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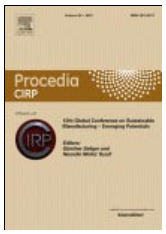

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Key Performance Indicators for Sustainable Manufacturing Evaluation in Cement Industry

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Abstract

The cement industries are facing challenges to implement sustainable manufacturing into their products and processes. Cement manufacturing has remarked as an intensive consumer of natural raw materials, fossil fuels, energy, and a major source of multiple pollutants. Thus, evaluating the sustainable manufacturing in this industry is become a necessity. This paper proposes a set of Key Performance Indicators (KPIs) for evaluating the sustainable manufacturing believed to be appropriate to the cement industry based on the triple bottom line of sustainability. The Analytical Hierarchy Process (AHP) method is applied to prioritize the performance indicators by summarizing the opinions of experts. It is hoped that the proposed KPIs enables and assists the cement industry to achieve the higher performance in sustainable manufacturing and so as to increase the competitiveness.

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Keywords: analytic hierarchy process; cement industry; key performance indicators; sustainable manufacturing

1. Introduction

Nowadays, sustainable manufacturing has become a very important issue amongst industries around the world. Achieving sustainable manufacturing has been recognized as a critical need due to diminishing non-renewable resources, stricter regulations related to environment and occupational health and safety, and increasing consumer preference for environmental-friendly products [1]. It has been reported that those companies adopting sustainable practices are able to achieve better product quality, higher market share, and increased profits [2]. Sustainable manufacturing practices have also been seen to be positively associated with competitive outcomes [3]. Therefore, developing sustainable approaches to manufacturing companies has been regarded as a critical global concern [4].

Sustainable manufacturing defined as the creation of manufactured products that minimize negative environmental impacts, conserve energy and natural resources, are safe for employees, communities and consumers and are economically sound [5]. The general principle of sustainable manufacturing is to reduce the intensity of materials use, energy consumption, emissions, and the creation of unwanted by-products while maintaining, or improving, the value of products to society and to organizations [6]. According to the definition, sustainable manufacturing must address the integration all the three indicators of environmental, social, and economic, known as the triple bottom line of sustainability. Thus, sustainable manufacturing should be evaluated with respect to those three indicators.

Sustainable manufacturing is certainly one of the critical issues for the cement industry. Cement, as the most important ingredient of concrete, is a fundamental building material for society's infrastructure construction around the world [7]. According to United Nations Environment Program report [8] "Basic construction materials serve an ever increasing demand for the building sector; this leads to annual growth rates of about 6% for cement. At the same time these industries caused about 6% of global anthropogenic greenhouse gas emissions". Generally, the cement plants are characterised as an intensive consumer of natural raw materials and fossil fuels, and has remarked as emitters of pollutants [9, 10]. Furthermore, the

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cement industry has regarded as one of the most energy intensive consumers amongst industries in the world [11]. Therefore, evaluating sustainable manufacturing has become a necessity for this industry.

In this study, a literature review was carried out in an attempt to determine indicators commonly used in sustainable manufacturing evaluation. The most commonly used indicators for sustainable manufacturing evaluation in the cement industry is referred to the World Business Council for Sustainable Development (WBCSD) consisting of tones of cement per MJ, fuel and raw material substitution rates, non product output, net CO2 per tonne of cement, and incident rate. Besides, there are a number of indicators proposed by various organizations such as ISO 14031, Global Reporting Initiative (GRI), and Organization for Economic Co-operation and Development (OECD).

This paper proposes a set of Key Performance Indicators (KPIs) for evaluating the sustainable manufacturing believed to be appropriate to the cement industry based on the triple bottom line of sustainability. The KPIs are then used to develop an evaluation model of sustainable manufacturing. The Analytical Hierarchy Process (AHP) methodology is applied to weighting the KPIs. It is believed that the proposed KPIs and the evaluation model enable and assist the cement industry in effort to increase their sustainable manufacturing performance.

2. Methodology

The methodology has three main stages. First, the initial key performance indicators (KPIs) for sustainable manufacturing evaluation were identified and derived from the literature. Second, the initial KPIs were then validated to industry practices. Finally, a sustainable manufacturing performance evaluation based on the KPIs was developed using Analytic Hierarchy Process (AHP) methodology. The details are presented in the following sections.

