

# Hybrid Computing and Decision Technologies in Improving Accuracy of Structural Equation Model for Sustainable Environmentally Friendly Product Management

Phatchanok Luangpaiboon, Chandej Charoenwiriyaikul, and Siravit Koolrojanaput

**Abstract**—Main purpose of this research is to study influential variables of green innovation strategy, corporate social responsibility, government policy, transformation leadership including human resource development on the success level in managing sustainable environmentally friendly products of industrial plants. The sequential procedures on statistical techniques are proposed with the survey data on both quantitative and qualitative research elements. Confirmatory factor and path analysis including the structural equation modeling are mixed to identify the causal relationship between variables and the dependent variables. In this article, two metaheuristic algorithms namely sequential evolutionary elements based on variable neighborhood search and particle swarm optimization algorithms are proposed to enhance the sustainable environmentally friendly product management model. The results show that all performance measures of the particle swarm optimization algorithm are better, but not statistically significant when compared. Evolutionary elements from Metaheuristic approaches are the powerful tool for generating the management model and aiding the industries for decision making. The qualitative research was from the multistage sampling and in-depth interviews to finally provide guidelines for managing environmentally friendly products. From the numerical results all of proposed variables affected the success at a high level of opinions. The results of this research will be efficiently used to promote sustainable environmentally friendly products for the manufacturing in Thailand.

**Index Terms**—Confirmatory factor analysis, path analysis, structural equation modeling, and variable neighborhood search and particle swarm optimization algorithms.

## I. INTRODUCTION

To solve environmental problems, it is very important that all sectors need to be aware and start working with industrial economic development. As a result, Thai entrepreneurs have to adapt to the changes. The researcher is therefore interested in studying "achievement in the management of environmentally friendly products that are environmentally sustainable" by specifying objectives to test the influential variables and the results of successful management of environmentally friendly products. The results of the research can be used to provide information for government agencies and private sectors in determining the guidelines. There are policy framework and directions for promoting green industrial development to achieve goals, resulting in

success at both the entrepreneur and industry levels.

Research objectives are to study the influence of green innovation strategies (GIS), corporate social responsibility (CSR), government policy (GP), transformational leadership (TL) and human resource development (HRD). These result in the successful management of environmentally friendly products which is sustainable in factories. It is also of importance to study guidelines for sustainable and environmentally friendly product management of industrial plants. The dependent variable is a success (SUCCESS) in sustainable and environmentally friendly product management. According to the theory of dynamic ability for organizations to achieve their goals the success means an increase in the ability to competition, having good performance, and having a good image to those involved [1].

Theory and research related to variables in the research framework are followed. On the first variable of GIS, the important concepts in the study are the changes in the business working methods according to the concepts that will lead to environmental development such as creating green products, development of production processes for the environment and environmentally friendly management styles [2]. CSR consists of economics, legal and ethical. It is the introduction of ideas from various theories, namely shareholder value, social business, stakeholder and business organizations as citizens theories [3]. For the GP, the Ministry of Industry has established the Industrial Development Master Plan for the year 2012-2031 under the concept of green industry or the strategic industry plan, Ministry of Industry 2017 – 2021. GP consists of production modifications and development, incentive measures including sustainable development of knowledge of entrepreneurs and industrial personnel.

TL means the leadership behavior that encourages and motivates employees to achieve good results. There are four important characteristics, which are ideological influence, inspiration, stimulation of intelligence and personal consideration [4]. For HRD the main activities consist of five sub-activities which are training, educational, personal development, professional development and organizational development activities [5].

## II. SUSTAINABLE ENVIRONMENTALLY FRIENDLY PRODUCT MANAGEMENT

The researcher studied from the concepts, theories and related research. Taken to define as a research concept frame as in the Fig. 1. From studying various associated variables,

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the researcher therefore makes assumptions of the research through the 11 hypotheses of the first five variables of GIS, CSR, GP, TL and HRD affecting the SUCCESS or a success in managing environmentally friendly and sustainable products of industrial factories. The remaining are hypotheses to study the variables of CSR, GP and HRD affecting GIS, the variables of GP and TL affecting CSR including the TL affecting HRD.

