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Welcome Message

Welcome to Malaysia and the 2014 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM2014).

IEEM2014 is the ninth in the series of IEEM conferences since 2006. It is the first time the conference is jointly organized by IEEE Technology Management Council Malaysia and Hong Kong Chapters. The conference is supported by Monash University and the City University of Hong Kong.

The strength of IEEM conference is its high conference standard and diversity, bringing together researchers and practitioners from different branches of industrial engineering and engineering management from around the world. In keeping a high standard as for the past IEEM series, each paper went through a rigorous review process. IEEM2014
received almost 550 submissions and each paper was sent to 3-5 reviewers. The acceptance decisions were made based on at least two consistent recommendations. To represent the global diversity, we have an outstanding program, including 20 topics presented in oral and poster sessions, as well as a distinguished set of keynote speakers:

Hean Teik Chuah, President, Universiti Tunku Abdul Rahman (UTAR), Malaysia, will present "Science, Engineering, Technology & Innovation (SETI) Education for Economy Transformation."

Tariq S Durrani, Research Professor, University of Strathclyde, United Kingdom, will discuss "Science, Engineering, Innovation and Competitiveness - An international assessment and comparison."

Thomas L. Magnanti, President, Singapore University of Technology and Design (SUTD), Singapore, will highlight "Educating Technology Leaders for Design-Driven Innovation."

The organising committee is very grateful to Professor Hean Teik Chuah, Professor Tariq S Durrani and Professor Thomas L. Magnanti to deliver their keynote speech at this conference. We would like to thank all the authors and participants for their contribution and support. We would also like to acknowledge the contribution by technical programme committee members and the reviewers for their help in the review process.

We hope you enjoy the conference and the cultural and scenic experiences in Malaysia.

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Poster Session

Interpretive Structural Model of Key Performance Indicators for Sustainable Manufacturing Evaluation in Cement Industry

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Abstract – **This paper aims to analyze the relationships among the Key Performance Indicators (KPIs) for sustainable manufacturing evaluation in the cement industry. The initial KPIs have been identified and derived from literature, and then validated by industry survey. As a result, three factors dividing into a total of thirteen indicators have been proposed as the KPIs for sustainable manufacturing evaluation in cement industry. Interpretive structural modeling (ISM) methodology is applied to develop a network structure model of the KPIs. The results show the indicators of economic factor are regarded as the basic indicator, while the indicators of environmental factor are indicated to be the leading indicator. Of those indicators, raw material substitution is regarded as the most influencing indicator. The ISM model can aid the cement companies by providing a better insight in evaluating sustainable manufacturing performance.**

Keywords - **Cement, interpretive structural modeling, key performance indicators, sustainable manufacturing**

I. INTRODUCTION

Nowadays, the cement industry is facing challenges to implement sustainable manufacturing into their products and processes. Cement plants have been characterised as an intensive consumer of natural raw materials and and have remarked as emitters of pollutants [1, 2]. Furthermore, the cement industry has regarded as one of the most energy intensive consumers amongst industries in the world [3]. Thus, evaluating sustainable manufacturing has become a necessity for this industry.

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 [4]. 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 [5]

Sustainable manufacturing must respond to [6]: (i) economical challenges, by producing wealth and new services ensuring development and competitiveness through time; (ii) environmental challenges, by promoting minimal use of natural resources (in particular non-renewable) and managing them in the best possible way while reducing environmental impact; and (iii) social challenges, by promoting social development and improved quality of life through renewed quality of wealth and jobs.

It has been suggested that sustainable manufacturing has to be evaluated based on the triple bottom line of economic, environmental, and social performance [7] as well as to consider their interdependencies [8]. In this research, attempt is made to analyze the relationships amongst the KPIs. A network structure model has been developed using the Interpretive Structural Modeling (ISM) methodology.

II. METHODOLOGY

The methodology has three main stages.

Stage 1: Identification of KPIs

This study starts with the development of initial key performance indicators (KPIs) for sustainable manufacturing evaluation in cement industry. A literature review was carried out in an attempt to determine indicators that are most commonly used. The initial KPIs are constructed using the triple bottom line of sustainability consisting of environmental, economic, and social factors. As a result, the initial KPIs consist of three factors divided into nineteen indicators are identified as shown in Table I.