2.1. Identification of KPIs

This study starts with the development of initial key performance indicators (KPIs) for sustainable manufacturing evaluation in cement industry through literature review. The initial KPIs have been constructed by adopting the triple bottom line of sustainability consisting of economic, environmental, and social performance factors. As a result, the initial KPIs consist of three factors divided into nineteen indicators were identified as shown in Table 1.

2.2. Conducting industry survey

The initial KPIs were then validated by an industry survey conducted to a cement manufacturing company located in Padang, Indonesia. Established in 1910, the company is the first cement manufacturing plant in Indonesia. Currently, the company has four plants with a total of production capacity of 5.240.000 tons per year. The company has been certified by ISO 9001, ISO 14001, and OHSAS 18001.

Table 1. Initial KPIs of sustainable manufacturing evaluation.

Factors	Indicators
1. Economic	1. Inventory cost
	2. Labor cost
	3. Material cost
	4. Product delivery
	5. Raw material substitution
2. Environmental	6. Air emission
	7. Energy consumption
	8. Fuel consumption
	9. Material consumption
	10. Noise pollution
	11. Nonproduct output
	12. Water utilization
	13. Land utilization
3. Social	14. Accident rate
	15. Employee involvement
	16. Labor relationship
	17. Gender equity
	18. Occupational health and safety
	19. Training and education

A total of 12 managers of production and manufacturing division were asked to rate the importance level of each KPIs of sustainable manufacturing evaluation in the cement industry. A five-point likert scale ranging from 1 (not important at all) to 5 (very important) was used to rate the perspective of managers to the importance level of the KPIs. The mean importance values ranged from 3.083 to 4.750 as presented in Table 2.

Table 2. Mean importance values of the initial KPIs.

Indicators	Mean
Material cost	4.750
Energy consumption	4.667
Inventory cost	4.667
Occupational health and safety	4.667
Fuel consumption	4.500
Labor cost	4.500
Accident rate	4.417
Training and education	4.417
Product delivery	4.333
Raw material substitution	4.333
Air emission	4.250
Labor relationship	4.083
Material consumption	4.083
Employee involvement	3.833
Noise pollution	3.833
Water utilization	3.750
Gender equity	3.417
Land utilization	3.417
Nonproduct output	3.083

The results indicated that material cost is regarded as the most important KPI with a mean importance value of 4.750 representing an 95% importance. This is followed by energy consumption, inventory cost, and occupational health and safety with a same mean importance value of 4.667. On the other hand, employee involvement, noise pollution, water utilization, gender equity, land utilization, and nonproduct output were regarded as the least important indicators.

Based on the results, the initial KPIs of sustainable manufacturing evaluation in cement industry have been modified. Due to the less importance, six indicators were removed from the initial KPIs. Finally, three factors with a total of thirteen indicators have been proposed as the KPIs for sustainable manufacturing evaluation in cement industry.

2.3. Developing AHP-based evaluation model

An evaluation model for sustainable manufacturing performance in cement industry was developed based on the proposed KPIs. Analytic Hierarchy Process (AHP) methodology was applied in the developing of the model consisting of constructing the hierarchy, weighting the KPIs, rating the KPIs, and computing the scores of companies, and ranking the companies. Details are given in the following section.

3. Sustainable manufacturing evaluation model for the cement industry

Analytic Hierarchy Process (AHP) first introduced by Thomas L. Saaty in 1971 has become one of the most widely used methods for multiple criteria decision making (MCDM) problems. It is a decision approach designed to aid in making the solution of complex multiple criteria problems to a number of application domains [12]. It has been known as an essential tool for both practitioner and academics to conduct researches in decisions making and examining management theories [13]. AHP as a problem solving method is flexible and systematic that can represent the elements of a complex problem [14].

AHP methodology has several benefits [13]. First, it helps to decompose an unstructured problem into a rational decision hierarchy. Second, it can elicit more information from the experts or decision makers by employing the pair-wise comparison of individual groups of elements. Third, it sets the computations to assign weights to the elements. Fourth, it uses the consistency measure to validate the consistency of the rating from the experts and decision makers. The following steps show the development of an AHP-based model for sustainable manufacturing performance evaluation in cement industry.