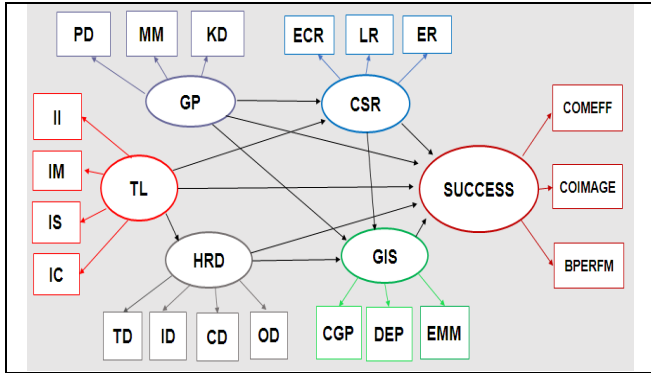


Fig. 1. Research conceptual framework.

#### A. Confirmatory Factor Analysis

After seeking the number of variables via an exploratory factor analysis or a research survey, a confirmatory factor analysis (CFA) is introduced. The CFA starts with a hypothesis about how many variables there are and variable correlations. A statistical test is done to investigate how well the hypothesized variable structure fits with the survey data. The fit test is used to determine a non-significant result, indicating good fit to the data. The model fit is derived from a comparison of all the variable correlations or covariances. Generally, certain mathematical models imply certain correlations. If the model specifies that two variables are uncorrelated, then the model will not fit well if items from one variable tend to be correlated with items from another variable. Many fit indices will be used to determine whether or not the model fit well. It can be altered and retested via various loading structures. The indices include performance measures via the traditional chi-square goodness of fit ( $\chi^2$ ). They consist of p-value, Joreskog goodness of fit index (GFI), an adjusted version of GFI (AGFI), standardized root mean square residual (RMR), a traditional root mean square error of approximation (RMSEA), and a comparative fit index (CFI) with the cut value of  $\leq 0.05$ ,  $> 0.90$ ,  $> 0.90$ ,  $\leq 0.05$ ,  $\leq 0.05$ , and  $> 0.90$ , respectively.

#### B. Path Analysis

Path analysis is employed to determine whether or not a multivariate set of data fits well with a particular model. A path analysis can be conducted as a sequential procedure of multiple regression analyses. For each variable a multiple regression analysis is conducted to predict dependent variable or SUCCESS from all other influential variables which are hypothesized to have direct effects on SUCCESS. There is no consideration of the multiple regressions on any variables hypothesized to affect SUCCESS only indirectly through one or more intervening variables. The regression coefficients weight from these multiple regressions are the path coefficients shown a path analysis. From a predetermined model, an evaluation to ignore one or more of the paths would substantially reduce the fit between the

model and the data via statistical significance criterion. For retaining any coefficient, any path should be deleted from the multiple regression analysis indicated the regression coefficients was not statistically significant at a preset level of confidence interval. With a satisfied model, the fit between data and model will be perfect. The chi-square or related performance measures that test the null that the fit is perfect will have their specific levels indicating the perfect fit.

### III. PROPOSED METHODS

Structural equation modeling (SEM) is a powerful technique for analyzing multivariate data. SEM is closed to an ordinary regression model to incorporate multiple independent and dependent variables. It is used to combine complex path models with latent variables with dependent variables. Based on SEM, the confirmatory factor analysis models, regression models, and complex path models can be specified. It can be viewed as a combination of confirmatory factor analysis and regression or path analysis. A regression or path coefficients between the variables represents the relationships between the theoretical constructs upon a research framework. SEM can use latent variables in regression analysis to predict other dependent variables or be predicted by other independent variables. A graphical path diagram is usually applied to visualize structural equation models. If a given model approximates the true model, the RMSEA should be small. Typically, a RMSEA of less than 0.05 is preferred. The SEMs for this research consist of

$$\begin{aligned} \text{SUCCESS} &= \alpha_1 * \text{GIS} + \alpha_2 * \text{CSR} + \alpha_3 * \text{GP} + \alpha_4 * \text{TL} + \alpha_5 * \text{HRD} \\ \text{GIS} &= \alpha_6 * \text{GP} + \alpha_7 * \text{HRD} + \alpha_8 * \text{CSR} \\ \text{CSR} &= \alpha_9 * \text{GP} + \alpha_{10} * \text{TL} \\ \text{HRD} &= \alpha_{11} * \text{TL} \end{aligned}$$

In order to enhance the preferable levels of the coefficients, evolutionary elements form metaheuristics have been widely used in various industrial problems. The objective is to produce alternatives to be applied under with or without resource limitations. Therefore, in this research the variable neighborhood and particle swarm algorithms were introduced to get the estimated coefficients of the structural equation model of the product management problem.