TABLE I
INITIAL KPIs

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. Land utilization
	10. Material consumption
	11. Noise pollution
	12. Nonproduct output
	13. Water utilization
3. Social	14. Accident rate
	15. Employee involvement
	16. Gender equity
	17. Labor relationship
	18. Occupational health and safety
	19. Training and education

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Stage 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. A total of 15 managers of production and manufacturing division were asked to rate the importance level of each initial KPIs of sustainable manufacturing evaluation in 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 on the importance level of the initial KPIs. The mean importance values ranged from 3.083 to 4.750 as shown in Table II.

TABLE II
MEAN IMPORTANCE VALUES OF THE INITIAL KPI

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 material cost is regarded as the most important KPI with a mean importance value of 4.750. This followed by three indicators of energy consumption, inventory cost, and occupational health and safety with a same mean importance value of 4.667. On the other hand, six indicators of 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 as shown in Table III.

TABLE III
PROPOSED KPIs

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
3. Social	10. Accident rate
	11. Labor relationship
	12. Occupational health and safety
	13. Training and education

Stage 3: Conducting ISM survey

An ISM survey was conducted to develop a network structure model of the KPIs for sustainable manufacturing evaluation in cement industry. A questionnaire was then designed and sent to 15 managers from the cement company in Padang, Indonesia. Those managers were carefully selected based on their experience in cement industry. Details are given in the following section.

III. DEVELOPMENT OF INTERPRETIVE STRUCTURAL MODEL

Interpretive Structural Modeling (ISM) methodology is an interactive learning process that enables one to develop a map of the complex relationships among many elements involved in a complex problem [9]. ISM helps build an interaction map to identify the interrelationships among system variables. It provides a better understanding of a system structure and draws up a useful guideline in generating a graphical representation of the structure [10]. The following steps show the development of an interpretive structural model of the thirteen KPIs for sustainable manufacturing evaluation in cement industry.

A. Structural self-interaction matrix (SSIM)

Through the ISM survey, fifteen experts were consulted to identify the relationships amongst the KPIs of sustainable manufacturing evaluation in cement industry. Answers to the questions from the experts were averaged. The results indicated a total of 30 direct relationships amongst the KPIs. The SSIM for the KPIs is presented in Table IV.

Four symbols are used to denote the direction of relationship between the indicators (*i* and *j*):

V for the relation from *i* to *j*
A for the relation from *j* to *i*
X for both directions, relations from *i* to *j* and *j* to *i*.
O if the relation between the indicators does not appear valid.

TABLE IV
STRUCTURAL SELF-INTERACTION MATRIX (SSIM)

Indicators	1	2	3	4	5	6	7	8	9	10	11	12	13
1	-	O	O	A	A	O	O	A	A	O	O	O	O
2		-	O	O	O	O	O	O	O	A	O	A	A
3			-	A	A	O	A	A	A	O	O	O	O
4				-	A	O	O	O	O	O	O	O	O
5					-	O	X	A	X	O	O	O	O
6						-	A	O	O	O	O	V	O
7							-	X	A	O	O	O	O
8								-	O	O	O	O	O
9									-	O	O	O	O
10										-	A	X	A
11											-	V	A
12												-	A
13													-

B. Initial reachability matrix

The SSIM is then transformed into the initial reachability matrix by substituting the symbols of V, A, X, and O into a binary matrix of 1 and 0, where 1 means there is relationship between the indicators and otherwise, 0 means there is no relationship between the indicators. The substituting process is as per the following rules:

1) If (*i*, *j*) entry in the SSIM is V, then (*i*, *j*) entry in the reachability matrix is 1 and (*j*, *i*) entry is 0.
2) If (*i*, *j*) entry in the SSIM is A, then (*i*, *j*) entry in the reachability matrix is 0 and (*j*, *i*) entry is 1.
3) If (*i*, *j*) entry in the SSIM is X, then entry for both (*i*, *j*) and (*j*, *i*) is 1.
4) If (*i*, *j*) entry in the SSIM is O, then entry for both (*i*, *j*) and (*j*, *i*) is 0.

The initial reachability matrix of the KPIs for sustainable manufacturing evaluation in cement industry is obtained by the rules above and the result is shown in Table V.

