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MODELING SUSTAINABLE MANUFACTURING PRACTICES TOWARDS ECONOMY SUSTAINABILITY PERFORMANCE

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ABSTRACT

The purpose of this study is to present relationship between sustainable manufacturing practices (SMP) and economy sustainability performance (SP1_Economy). Eight practices that may affect SP1_Economy were studied. In the first phase, a multiple regression model considered a linear relationship between eight variables and SP1_Economy as performance was considered to the best fit of the observed values. It was perceived that multiple linear regression method indicated 24% from SP1_Economy of the variation in the observed data. Finally, it can be conclude that multiple linear regression method can predict the performance from observed practices in manufacturing firms.

Keywords: sustainable manufacturing practices, economy sustainability performance, multiple linear regression.

INTRODUCTION

The role of manufacturing method has changed significantly in today's competitive environment. Quality, flexibility and quick response have become important for the manufacturers in regard to achieve customer satisfaction. Therefore, an improved manufacturing method and technology becomes necessary toward achieving the effective manufacturing system. The use of improved manufacturing method and technology would maintain the sustainability. It involves the entire of life cycle especially the manufacturing system to become a sustainable sector. Sustainable manufacturing is important in today's competitive environment due to lack of non-renewable resources, higher customer priority in environment-friendly services and products and also high standard of living. Besides that, the development also being stimulated by growing responsibilities towards the environment, stringent government regulation and companies nowadays see that by collecting, recycling and reusing product and material, may provide valuable commercial opportunities.

The previous research face a lot of difficulties in gaining reliable data and doing analysis about manufacturing practices and the performances [1-2]. Time and cost consuming becomes the major reason of the difficulties. This is followed by lack of knowledge about the manufacturing practices and performance of the manufacturing firms itself [1-2]. Instead of direct execution, it is judiciously to provide the statistically evidences through mathematical modeling and analysis before the manufacturing practices implementation.

Therefore, the aim of this paper is to develop a mathematical model for sustainable manufacturing practices (SMP) and economy sustainability performance (SP1_Economy). This will show relationship in the wider perspective encompassing economic dimension. In the next section, review of the related literatures is presented followed by explanation of research methods in the subsequent section. The results of the study is presented and further discussed in the consequent section. The paper concludes with implication and recommendation for future research

LITERATURE REVIEW

Sustainable manufacturing practices (SMP) were developing from eight practices [2]. There are cleaner production, eco-efficiency, employee relation, supplier relation, customer relation, community relation, closed-loop production and industrial ecology. This subsequence paragraph explains in details about all of the eight practices.

Cleaner production (CP) introduced in 1989 by United Nations Environment Program (UNEP) define as controlling the pollution at the first stage; in the product and manufacturing process [3] to prevent creation of pollution. While for the second practice, eco-efficiency (EE) define as state that can be reach through the producing more products and delivery of competitively price goods and services that satisfy human needs and bring quality of life while reducing environmental impact of goods and resource intensity [2, 3] throughout the entire life-cycle to a level at least in line with the earth's estimated carrying capacity (WBCSD, 1996) [4].

Third practice was employee relation (ER) focusing on implementation of scheduling plans or programs to improve employees' well-being and skills [3]. In [5], it describe about implementation of total quality influence and development [6] to achieve greater sustainable performances.

While for fourth practice, supplier relation (SR) mention about a relationship between manufacturer and supplier through monitoring and collaboration of minimizing waste throughout the production line [6] to improve supplier performance [3]. The fifth practice was customer relation (CuR). It can be define as the wellness of manufacturer in managing their customers in term of improving customers' well-being [3] by giving appropriate feedback [7] on the service provided.

Community relation (CoR) is an implementation of manageable plans or programs to improve community

performance [3] that is related with environmental and social issues [7, 8]. Employees are encouraged by many to actively participate in community-based volunteer programs.

While for the seventh practice, closed-loop production (CLP) is a new sustainable concept that changing to systematic approach from linear production methods. This practice changing from single life cycle to multiple life cycles as respond to closes material resource cycle [9, 10] and consists of reduce, reuse, recycle, recover, redesign and remanufacture activities [9 - 13].

The last practice in sustainable manufacturing practices (SMP) was industrial ecology (IE). This was first introduced by [14] which initiate the activities that cooperate with many companies and communities. They cooperates each other in order to fulfill the aim of sustainability manufacturing. The aim is to reduce waste and pollution, improve economic profit, and increase environmental quality and social being [3].

Sustainability performance (SP) consists of economic, environmental and social performance [11]. The economic, environmental and social aspects cooperates each other to maintain sustainability performance. Triple bottom line (TBL) approach suggests that apart from concentrating on economic goals, manufacturing sustainability should positively affect the environment and social performance [15 - 19].