#### A. Variable Neighborhood Search Algorithm (VNS)

Variable neighborhood search (VNS) is a metaheuristic framework proposed by Mladenovic and Hansen in 1997. The development of the VNS algorithm generated from the weakness of local search with no ability to leave it. Its main idea of changing dynamically neighborhood is then applied when a local optimum is reached. The summarized procedures of the proposed VNS by Hansen and Mladenovic are shown below [6].

#### Procedure VNS Metaheuristic()

**Begin:**

**Initialize algorithm parameters:**

**Initialization**

Select a set of neighbourhood structures  $N_k$  ( $k=1, \dots, k_{max}$ ), that will be used in searching.

Find an initial solution  $x$ .

Choose a stopping condition and set  $k \leftarrow 1$ .

**Repeat the following steps until  $k = k_{max}$**

**Shaking.**

Generate a point  $x'$  from  $k$ th neighbourhood of  $x$

**Local search.**

Application of some local search method with  $x'$  as initial solution;  
denote by  $x''$  the obtained local optimum

**Move or not.**

If this local optimum  $x''$  is better than the incumbent, move there  
( $x \leftarrow x''$ ), and continue search with  $N1$  ( $k \leftarrow 1$ ), otherwise set  $k \leftarrow k + 1$

**End procedure;**

Fig. 2. Procedures of the VNS Metaheuristic [7].

**B. Particle Swarm Optimization Algorithm (PSO)**

Particle swarm optimization algorithm (PSO) was first described by James Kennedy and Russell Eberhart in 1995. The PSO were derived from two concepts. The first is the observation of swarming habits of animals such as birds or fish. The latter is the field of evolutionary computation such as genetic algorithms, simulated annealing and so on. The PSO maintains multiple potential candidates at one time. In each iteration of the algorithm, each candidate is evaluated by an objective function to determine its fitness or response. Each solution is represented by a particle in the fitness or response search space. The particles “fly” or “swarm” through the search space to find the optimum value returned by the objective function or response. Each particle or candidate maintains position in the search space of solution and fitness, velocity and individual best position. Moreover, the swarm maintains its global best position. The PSO algorithm consists of just three steps as follow [8].

**Procedure PSO Metaheuristic()****Begin**

Evaluate fitness of each particle

Update individual and global bests

Update velocity and position of each particle

Repeat the following steps until some stopping condition is met.

**End procedure;**

Fig. 3. Procedures of the PSO metaheuristic.

**IV. NUMERICAL RESULTS**

In this research, the researcher uses the sequential statistical methods, by specifying the population boundary of 7,620 factories in Samut Prakan and Samut Sakhon provinces, with 4,965 factories and Samut Sakhon provinces [9]. Data collection period started from May until August, 2019. On the quantitative research, the sample group consists of executives or managers in the factory. By considering the suitability of the analysis of structural models [10], the researcher has 20 parameters in the model. The suitable sample size is 400 sets. Data collection was carried out by using multistage sampling and questionnaires to gather opinions of factory managers. Data analysis applied both descriptive and inferential statistics to test hypotheses. Statistical analysis developed the confirmatory factor analysis, the structural equation model and path analysis using LISREL package.

Confirmatory Factor Analysis, CFA was used to confirm the independent variables in the measurement model of the successful management of environmentally friendly products that are sustainable in industrial plants. This would be applied to construct the Structural Equation Modeling in the next phase. This analysis can be divided into 6 sub-models which include GIS, CSR, GP, TL, HRD and SUCCESS. The

first and second CFA on the first influential variable of GIS is summarized on Table I.

TABLE I: FIRST AND SECOND CFA ON GIS

CF	Latent	b	SE	t-value	$R^2$
First CFA					
CGP	CGP1	0.76	-	-	0.58
	CGP2	0.81	0.03	21.76**	0.66
	CGP3	0.74	0.04	15.17**	0.55
	CGP4	0.76	0.04	15.06**	0.58
	CGP5	0.70	0.04	14.24**	0.50
DEP	DEP1	0.86	-	-	0.74
	DEP2	0.86	0.03	25.20**	0.74
	DEP3	0.85	0.03	22.12**	0.72
	DEP4	0.86	0.03	22.80**	0.74
	DEP5	0.85	0.03	22.08**	0.72
EMM	EMM1	0.88	-	-	0.78
	EMM2	0.81	0.03	21.24**	0.66
	EMM3	0.86	0.04	16.45**	0.73
	EMM4	0.92	0.04	20.00**	0.85
Second CFA					
GIS	CGP	1.00	0.06	17.33**	1.00
	DEP	0.97	0.05	20.19**	0.95
	EMM	0.87	0.05	17.45**	0.76