TABLE V
INITIAL REACHABILITY MATRIX

Indicators	1	2	3	4	5	6	7	8	9	10	11	12	13
1	1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	1	0	0	0	0	0	0	0	0	0	0	0
3	0	0	1	0	0	0	0	0	0	0	0	0	0
4	1	0	1	1	0	0	0	0	0	0	0	0	0
5	1	0	1	1	1	0	1	0	1	0	0	0	0
6	0	0	0	0	0	1	0	0	0	0	0	1	0
7	0	0	1	0	1	1	1	1	0	0	0	0	0
8	1	0	1	0	1	0	1	1	0	0	0	0	0
9	1	0	1	0	1	0	1	0	1	0	0	0	0
10	0	1	0	0	0	0	0	0	0	1	0	1	0
11	0	0	0	0	0	0	0	0	0	1	1	1	0
12	0	1	0	0	0	0	0	0	0	1	0	1	0
13	0	1	0	0	0	0	0	0	0	1	1	1	1

C. Final reachability matrix

The final reachability matrix is developed from the initial reachability matrix by incorporating the transitivities using the following equation:

$$M = M^k = M^{k+1},\ k>1 \qquad (1)$$

where k denotes the powers and M is the reachability matrix. Noted that the reachability matrix is under the Boolean operations. The transitivity is a basic assumption of ISM methodology, which stated that if variable-A related to variable-B and variable-B related to variable-C, then variable-A necessarily related to variable-C [9]. The final reachability matrix of the KPIs is shown in Table VI.

TABLE VI
FINAL REACHABILITY MATRIX

Indicators	1	2	3	4	5	6	7	8	9	10	11	12	13	Driving prower
1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
2	0	1	0	0	0	0	0	0	0	0	0	0	0	1
3	0	0	1	0	0	0	0	0	0	0	0	0	0	1
4	1	0	1	1	0	0	0	0	0	0	0	0	0	3
5	1	1	1	1	1	1	1	1	1	1	0	1	0	11
6	0	1	0	0	0	1	0	0	0	1	0	1	0	4
7	1	1	1	1	1	1	1	1	1	1	0	1	0	11
8	1	1	1	1	1	1	1	1	1	1	0	1	0	11
9	1	1	1	1	1	1	1	1	1	1	0	1	0	11
10	0	1	0	0	0	0	0	0	0	1	0	1	0	3
11	0	1	0	0	0	0	0	0	0	1	1	1	0	4
12	0	1	0	0	0	0	0	0	0	1	0	1	0	3
13	0	1	0	0	0	0	0	0	0	1	1	1	1	5
Dependence power	6	10	6	5	4	5	4	4	4	9	2	9	1	

The driving power and dependence power for each indicator are also presented in the table. The driving power is the total number of indicators (including indicator itself) which it may relate, while the dependence power is the total number of indicators which may relate to it.

It can be seen from the table that raw material substitution, energy consumption, fuel consumption, and material consumption have the highest value of driving power. On the other hand, three indicators of inventory cost, labor cost, and material cost have the least driving power that means these indicators are not affecting the other indicators. In term of dependence power, labor cost is the most dependent indicator, followed by accident rate, and occupational health and safety. Training and education has the least value of dependence power that means this indicators is not affected by any other indicators.

D. Level partitions

From the final reachability matrix, the reachability set and antecedent set [11] for each indicator can be obtained. The reachability set consists of the indicator itself and the other indicators, to which it may relate. The antecedent set consists of the indicator itself and the other indicators, which may relate to it. The intersection of these sets then is derived for all indicators. The indicators for which the reachability and the intersection sets are the same are put into the top-level indicators in the ISM hierarchy. After the identification of the top-level indicators, those indicators discarded from the other remaining indicators.

This iteration is continued until the level of all indicators is obtained as shown in Table VII.

