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Interpretive Structural Model of Key Performance Indicators for Sustainable Maintenance Evaluatian in Rubber Industry

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Abstract. Sustainable maintenance is a new challenge for manufacturing companies to realize sustainable development. In this paper, an interpretive structural model is developed to evaluate sustainable maintenance in the rubber industry. The initial key performance indicators (KPIs) is identified and derived from literature and then validated by academic and industry experts. As a result, three factors of economic, social, and environmental dividing into a total of thirteen indicators are proposed as the KPIs for sustainable maintenance evaluation in rubber industry. Interpretive structural modeling (ISM) methodology is applied to develop a network structure model of the KPIs consisting of three levels. The results show the economic factor is regarded as the basic factor, the social factor as the intermediate factor, while the environmental factor indicated to be the leading factor. Two indicators of social factor i.e. labor relationship, and training and education have both high driver and dependence power, thus categorized as the unstable indicators which need further attention. All the indicators of environmental factor and one indicator of social factor are indicated as the most influencing indicator. The interpretive structural model hoped can aid the rubber companies in evaluating sustainable maintenance performance.

1. Introduction

Companies today has facing a challenge to implement sustainability in all the business aspects. Sustainability is commonly defined as meeting the needs of the present without compromising the ability of future generations to meet their own needs [1]. Companies that adopt sustainability practices can achieve a better product quality, a higher market share, and an increased profit [2]. Maintenance as one of manufacturing function has become an important part to achieve the sustainable company's status [3]. Besides its benefits in minimizing the operating costs and optimizing the equipment durability, an appropriate maintenance also affects the overall company's performance [4]. Thus, integrating the sustainability into the maintenance activities has become a need.

Sustainable maintenance is a process of continuous development and constant improvement of maintenance processes, increasing efficiency (operational excellence), safety of operations and maintenance of technical objects and installations, and focused on employees [4]. Sustainability has usually evaluated in three aspects known as the triple bottom line of sustainability consist of economic, environmental, and social [5]. Since any change in an aspect will influence the other aspects, these three aspects are interrelated and thus, should be assessed with considering their relationships [6].

This paper develops an interpretive structural model of key performance indicators (KPIs) evaluation for sustainable maintenance evaluation in rubber industry. A literature study is conducted to identify the initial KPIs of sustainable maintenance evaluation in rubber industry. The initial indicators

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are then validated by academic and industry experts. Finally, a network relationship model is then developed using Interpretive Structural Modelling (ISM) method.

2. Methodology

The methodology has three main stages.

2.1. Identification of KPIs

A literature review is carried out to identify the KPIs of sustainable maintenance evaluation in rubber industry. The initial KPIs are developed using the three factors of sustainability consist of environmental, economic, and social. Furthermore, the three factors are then divided into seventeen indicators as shown in Table 1.

Table 1. The initial KPIs.

Factors	Indicators	References
Environmental	1. Energy consumption	[3], [4], [8], [9], [10]
	2. Water utilization	[3], [10]
	3. Lighting and ventilation	[3], [8], [9], [10]
	4. Emission	[3], [4], [8], [9], [10]
	5. Material consumption	[3], [4], [7], [8], [9], [10]
	6. Working environment	[3], [7], [8], [10]
	7. Land utilization	[4], [9]
Economic	8. Preventive cost	[3], [10]
	9. Failure cost	[3], [10]
	10. Maintenance procedure	[3], [9], [10]
	11. Breakdown rate	[3], [4], [10]
	12. Failure rate	[3], [4], [7], [9], [10]
	13. Product quality	[3], [4], [7], [8], [10]
	14. Availability rate	[3], [7], [8], [10]
Social	15. Occupational health and safety	[3], [4], [7], [8], [9], [10]
	16. Employee involvement	[3], [4], [10]
	17. Training and education	[3], [10]

2.2. Validation of KPIs

The initial KPIs of sustainable maintenance evaluation in the rubber industry are then validated by academic and industry experts. Four academics in maintenance expertise area are consulted to determine the importance of the initial KPIs. Six managers of production and maintenance department from a rubber company located in Padang, Indonesia are also asked to validate the initial KPIs. A five-point Likert scale ranging from 1 (not important at all) to 5 (very important) is used to rate the perspective of academics and managers on the importance level of the initial KPIs. The mean importance values ranged from 2.00 to 4.40 as shown in Table 2.