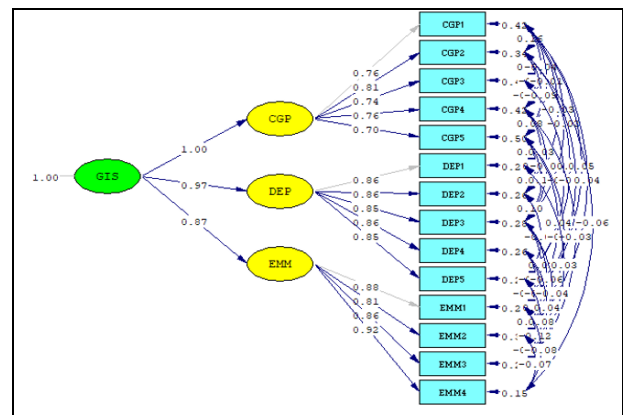


Fig. 4. First and second CFA on GIS.

From Table I and Fig. 4, the traditional chi-square goodness of fit ( $\chi^2$ ), p-value, Joreskog GFI, AGFI, RMR, RMSEA, and CFI were 44.45, 0.07058, 0.98, 0.95, 0.009, 0.031, and 1.00, respectively. From the GIS analysis, it is found that the composition weights of all 14 latent variables are positive and have acceptance values from 0.30 and above. They are from 0.70 to 0.92 and have a statistical significance at the confidence interval of 99% for all latent variables. These 14 latent indicators are important for the sub-components as follow. The CGP1-CGP5 indicators with the coefficients of 0.70-0.81 are important for the CGP sub-element. The DEP1-DEP5 indicators with the coefficients of 0.85-0.86 are important for the DEP sub-element and the EMM1-EMM5 indicators with the coefficients of 0.81-0.92 is the most important of the EMM sub-elements. These latent indicators have the variance ratio that is explained by the sub-elements or the forecast coefficient of the indicator from 0.50 to 0.85.

The results of the analysis of the sub-elements showed that the weight of all three sub-elements were positive and greater than 0.30, with values ranging from 0.87 to 1.00 at the confidence interval of 99% for all values. These sub-elements are then suitable as a component of a green innovation strategy (GIS). The descending orders of all sub-elements are CGP, DEP and EMM with the regression coefficients of 1.00,

0.97 and 0.87, respectively. The main components have the variance ratio that is explained by the sub-elements or the forecast coefficient of the indicator from 0.76 to 1.00. All remaining variables of CSR, GP, TL, HRD and SUCCESS were also considered. The numerical results provided the same conclusions on latent variables to the manifest and dependent variables.

Based on path analysis, a relational structure model is the combination of the path relationship of external and internal latent variables. It is carried out by analyzing the rational relationships and effects of the main variables specified in the conceptual model. This will point out the structural model relates to the relationships between latent variables. Therefore, it will be best suited to the data. In the case that the model is not consistent with the empirical data via model modification indices and the theoretical reasoning, the model modification is then needed. By agreeing, it is necessary to relax the initial agreement by adjusting the variable one by one. Therefore, in order to show the theoretical relationship specified in the conceptualization process. Here are the sequential procedures to generate the path and structural equation model analyses.

The numerical results of the first structural or hypothesis model are shown in Table II and Fig. 5. The research hypothesis model shows that the manifest variables in each latent variable of the model reflected the actual measure of the proposed conceptual research framework. When considering the causal relationship, it was found that the model did not match well with the empirical data due to the statistical indices. The Root Mean Square Error of Approximation is 0.104, which is higher than the standard level of 0.05. Model modification was then developed by the researchers based on the additional related concepts and theories. Other hypothesized (HYPO) statistics of Chi-square, p-value, GFI, AGFI, RMR, RMSEA, and CFI are 845.08, 0.000, 0.83, 0.77, 0.028, 0.104, and 0.98, respectively. Some important statistical indices have not met the criteria [11].

