
Flexibility	0,33	0,33	1,00	3,00
Cost	0,20	0,33	0,33	1,00
Total	1,78	5,67	7,33	12,00

To determine the weights assigned to each attribute, the first thing to do is to obtain the results from the normalization matrix and then input the values into the columns of the normalization matrix.

Table 3. Normalization Results Level 1

Criteria	Reliability	Responsiveness	Flexibility	Cost
Reliability	0,56	0,71	0,41	0,42
Responsiveness	0,14	0,18	0,41	0,25
Flexibility	0,19	0,06	0,14	0,25
Cost	0,11	0,06	0,05	0,08
Total	1	1	1	1

After obtaining the normalization values for each attribute, the next step is to conduct a consistency test among the attributes to determine the CR value. The weighted questionnaire is considered consistent if and only if the consistency ratio is less than 0,1 (every ten percent). If the consistency ratio is less than 0,1 then this weighting ratio can be used as the criterion weighting value.

Table 4. Results of Weighting and Consistency Level 1

Criteria	Total Weight Matrix	Eigen Vektor	Matrix Multiplication	Eigen Value	λ maks	CI	IR	CR
Reliability	2,09	0,52	2,35	4,49				
Responsiveness	0,98	0,24	1,07	4,40				
Flexibility	0,63	0,16	0,64	4,04	4,28	0,09	0,90	0,10
Cost	0,30	0,07	0,31	4,18				
Total	4,00	1,00	4,37	17,11				

The maximum eigenvalue (λ) obtained is 4,28 with a Consistency Index (CI) of 0,09 and a Random Index (RI) of 0,90 in the make process. Thus, the Consistency Ratio (CR) is 0,10. A CR value of 0,1 or less indicates that the data is reliable and can be properly considered in the calculations.

In the study conducted by Yahya (2023), the maximum eigenvalue (λ) obtained was 5,29 with a Consistency Index (CI) of 0,075 and a Random Index (RI) of 1,12. Therefore, the Consistency Ratio (CR) value is 0,068. If the CR value is 0,1 or less, then the data can be considered reliable and can be well accounted for in calculations.

Table 5. Results of Green SCOR Matrix Weighting

No	Process	Attribute	Weight Level 1	KPI	Weight Level 2	Final Weight
1	Make	Reliability	0,52	Yield	0,35	0,18
2				Water Usage	0,26	0,14
3				Energy Used	0,17	0,09
4				Recyclable Waste	0,11	0,06
5				Hazardous Material Used	0,08	0,04
6				Waste Disposition	0,04	0,02
7		Responsiveness	0,24	Waste Produced	0,59	0,14
8				Make Cycle Time	0,25	0,06
9				Production Schedule	0,16	0,04
10		Flexibility	0,16	Upside Make Flexibility	1	0,16
11		Cost	0,07	Production Cost	0,25	0,02
12				Waste Treatment Installation Cost	0,75	0,05

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The findings of the pairwise comparisons made at Level 1 for the four attributes in the make process are shown in Table 5. The reliability attribute has the highest weight (0,52), followed by the responsiveness attribute (0,24), the flexibility attribute (0,16), and the cost attribute (0,07).

The weighting results for each pairwise comparison indicator at Level 2 are as follows Yield has a weight of 0,35 with a final weight of 0,18; Water usage has a weight of 0,26 with a final weight of 0,14; Energy used has a weight of 0,17 with a final weight of 0,09; Recyclable waste has a weight of 0,11 with a final weight of 0,06; Hazardous material used has a weight of 0,08 with a final weight of 0,04; Waste disposition has a weight of 0,04 with a final weight of 0,02; Waste produced has a weight of 0,59 with a final weight of 0,14; Make cycle time has a weight of 0,25 with a final weight of 0,06; Production schedule has a weight of 0,16 with a final weight of 0,04; Upside make flexibility has a weight of 1 with a final weight of 0,16; Production cost has a weight of 0,25 with a final weight of 0,02; Waste treatment installation cost has a weight of 0,75 with a final weight of 0,05.