The results show preventive cost and failure cost are regarded as the most important KPIs. These two costs are the indicators of economic factor which most related to the maintenance cost. It followed by occupational health and safety. On the other hand, four indicators of product quality, material consumption, water utilization, and land utilization are regarded as the least important indicators. Based on the results, the initial KPIs of sustainable maintenance evaluation in rubber industry are then modified. Because of the less importance, four indicators are removed from the initial KPIs. As a result, three factors with a total of thirteen indicators have proposed as the KPIs for sustainable maintenance evaluation in rubber industry as shown in Table 3.

Table 2. The mean importance values of initial KPIs.

Indicators	Mean	Indicators	Mean
Preventive cost	4.40	Lighting and ventilation	3.80
Failure cost	4.40	Working environment	3.80
Occupational health and safety	4.20	Energy consumption	3.60
Maintenance procedure	4.00	Emission	3.60
Breakdown rate	4.00	Product quality	2.80
Failure rate	4.00	Material consumption	2.60
Training and education	4.00	Water utilization	2.20
Availability rate	3.80	Land utilization	2.00
Employee involvement	3.80		

Table 3. The proposed KPIs.

Factors	Environmental	Economic	Social
Indicators	1. Energy consumption 2. Lighting and ventilation 3. Emission 4. Working environment	5. Preventive cost 6. Failure cost 7. Maintenance procedure 8. Breakdown rate 9. Failure rate 10. Availability rate	11. Occupational health and safety 12. Employee involvement 13. Training and education

2.3. Development of network structure model

The Interpretive Structural Modeling (ISM) methodology is applied to develop a network structure model of the KPIs for sustainable maintenance evaluation in rubber industry. An ISM questionnaire is then designed to determine the relationships amongst the KPIs. A total of 11 managers and staffs of production and maintenance department from the rubber company located in Padang, Indonesia are consulted. These managers and staffs are carefully selected based on their knowledge and experience in maintenance area. Experts are asked through the questions such as "will indicator *i* affect indicator *j*?" to indicate the direct influence that they believe each indicator on each of the other indicators according to an integer scale ranging from 0 = there is no relationship to 1 = there is a relationship. The details are given in the following section.

3. Development of Interpretive Structural Model

The Interpretive Structural Modeling (ISM) method proposed by Warfield in 1973 is an interactive learning process that enables to develop a map of the complex relationships among many elements involved in a complex problem [11]. ISM aids in developing an interaction map to identify the interrelationships amongst system variables. ISM method provides a better understanding of a system structure and draws up a useful guideline in generating a graphical representation of the structure [12]. It is often used to provide fundamental understanding of complex situations, as well as to find solutions for complex problem. ISM can reduces the complex system interactions into a logically oriented matrix which is useful for the purpose of structure determination. The procedures of ISM methodology consist of five steps as follows:

3.1. Developing structural self interaction matrix (SSIM)

A total of 11 experts are consulted to determine the interrelationships amongst the KPIs of sustainable maintenance evaluation in rubber industry through ISM survey. The answers of each question are averaged. In total, 38 direct relationships are confirmed from the survey. The SSIM of the KPIs is presented in Table 4. Four symbols are used to denote the direction of relationship between the KPIs (*i* and *j*) consist of 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*, and O if the relation between the indicators does not appear.

3.2. Constructing 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 KPIs and otherwise, 0 means there is no relationship between the KPIs. The substituting rule is as follows:

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 maintenance evaluation in rubber industry is presented in Table 5.

Table 4. Structural Self-Interaction Matrix (SSIM) of KPIs.

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

Table 5. Initial Reachability Matrix of KPIs.