TABLE II: PERFORMANCE MEASURES VIA STATISTICAL INDICES

Item	Index	HYPO	MOD1	MOD2	MOD3
Chi-square ( $\chi^2$ )	-	845.08	87.56	107.65	88.03
p-value	<0.05	0.000	0.102	0.125	0.093
Relative $\chi^2$	< 2.00	5.35	1.22	1.42	1.36
GFI	> 0.90	0.83	0.98	0.92	0.96
AGFI	> 0.90	0.77	0.94	0.91	0.98
RMR	< 0.05	0.028	0.013	0.037	0.024
RMSEA	< 0.05	0.104	0.023	0.048	0.018
CFI	> 0.90	0.98	1.00	1.00	1.00
CN	> 200	91.69	447.70	489.56	454.89

Model modification via the program (MOD1) was then performed via the preset level of Model Modification Indices (MI). An adjustment of the variables was performed with the relaxation of the initial agreement to the empirical data. Therefore, obtaining an alternative model was then formulated with the modified statistics of Chi-square, p-value, GFI, AGFI, RMR, RMSEA, and CFI of 87.56, 0.102, 0.98, 0.94, 0.013, 0.023, and 1.00, respectively. Two metaheuristic

algorithms of VNS (MOD2) and PSO (MOD3) were included to optimize coefficients of the influential factors. It exposes that the PSO is providing better-fit estimation than the VNS. However, an analysis of variance (ANOVA) reveals that there is no sufficient evidence to show that MOD1 and MOD3 provide statistically significant results at the confidence interval of 95%. In conclusion, the modified model of the structural equation model is appropriate in harmony with empirical data.

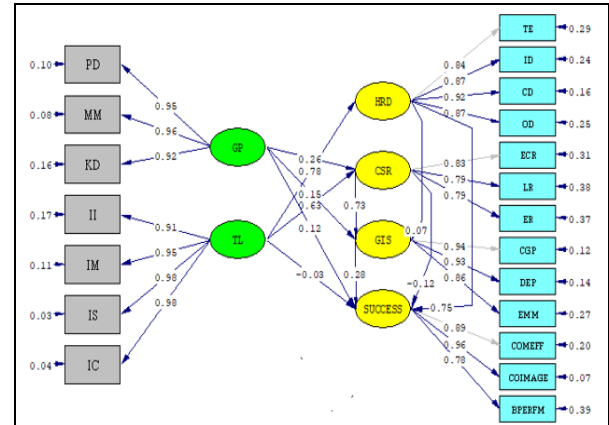


Fig. 5. SEM based on the hypothesis model.

Based on the structural equation modeling, the numerical results of the analysis of the causal relationships of successful management of environmentally friendly products in industrial factories can be categorized via the influential variables. From Table III a success in the management of environmentally friendly products for sustainability (SUCCESS) depends on government policy (GP), change leadership (TL), human resource development (HRD), corporate social responsibility (CSR) and green innovation strategy (GIS), which can explain 76% of the variation in success in managing sustainable products that are environmentally friendly:  $[SUCCESS = 0.13*GP + 0.17*TL + 0.62*HRD + 0.27*CSR + 0.14*GIS, R^2 = 0.76]$ .

TABLE III: RESULTS OF DIRECT RELATIONSHIP ANALYSIS BETWEEN INDEPENDENT VARIABLES AND DEPENDENT VARIABLES

Variable	SUCCESS	HRD	CSR	GIS
GP	0.13**	-	0.21*	0.25**
TL	0.17*	0.73**	0.78**	-
HRD	0.62**	-	-	0.12**
CSR	0.27*	-	-	0.60**
GIS	0.14*	-	-	-

Note: \*\*p-value < 0.01, \*p-value < 0.05

Green innovation strategy (GIS) is based on government policy (GP), human resource development (HRD) and corporate social responsibility (CSR), which can explain 75% of the green innovation strategy:  $[GIS = 0.25*GP + 0.12*HRD + 0.60*CSR, R^2 = 0.75]$ .

Corporate social responsibility (CSR) depends on government policy (GP) and transformational leadership (TL), which can explain 70% of the variation of corporate social responsibility:  $[CSR = 0.21*GP + 0.78*TL, R^2 = 0.70]$ .

Human resource development (HRD) depends on the transformational leadership (TL), which can explain 54 percent of the variation in human resource development:

[HRD =  $0.73 \cdot TL$ ,  $R^2 = 0.54$ ]. The hypothesis test found that all 11 research hypotheses were not statistically rejected at 95% confidence interval.