Linear regression is a statistical analysis that used to develop a mathematical equation and present relationships among inputs and output data. Multiple linear regression is best uses if input is more than one data. Gimenez *et al* [15] compares the impact on the three pillars (economy, environment and social) by studying the environmental and social programs that effective within the firm (internal) and amongst supply chain partners (external) using hierarchical regression. Regression has been used widely in manufacturing based on experimental. Hsieh [20] uses stepwise regression techniques in order to analyse the manufacturing process and defect for TFT-LCD products. MLR also used to estimate errors between measured and predicted values in spring back effect on automotive body [21]. Further research can be achieved by providing larger data because MLR can be more efficient with larger data to produce concrete result. Cheng [22] used support vector regression to develop a model for predicting the process mean shift. Li *et al* [23] also used MLR to find the manufacturing parameter's upper and lower limit. Although the MLR method is known as conventional method, its applications towards manufacturing firms provide reliable result.

Conclude that in this current paper, the independent variables consist of eight practices; CP, EE, ER, SR, CuR, CoR, CLP and IE. While economy sustainability performances (SP1_Economy) appears as dependent variables by using multiple linear regression (MLR) method.

METHODOLOGY

Multiple linear regression is a statistical tool to develop a mathematical model to represents relationship between dependent and independent variables. The dependent variable is economy sustainability performances (SP1_Economy). While the independent variables was x_1 = cleaner production (CP), x_2 = eco-efficiency (EE), x_3= employee relation (ER), x_4 = customer relation (CuR), x_5 = community relation (CoR), x_6 = supplier relation (SR), x_7= closed loop production (CLP) and x_8= industrial ecology (IE). It begins with the development of mathematical equation. Equation. 1 shows the linear model in regression analysis:

$$y = b_0x_0 + b_1x_1 + b_2x_2 + b_3x_3 + \cdots + b_kx_k + \varepsilon_i \quad (1)$$

The point prediction of Equation. (1) is

$$\hat{y} = \widehat{b_0}x_0 + \widehat{b_1}x_1 + \widehat{b_2}x_2 + \widehat{b_3}x_3 + \cdots + \widehat{b_k}x_k \quad (2)$$

and predictedε_i to be zero where $\hat{y}$ represents as predicted value of y and X's are the predictors or repressor, b indicates the regression coefficient or parameter and k is a total number of predictor variables.

The aim of regression analysis is to fit the data on the line in such a way that results in minimum error between observed and predicted data. Sum of squared error (SSE) as show in Equation. (2) is used instead of residual, e_i to gives an unbiased estimation of error.

$$SSE = \sum_{i=1}^{n} e_i^2 = \sum_{i=1}^{n} (y_i - \hat{y_i})^2 \quad (3)$$

Then the methodology followed by presenting the performance measures. It is required for validation process. Two performance measures chosen were coefficient of determination, R^2in Equation. (4) and t-test. $R^2$is the statistical measure to determine how close the data to the fitted regression line. Equation. (3) until Equation. (6) was used to determineR^2:

$$R^2 = \frac{SSR}{SST} = 1 - \frac{SSE}{SST} \quad (4)$$

$$SST = \sum_{i=1}^{n} (y_i - \bar{y})^2 \quad (5)$$

$$SSR = \sum_{i=1}^{n} (\hat{y_i} - \bar{y})^2 \quad (6)$$

The value lies between 0 and 1. Values that approach 1 indicate that the independent variables could explain most of the variability of the observed data while value approaches 0 mentions that the independent variables could explain less of the variability of the response data. T-test is a statistical test that can determine a significant difference between two groups on dependent variables. It compares the means between the observed data and predicted data. In this paper, the paired sample t-test was chosen. The paired sample t-test was looking at whether a group of subjects improve from one time period to another.

RESULTS AND DISCUSSIONS

Development of model

Multiple linear regression analysis was performed using SPSS software. The resource of data in this research is taken from Norsiah Hami (2015). The data was collected using 150 questionnaire survey data towards various Malaysian manufacturing firms. Table-1 shows results of linear regression model and corresponding coefficients for economy sustainability performances (SP1_Economy).

Table-1. Predictors value for original multiple linear regression model (SP1_Economy).