3.1. Construct the hierarchy

The proposed KPIs of sustainable manufacturing evaluation in the cement industry are used in constructing a hierarchy. The three groups were defined and constructed in the hierarchy including goal, factors, and indicators. In the hierarchy, evaluating sustainable manufacturing performance of cement industry is set to be the goal. The next level consists of three factors of environmental, economic, and social. The third level consists of the indicators that described each of factor with a total of thirteen. The hierarchy is depicted in Fig. 1.

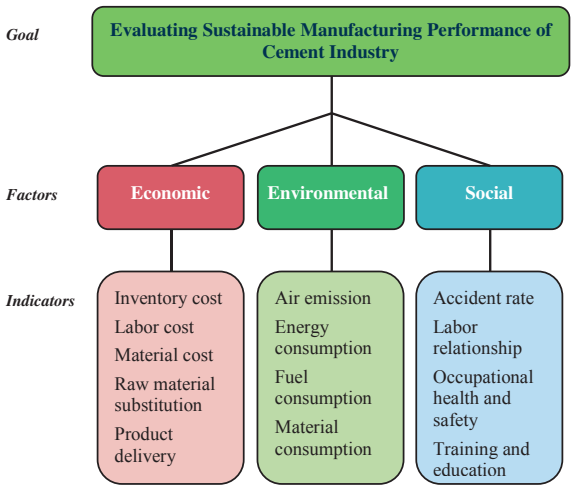

Fig. 1. The hierarchy structure of KPIs.

3.2. Weighting the KPIs

Once the hierarchy has been constructed, the importance weight of the KPIs should be calculated. A pairwise comparison questionnaire was then designed. A total of ten senior managers from the cement company were consulted to give their preferences on the KPIs. Those managers were carefully selected based on their experience in cement industry. The pairwise comparisons were determined between factors, and indicators within each factor of the KPIs. A Saaty' scale of 1 to 9 (1= equally, 3= moderate, 5= strong, 7= very strong, 9= extreme) was used to reflect these preferences. The Consistency Ratio (CR) was used to check the consistency of the pairwise comparisons for each expert. The CR values are less than 0.1 which means it matches the consistency test. If it is not yet consistent, the comparison has to be repeated again.

Answers to each question were geometrically averaged before calculating the importance weights. Then a pairwise comparison matrix was constructed. The consistency test was performed to all the combined pairwise comparison matrixes. The results show that the Consistency Ratio (CR) values ranged from 0.0098 to 0.0173, which means that all the pairwise comparisons are consistent since the values are within the acceptable level recommended [12]. It indicates that the experts have assigned their preferences consistently in determining the importance weights of the KPIs of sustainable manufacturing evaluation in cement industry

Table 3 presents a summary of the result of the importance weights of the KPIs of sustainable manufacturing evaluation in cement industry. The importance weights show the importance value of one indicator over another indicator. In

term of factors, economic is the highest importance weight with a value of 0.3985. Material cost (0.0995) is regarded to the highest important indicator to economic factor. With regard to environmental factor, energy consumption is the most important indicator with a value of 0.1013 over another. Occupational health and safety (0.0961) is considered much more important indicator than another in term of social factor.

Table 3.The importance weights of KPIs.

Factors	Weight	Indicators	Weight
1. Economic	0.3985	1. Inventory cost	0.0917
		2. Labor cost	0.0763
		3. Material cost	0.0995
		4. Product delivery	0.0642
		5. Raw material substitution	0.0668
2. Environmental	0.3059	6. Air emission	0.0665
		7. Energy consumption	0.1013
		8. Fuel consumption	0.0833
		9. Material consumption	0.0547
3. Social	0.2956	10. Accident rate	0.0730
		11. Labor relationship	0.0525
		12. Occupational health and safety	0.0961
		13. Training and education	0.0739

3.3. Rating the KPIs

The next step in the sustainable manufacturing evaluation is to rate the KPIs. In this study, a scale range from 1 to 10 is used to assess performance of each of the KPIs, where:

1= highly poor
2= moderately poor
3= lowly poor
4= lowly fair
5= moderately fair
6= highly fair
7= lowly good
8= moderately good
9= highly good
10= excellent

3.4. Computing the company scores

The values generated from the performance rating are combined with the corresponding importance weights of the KPIs to obtain the company scores. The company score is calculated for the overall score and as well as for individual score of each factor. The overall score and individual score of each factor of companies are then classified into four performance levels based on the following rules:

If $1 \leq$ scores ≤ 4 then performance level is poor
If $4 <$ scores ≤ 7 then performance level is fair
If $7 <$ scores ≤ 9 then performance level is good
If scores > 9 then performance level is excellent

The overall score and the individual score of factor of the companies evaluated are then ranked in descending order. The company with the highest score can be considered as attaining best practice.