In general, the researcher has specified the guideline for collecting according to the guidelines (Nastasi and Schensul, 2005). There are five variables therefore 15 samples are needed for in-depth interviews, data analysis, and content analysis. By grouping, a separation of contents requires an analysis and a comparison of the properties of all data according to the research framework. Interview results were also performed to study the variables affecting a success in sustainable and environmentally friendly product management. The interviewees commented that the business adheres to good corporate governance with honesty, transparency, while demonstrating social and environmental responsibility including religion and culture. They are proud to be a part of helping the community continuously through collaborative activities in creating a society of various departments.

Based on green innovation strategy, the interviewees commented that in the business, there has been an adjustment to the path of green innovation by using natural raw materials as part of production to meet the concern for the environment and differentiate the product and to meet the changing consumer behavior. "Green Innovation Strategy" will lead to innovations that help improve the quality of life. The interviewees commented that a corporate social responsibility is valuable and meaning for everyone. Although the organization is doing business to make money, but at the same time it would be very beautiful. If the business grows this could create more wealth for yourself and also create quality of life and happiness for the society as well. Moreover, the green business will bring change to the global society.

On the government policies, the interviewees commented that at present, entrepreneurs are alert and aware of self-development of innovation for enhancing the competitiveness of environmental conservation organizations. With expectations, promotion, support, and motivation for entrepreneurs could effectively use clean and modern technologies, personnel development to meet their needs, speeding up skills development and knowledge development of for the private sector. When focusing on transformational leadership, the interviewees commented that everyone in the organization must move forward together, exchange knowledge and create new work processes. It would be even more effective, with the organization's leaders showing their decisiveness and vision to determine the direction for managing environmentally friendly products. This would benefit the operations of the organization and society.

On human resource development, the interviewee commented that the culture of the people in the organization plays an important role in creating and changing to a successful organization while doing business with environmental awareness. The organization gives importance to personnel development and develops skills of personnel while creating new culture while exchanging ideas, working processes with the network to learn new things to create "Business Ecosystem" that is conducive to environmental conservation.

## V. CONCLUSION AND DISCUSSION

The success of sustainable management of environmentally friendly products in industrial plants depends on five focused variables. On the human resource development, it is found that innovation ability has a positive influence on competitiveness. Good performance has the ability to innovate in various fields by using human resource management strategies to drive personnel to be creative, develop and improve. It is important to create quality new products and to change the production process. Different management processes make the difference and production costs reduction. In addition, when the organizations focus on quality management this makes its products recognized for quality and standards [1].

When focusing on corporate social responsibility, the practices of business organizations with the social responsibility help to develop the business to succeed under the intense competition. In line with the Strand's study, it is found that corporate social responsibility for the public will help create a good corporate image and to bring customer loyalty with good performance [12].

Transformational leadership can help an increase in the performance of the organization. It helps to create learning processes and skills. This results in improved overall company performance measures. This is consistent with the study of Mohsen & Mohammad which states that resources and competency factors of an organization's leadership influence the organization's competitive advantage [13].

The findings on green innovation strategy are consistent with the concepts of Sheng, Zhou & Lessassy [14] and Bartelmus [12]. The creation and productivity of green innovation strategies have a positive effect on the business performance, profits and good image of the organization.

The government policy results align with the research studies conducted by Dangelico and Pujari [15] and Robertson and Barling [16]. An innovation and competitiveness of various countries move forward into the creative economy. The creation of innovation is necessary for the country's competitiveness. It cannot happen from the private sector alone but requires cooperation from the government.

These five influential variables have resulted in successful management of environmentally friendly products that are sustainable in industrial plants. By considering the efficiency of the competition, corporate image and improved operating results. Suggestions for further research should study the variables of the 20 year national strategic plan of Thailand (2018-2037) which may have an impact on the success of the management of environmentally friendly products such as sustainability of industrial plants. Our results suggest that the particle swarm optimization (PSO) is the preferred approach to generate the SEM with a higher level of performance measures. Although there are only two algorithms have been provided to the product management forecasting in this study, researching other metaheuristics also will be necessary in the future.

## CONFLICT OF INTEREST

The author declares no potential conflicts of interest with respect to the research, authorship, and/or publication of this



article.

#### AUTHOR CONTRIBUTIONS

The first author defined research design and questions, collected, analyzed and interpreted the data. All authors had formulated plan and methodology and approved the final version.

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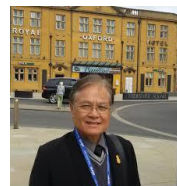


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