TABLE VII
LEVEL PARTITIONS (ITERATION 1-4)

Indicators	Reachability set	Antecedent set	Intersection set	Level
1.Inventory cost	1	1, 4, 5, 7, 8, 9	1	I
2. Labor cost	2	2, 5, 6, 7, 8, 9, 10, 11, 12, 13	2	I
3. Material cost	3	3, 4, 5, 7, 8, 9	3	I
4. Product delivery	1, 3, 4	4, 5, 7, 8, 9	4	II
5. Raw material substitution	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12	5, 7, 8, 9	5, 7, 8, 9	IV
6. Air emission	2, 6, 10, 12	5, 6, 7, 8, 9	6	III
7. Energy consumption	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12	5, 7, 8, 9	5, 7, 8, 9	IV
8. Fuel consumption	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12	5, 7, 8, 9	5, 7, 8, 9	IV
9. Material consumption	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12	5, 7, 8, 9	5, 7, 8, 9	IV
10.Accident rate	2, 10, 12	5, 6, 7, 8, 9, 10, 11, 12, 13	10, 12	II
11.Labor relationship	2, 10, 11, 12	11, 13	11	III
12.Occupational health and safety	2, 10, 12	5, 6, 7, 8, 9, 10, 11, 12, 13	10, 12	II
13.Training and education	2, 10, 11, 12, 13	13	13	IV

The process of level partitions for the indicators involved four iterations. In the first iteration, inventory cost, labor cost, and material cost were identified as the indicators to level I. Then, three indicators of product delivery, accident rate, and occupational health and safety were determined to be placed at level II through the second iteration. In the third iteration, air emission and labor relationship were included into level III. Finally, the remaining five indicators were determined into level IV. The identified levels of the indicators will aid in building the digraph and the final model of ISM [9]. The final reachability matrix then is converted into the canonical matrix by arranging the indicators according to their determined levels as shown in Table VIII.

TABLE VIII
CANONICAL MATRIX

Indicators	1	2	3	4	10	12	6	11	5	7	8	9	13
1	1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	1	0	0	0	0	0	0	0	0	0	0	0
3	0	0	1	0	0	0	0	0	0	0	0	0	0
4	1	0	1	1	0	0	0	0	0	0	0	0	0
10	0	1	0	0	1	1	0	0	0	0	0	0	0
12	0	1	0	0	1	1	0	0	0	0	0	0	0
6	0	1	0	0	1	1	1	0	0	0	0	0	0
11	0	1	0	0	1	1	0	1	0	0	0	0	0
5	1	1	1	1	1	1	1	0	1	1	1	1	0
7	1	1	1	1	1	1	1	0	1	1	1	1	0
8	1	1	1	1	1	1	1	0	1	1	1	1	0
9	1	1	1	1	1	1	1	0	1	1	1	1	0
13	0	1	0	0	1	1	0	1	0	0	0	0	1

E. MICMAC analysis

The indicators were then categorized based on their driving power and dependence power using MICMAC analysis. The MICMAC analysis is used to analyze the driving power and dependence power of the indicators [12]. The indicators are classified into four clusters named autonomous, dependent, linkage, and driver as depicted in Fig. 1.

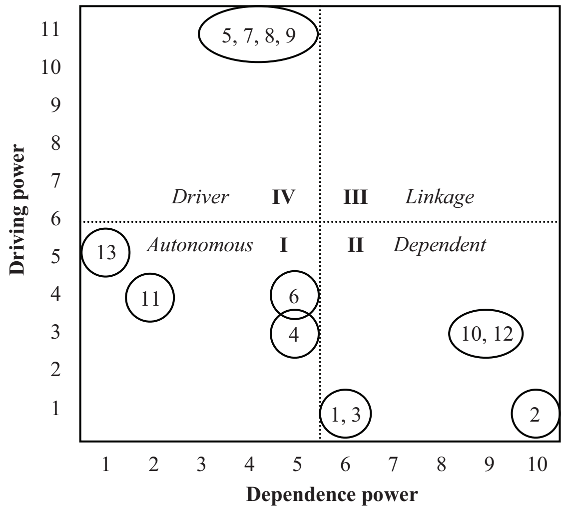

Fig. 1. Driver-dependence power diagram

It can be seen that there is no linkage indicator (in the third quadrant) in the driver–dependence power diagram. This indicated no dominant indicator of the KPIs which has both high driving power and dependence power. In the first quadrant, four indicators of product delivery, air emission, labor relationship, and training and education identified as autonomous indicators. These indicators have both low driving power and low dependence power. Training and education is identified as the most independent indicators since has no affected by any other indicators.