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

3.3. Establishing final reachability matrix

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

$$M = M^k = M^{k+1},\ k>1 \tag{1}$$

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 method, which stated that if indicator-A related to indicator -B and indicator -B related to indicator -C, then indicator -A

necessarily related to indicator -C [11]. The final reachability matrix of the KPIs for sustainable maintenance evaluation in rubber industry is presented in Table 6.

3.4. Level partitions

From the final reachability matrix, the reachability set and antecedent set [13] for the KPIs can be determined. The reachability set consists of the KPI itself and other KPIs, to which it may relate. The antecedent set consists of the KPI itself and other KPIs, which may relate to it. Then, the intersection of these sets is derived for all KPIs. The KPIs for which the reachability and the intersection sets are the same is placed at the top-level KPIs. After the identification of top-level KPIs, those KPIs discarded from other remaining KPIs. This iteration is continued until the level of all KPIs is obtained. The level partitions are then summarized and shown in Table 7.

Table 6. Final Reachability Matrix of KPIs.

KPIs	1	2	3	4	5	6	7	8	9	10	11	12	13	Driver power
1	1	1	1	1	1	1	1	1	1	1	1	1	1	13
2	1	1	1	1	1	1	1	1	1	1	1	1	1	13
3	1	1	1	1	1	1	1	1	1	1	1	1	1	13
4	1	1	1	1	1	1	1	1	1	1	1	1	1	13
5	0	0	0	0	1	1	1	1	1	1	0	0	0	6
6	0	0	0	0	1	1	1	1	1	1	0	0	0	6
7	0	0	0	0	1	1	1	1	1	1	0	0	0	6
8	0	0	0	0	1	1	1	1	1	1	0	0	0	6
9	0	0	0	0	1	1	1	1	1	1	0	0	0	6
10	0	0	0	0	1	1	1	1	1	1	0	0	0	6
11	1	1	1	1	1	1	1	1	1	1	1	1	1	13
12	0	0	0	0	1	1	1	1	1	1	0	1	1	8
13	0	0	0	0	1	1	1	1	1	1	0	1	1	8
Dependence power	5	5	5	5	13	13	13	13	13	13	5	7	7	

Table 7. Level Partitions of KPIs.

Indicators	Reachability set	Antecendent set	Intersection	Level
1. Energy consumption	All indicators	1,2,3,4,11	1,2,3,4,11	III
2. Lighting and ventilation	All indicators	1,2,3,4,11	1,2,3,4,11	III
3. Emission	All indicators	1,2,3,4,11	1,2,3,4,11	III
4. Working environment	All indicators	1,2,3,4,11	1,2,3,4,11	III
5. Preventive cost	5,6,7,8,9,10	All indicators	5,6,7,8,9,10	I
6. Failure cost	5,6,7,8,9,10	All indicators	5,6,7,8,9,10	I
7. Maintenance procedure	5,6,7,8,9,10	All indicators	5,6,7,8,9,10	I
8. Breakdown rate	5,6,7,8,9,10	All indicators	5,6,7,8,9,10	I
9. Failure rate	5,6,7,8,9,10	All indicators	5,6,7,8,9,10	I
10. Availability rate	5,6,7,8,9,10	All indicators	5,6,7,8,9,10	I
11. Occupational health & safety	All indicators	1,2,3,4,11	1,2,3,4,11	III
12. Employee involvement	5,6,7,8,9,10,12, 13	1,2,3,4,11,12,13	12,13	II
13. Training and education	5,6,7,8,9,10,12, 13	1,2,3,4,11,12,13	12,13	II

The determining process of level partitions for the KPIs consists of three iterations. In the first iteration, six KPIs of economic factor are identified as the KPIs at level I. Then, two KPIs of employee involment and training and education are determined to be placed at level II through the second iteration. Finally, the remaining five indicators are determined into level III. The identified levels of the KPIs can aid in building the digraph and the final model of ISM [11].