To determine the company's final performance score according to the Green SCOR concept, the weight value (scoring) of each indicator will be multiplied by the score. The results of the Snorm calculations used in this study are shown in Table 6.

Table 6. Final Performance Values of Green Manufacturing at PT. ABC

KPI	Weight Level 2	Actual (Si)	Min	Max	Snorm	Final Weight	Normalization x Weight	Final Performance
Yield	0,35	88,04%	80%	95%	53,60	0,18	0,09	
Water Usage	0,26	6,83	5	15	81,70	0,14	0,11	
Energy Used	0,17	1,23	0,5	2,5	63,50	0,09	0,05	
Recyclable Waste	0,11	72,16%	60%	90%	40,53	0,06	0,02	
Hazardous Material Used	0,08	41,21%	30%	85%	79,62	0,04	0,03	
Waste Disposition	0,04	294	0	294	0	0,02	0	
Waste Produced	0,59	4,52%	2%	7%	49,60	0,14	0,12	**67,53**
Make Cycle Time	0,25	2,12	1,5	4	75,20	0,06	0,04	
Production Schedule	0,16	94,88%	80%	100%	74,40	0,04	0,02	
Upside Make Flexibility	1	100	90	100	100	0,16	0,16	
Production Cost	0,25	10.122,94	10.000	13.000	61,42	0,02	0,01	
Waste Treatment	0,75	41.051.240	40.000.000	43.000.000	64,96	0,05	0,03	

KPI	Weight Level 2	Actual (Si)	Min	Max	Snorm	Final Weight	Normalization x Weight	Final Performance
Installation Cost								

After calculating the Snorm values, the final performance score for green manufacturing at PT. ABC was determined to be 67,53. This score falls into the marginal (average) or satisfactory category. Next, the traffic light system method will be used to identify which indicators need improvement.

Table 7. TLS Scoring Results

KPI	Actual (Si)	Min	Max	Snorm
Yield	88,04%	80%	95%	**53,60**
Water Usage	6,83	5	15	**81,70**
Energy Used	1,23	0,5	2,5	**63,50**
Recyclable Waste	72,16%	60%	90%	**40,53**
Hazardous Material Used	41,21%	30%	85%	**79,62**
Waste Disposition	294	0	294	**0**
Waste Produced	4,52%	2%	7%	**49,60**
Make Cycle Time	2,12	1,5	4	**75,20**
Production Schedule	94,88%	80%	100%	**74,40**
Upside Make Flexibility	100	90	100	**100**
Production Cost	10.122,94	10.000	13.000	**61,42**
Waste Treatment Installation Cost	41.051.240	40.000.000	43.000.000	**64,96**

The table above indicates that three KPIs fall under the green category, three KPIs fall under the red category, and six KPIs fall under the yellow category. The overall performance of the company currently achieves a score of 67.53, which falls within the yellow category, indicating satisfactory performance.

According to this figure, the Green Manufacturing Performance Analysis of PT. ABC is in the yellow zone, indicating that the company has met its targets based on an average level of performance or achievement of performance indicators. The company can improve its green manufacturing performance by focusing on key performance indicators (KPIs) that have not yet met their targets and making adjustments to achieve them. However, the red KPIs must be addressed first, as they have very low achievement values compared to the targets. If these critical performance indicators are not addressed promptly, it will negatively impact the company's production activities.

CONCLUSION

PT. ABC has achieved an overall performance score of 67,53 for green manufacturing, placing it in the yellow category, indicating satisfactory performance. However, four indicators yield, recyclable waste, waste disposition, and waste produced are categorized as red, suggesting areas needing improvement. Recommended improvements for the company include: Providing training to machine operators to enhance skills in operating cutting machines efficiently; Choosing materials that are easier to recycle, such as used cooking oil, which can serve as an alternative to oil for fuel bolt production; Enhancing waste processing facilities to handle the generated waste volume effectively; Optimizing oil change schedules based on machine analysis and needs. These steps aim to improve operational efficiency, resource utilization, and environmental sustainability within PT. ABC's manufacturing processes.

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