Five indicators of inventory cost, labor cost, material cost, accident rate, and occupational health and safety are in second quadrant as dependent indicators. Three of those indicators are not driving any other indicators but driven by other indicators. Accident rate was identified as the most dependent indicator. The remaining two indicators have low driving prower and high dependence power. On the other hand, raw material substitution, energy consumption, fuel consumption, and material consumption in fourth quadrant as the most driver indicators, are driving the other ten indicators but only driven by three other indicators. Any action on these indicators will have a significant effect on the other indicators. Thus, the decision makers should pay more attention to these indicators in the context of sustainable manufacturing evaluation.

F. ISM-based network model

An ISM-based network model is then generated based on the relationships of indicators given in the canonical matrix. The transitivities of the indicators are removed from the matrix. The KPIs are organized in a hierarchical structure into four levels as shown in Fig. 2.

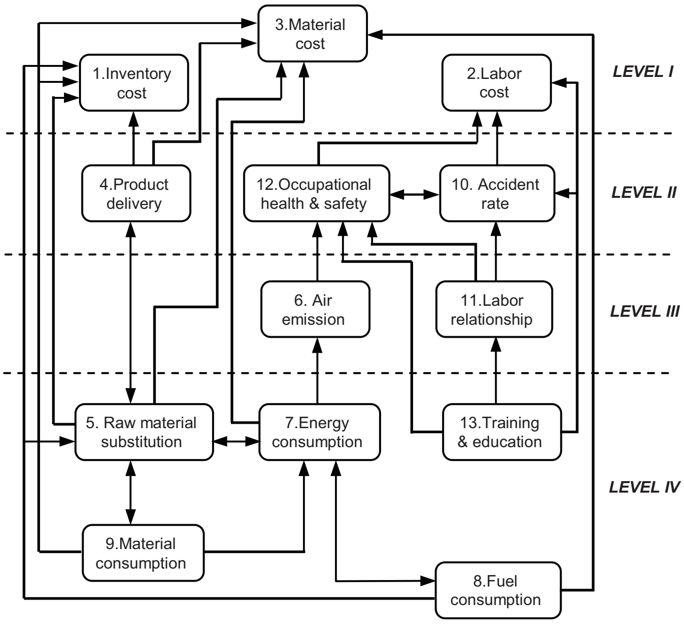

Fig. 2. ISM model for SMP dimensions

Inventory cost, labor cost, and material cost are regarded as the basic indicators in evaluating sustainable manufacturing in cement industry. All these indicators are KPIs of the economic factor. It can be concluded that economic still has get more attention from the cement industry. Level II consists of one indicator of economic factor of product delivery, and two indicators of social factors of accident rate, and occupational health and safety. Air emission and labor relationship are indicated as intermediate indicators at level III. It can be concluded that the cement industry has been put much effort to reduce air emission as one of sustainability issue in the cement industry.

Five indicators at level IV consisting of raw material substitution, energy consumption, fuel consumption, material consumption, and training and development were indicated to be the leading KPIs in achieving sustainable manufacturing in cement industry. The first four of those indicators are the most important issues in the context of sustainable manufacturing and related to the environmental aspect. Of those indicators, raw material substitution is regarded as the most influencing indicator for sustainable manufacturing evaluation in the cement industry.

IV. CONCLUSION

This paper has developed an interpretive structural model (ISM) of key performance indicators (KPIs) for sustainable manufacturing evaluation in cement industry. The KPIs are structured into four levels. The network model establishes the interrelationships amongst the KPIs. The interdependencies amongst the KPIs are also given by driver-dependence power diagram. The ISM-based model provides a better understanding of the interrelationship amongst the KPIs. The model can aid the decision makers with a more realistic representation of relationships amongst the KPIs for sustainable manufacturing evaluation in cement industry. Future work will further incorporate the model into Analytical Network Process (ANP) methodology to the development of sustainable manufacturing evaluation tool for cement industry.

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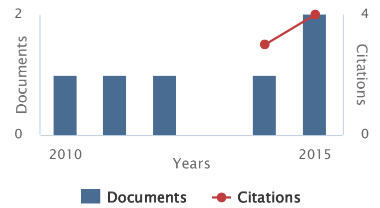

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