3.5. Developing network relationship model

Based on the level partitions of the KPIs, an ISM-based network model is generated . The KPIs are organized in a network structure into three levels as shown in Figure 1. All six indicators of economic factor are regarded as the basic KPIs in evaluating sustainable maintenance in rubber industry. It shows that economic factor still has get more attention from the rubber industry. Level II consists of two indicators of social factor of employee involvement and training and education as intermediate KPIs. The rubber industry must put much efforts to improve these two indicators. One indicator of social factor and all four indicators of environmental factor are indicated to be the leading KPIs in achieving sustainable maintenance in rubber industry. It is not surprisingly since environmental factor is most related to sustainability practices. Of those indicators, employee involvement is regarded as the most influencing KPIs for sustainable maintenance evaluation in the rubber industry.

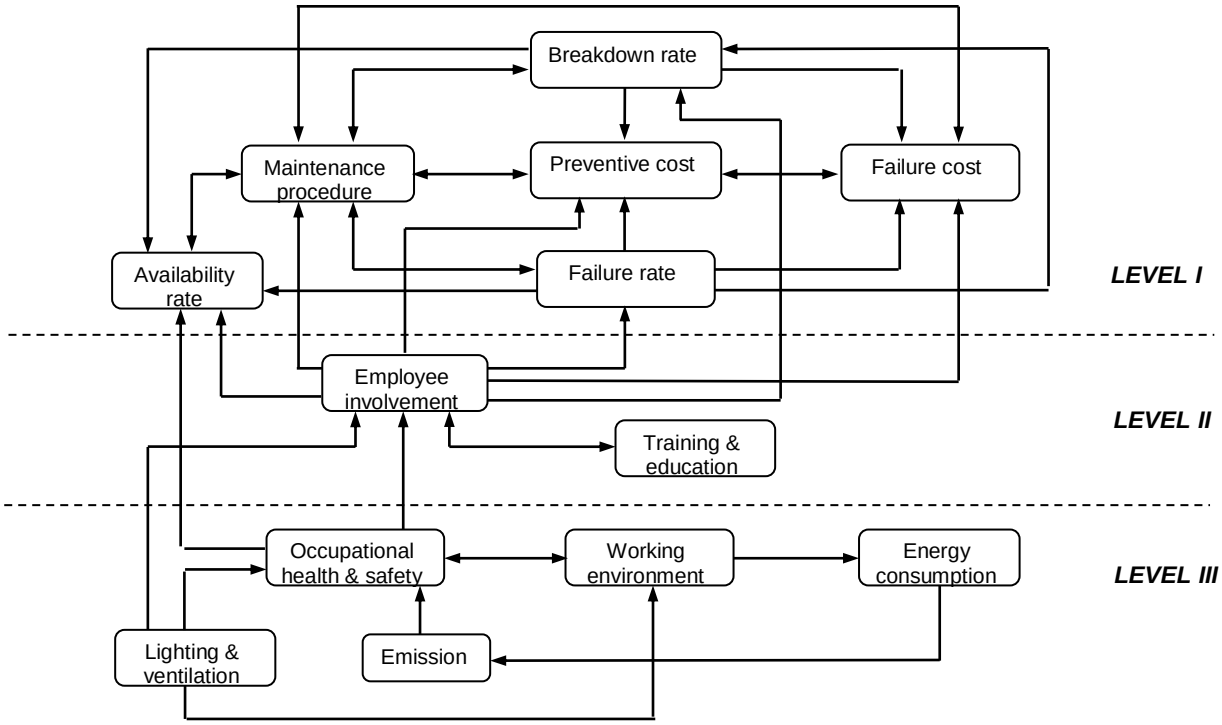

Figure 1. ISM Model

4. Conclusions

This paper has developed an interpretive structural model of KPIs for sustainable maintenance evaluation in rubber industry. The KPIs are structured into three levels. Economic factor are regarded as the basic indicators. On the other hand, environmental factor are indicated as the leading indicators in achieving sustainable maintenance in rubber industry. The rubber industry should put much attention into the indicators of environmental factor. The ISM model provides a better understanding of the relationship amongst KPIs. The model can aid the decision makers with a more realistic representation of relationships amongst KPIs for sustainable maintenance evaluation in rubber industry. Future study will further incorporate the model into Analytical Network Process (ANP) methodology to the development of sustainable maintenance evaluation model in rubber industry.

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