Source	Coefficient	Standard error	T-stat	P-value
Intercept	1.866	0.365	5.110	0.000
CP	0.067	0.110	0.614	0.540
EE	-0.076	0.126	-0.604	0.547
ER	0.274	0.092	2.989	0.003
SR	0.093	0.084	1.113	0.268
CuR	0.222	0.128	1.729	0.086
CoR	-0.007	0.100	-0.073	0.942
CLP	0.076	0.096	0.794	0.429
IE	-0.076	0.079	-0.965	0.336

Based on the result obtained, the equation of the model is given by:

$$\hat{y} = SP1_{Economy} = 1.866 + 0.067x_1 - 0.076x_2 + 0.247x_3 + 0.093x_4 + 0.222x_5 - 0.007x_6 + 0.076x_7 - 0.076x_8 \quad (7)$$

For testing whether the simple multiple regression model gives any useful information about the response variable or not, standard hypothesis testing was carried out using Analysis of Variance (ANOVA)

$$H_0 : y = b_0 + \varepsilon$$

$$H_1 : y = b_0x_0 + b_1x_1 + b_2x_2 + \cdots + b_kx_k + \varepsilon \quad (8)$$

Null hypothesis, H_0 states that the current model donot give any useful information about the dependent variables and also independent variables have no explanatory influence. Alternative hypothesis states that regression coefficient gives useful information about the response variable. Table-2 shows the result of ANOVA. The F test can be obtained by comparing the observed F value with the critical value obtained from the standard F distribution table. It shows that regression model has statistically significant predictive capability if the observed F value is greater than the F critical value.

Table-2. ANOVA table for economy sustainability performance (SP1_Economy).

Model	Sum of squares	df	Mean square	F value	Significant
Regression	14.254	8	1.782	6.19	0.000[a]
Residual	40.589	141	0.288		
Total	54.843	149			

F critical value can be found from standard F distribution table by F (8, 141, 0. 05). The observed F values 6.19 > F critical value 1.94, it can be conclude that regression model is statistically significant. The last column in Table-2 shows that the corresponding probability value P is less than 0.05 (i.e. 95% confident interval), H_0 is rejected. It can be conclude that for the current research, we accept the alternative hypothesis H_1 with 95% confident interval that the current regression model gives useful information about the response.

Table-3. Model summary for economy sustainability performance (SP1_Economy).

Model	R	R square	Adjusted R square	Std. error of the estimate
SP1_ Economy	0.510	0.260	0.218	0.537

Table-4. Statistics and correlations (questionnaire vs. regression) for SP1_Economy.

	Variable	Mean	N	Std. dev.	Std. error mean	Correlation, (N)	Sig.
Pair 1	SP1_ Economy	4.20	150	0.607	0.050	0.05	0
	SP1_ Reg Economy	4.1958	150	0.3088	0.0252		

Table-5. Paired samples t-test (questionnaire vs. regression) for SP1_Economy.

		Paired differences					T	Df	Sig. (2-tailed)
		Mean	Std. deviation	Std. error mean	95% Confidence interval of the difference				
					Upper	Lower			
Pair 1	$SP1\_Economy$ $SP1\_RegEconom$	0.00124	0.52171	0.04260	-0.08294	0.08541	0.029	149	0.977

For this current research, the paired-sample t-test was conducted using SPSS software to determine positive correlation between observed (questionnaires) and predicted (regression model) data for SP1_Economy. The questionnaires data of sustainability performances was compared with regression model introduced as Pair 1 (SP1_Economy vs. SP1_RegEconomy).

Table-4 shows that the pairs are positively correlated, r (N=150) = 0.510 for Pair 1. The questionnaires and regressions data shows significantly correlated and it prove that Equation. 7 can predict accurate performance for given manufacturing practices. From Table-5, it can be seen that the mean of economy sustainability performances (SP1_Economy) for Pair 1 decreased from the questionnaire result to the economy performance regression model by 0.00124, t (149) = 0.029, p = 0.977. The 95% confidence interval ranges from -0.08294 to 0.08541 and it is including zero. Therefore, the two means of questionnaire result and regression model are not significantly different from each other.

CONCLUSIONS

In this research we have demonstrated the use of multiple linear regression analysis for the prediction of economy sustainability performance (SP1_Economy) based on sustainable manufacturing practices (SMP). The analysis shows that the predicted mathematical equation consists of all the manufacturing practices give a lot of information regarding the responses (SP1_Economy).

Even though the coefficient of determination, R^2 from the equation only can describe 26 percent of the variation in the response variable but the T-test analysis shows that the observed response and predicted response are highly correlated and the means between observed and predicted data are not significantly different. It was concluded that multiple regression model can provide accurate prediction of SP1_Economy from sustainable manufacturing practices (SMP).

Hence, the result can provide guidelines, statistical evidence and analysis for manufacturing engineers and firms. It is crucial before implementing sustainable manufacturing practices (SMP). There also another two sustainability performance (SP) that can be modeled in term of environment and social aspects especially for further research.

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