4. Case study results

The evaluation model has been applied to a case of cement manufacturing company in Padang, Indonesia. The production managers were asked to evaluate their three plants using the 1 to 10 scale on the KPIs of sustainable manufacturing evaluation. The rating values are used to calculate the company score consisting of the overall score and the individual scores of each factor. The overall score and individual score of each factor of the companies compared are presented in a final result. The overall score of three plants compared is presented in Fig. 2.

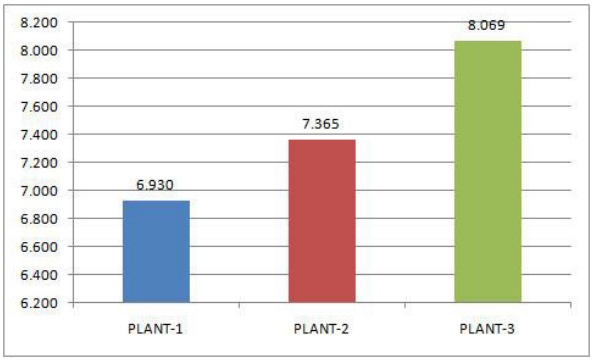

Fig. 2. The overall score of plants compared.

It can be seen that plant-3 has attained the highest overall score with a performance level of good. On the other hand, plant-1 has the lowest overall score with a performance level of fair. In order to provide a detail of the overall score, the individual scores are also computed for each factor of KPIs as shown in Table 4.

Table 4. The individual scores of plants compared.

Plant compared	Individual score (performance level)		
	Economic	Environmental	Social
Plant-1	6.712	7.386	6.753
	(Fair)	(Good)	(Fair)
Plant-2	7.520	7.272	7.250
	(Good)	(Good)	(Good)
Plant-3	8.099	7.783	8.325
	(Good)	(Good)	(Good)

The ranking and performance level of plants obtained are quite varied. Plant-3 is to be the top rank for all factors. Although has the lowest overall score, plant-1 is not at the lowest individual score for all factors. The plant-1 has the individual score of environmental factor higher than the plant-2. It can be concluded that the plant with the lowest overall score might be not the worst in all the factors. In order to

make a quality decision making, these things need to be viewed in detail to prioritize the company's performance indicators when evaluating sustainable manufacturing.

5. Conclusions

The cement industry is an intensive consumer of natural raw materials, fuels, energy, and high pollutant emitting industry. Thus, it is essential to evaluate the sustainable manufacturing in this industry. This paper has developed a set of Key Performance Indicators (KPIs) for sustainable manufacturing evaluation in cement industries. The initial KPIs identified and derived from the literature and then validated to industry practices. Based on the results, three factors with a total of thirteen indicators are proposed as the KPIs of sustainable manufacturing evaluation in cement industries. An evaluation model then developed using Analytic Hierarchy Process (AHP) methodology. The hierarchy structure is established based on the proposed KPIs of sustainable manufacturing evaluation in cement industries. Then, the importance weights of the KPIs s assigned by pairwise comparisons and calculated using AHP methodology. To assess the performance, the KPI is rated using a scale of 1 (highly poor) to 10 (excellent). Then, the company's scores and rank are computed to assess sustainable manufacturing performance against the KPIs.

A case study was conducted to a cement industry. The results show the existing performance level on company's strengths and weaknesses. It provides suggestions and directions for companies to take appropriate actions in improving their sustainable manufacturing performance. The model aids companies in achieving the higher performance and so as increasing the competitiveness. Future work will further incorporate the evaluation model to the development of sustainable manufacturing evaluation tool for the cement industries.

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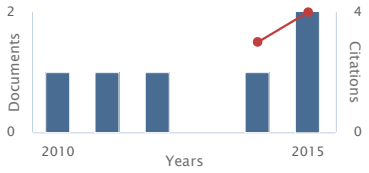

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