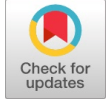


Modeling the Relationship Between Green Supply Chain Management (GSCM) Elements and Operational Cost Efficiency Improvement in Pharmaceutical Companies Based on Systems Dynamics: A Case Study of PT. XYZ

Kunta Mustaqim Abdul Somad, Yudha Prambudia, Iphov Kumala Sriwana



Abstract: PT. XYZ is a company operating in the pharmaceutical and biotechnology industries, with a focus on vaccine production and other biological products. In the current era of global competition, operational cost efficiency is a key factor in maintaining competitiveness through the implementation of Green Supply Chain Management (GSCM), as exemplified by PT. XYZ is expected to reduce operational costs through more efficient resource management, waste reduction, and improvements in process effectiveness. However, the relationship between GSCM elements and operational cost efficiency requires an in-depth and comprehensive understanding. This study aims to model the relationship between Green Supply Chain Management (GSCM) elements and operational cost efficiency improvement at PT. XYZ is using a systems dynamics approach. The GSCM elements analyzed include green product design, green innovation, green procurement, clean production, and green logistics. Through the design of a Causal Loop Diagram (CLD) and Stock Flow Diagram (SFD), 15 sub-variables that influence operational cost efficiency were identified. The simulation results indicate that the positive impact of GSCM elements on operational cost efficiency increases from the second year to the tenth year. This predictive model has an accuracy rate of 80.63%, which is considered a good prediction. Additionally, two alternative scenarios were developed to enhance efficiency further: a parameter scenario and a structural scenario. Clean production emerged as the most significant factor, with efficiency improvements reaching 110.05% and 110.94% in the 7th year.

Keywords: Cost Efficiency, System Dynamics, GSCM

Abbreviations:

GSCM: Green Supply Chain Management

CLD: Causal Loop Diagram

SFD: Stock Flow Diagram

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I. INTRODUCTION

According to Mousavi, S.A., & Noor, S.S. (2022), one of the challenges pharmaceutical companies face in remaining competitive in the global market is complying with increasingly stringent environmental regulations, which are prerequisites for selling products to consumers. These demands come not only from national regulations but also from international standards that require companies to operate in a more sustainable and environmentally friendly manner. According to PT. XYZ's 2020 Sustainability Report, the company began implementing Green Supply Chain Management (GSCM) as part of its sustainability strategy around the year 2020 [1].

The company aims for the implementation of GSCM to be driven not only by a focus on reducing environmental impact and meeting regulations but also by improving operational cost efficiency to maintain affordable product prices, which are essential for PT. XYZ needs to remain competitive in the global market. This is consistent with previous research on the positive impact of implementing GSCM on enhancing cost efficiency in pharmaceutical companies. However, prior studies were only static analyses. They could not be used to explore how changes in one element of GSCM might affect other elements and ultimately impact operational cost efficiency.

Zhu, Q., & Sarkis, J. argue that effective GSCM implementation requires a deep understanding of how various elements within GSCM interact with each other and impact operational cost efficiency. Dynamic system modeling can be used to analyze the dynamics of the relationships between these GSCM elements, enabling companies to simulate optimal scenarios and understand the impact of each element on overall operational performance.

II. LITERATURE REVIEW

According to Zhu, Q. (2017), Green Supply Chain Management (GSCM) is a supply chain management approach that integrates environmental sustainability principles into all aspects of the supply chain. GSCM encompasses the management of raw materials, production processes, packaging, transportation, and distribution, while also



considering environmental impact.

According to Sarkis, J., & Zhu, Q. (2021), the implementation of Green Supply Chain Management (GSCM) in the pharmaceutical industry has seen significant development in recent years. Along with the increasing awareness of environmental impact and regulatory pressures, pharmaceutical companies worldwide are becoming more committed to integrating sustainable practices into their operations.

Chiarini, A. (2020) [4] argues that the implementation of Green Supply Chain Management (GSCM) in pharmaceutical companies can significantly enhance cost efficiency. GSCM enables the reduction of energy and raw material costs through more efficient production processes, logistics optimization, and waste reduction. Additionally, the adoption of GSCM practices can strengthen a company's reputation, attract environmentally conscious consumers, and reduce costs associated with regulatory compliance. Therefore, GSCM not only contributes to environmental sustainability but also provides substantial economic benefits for pharmaceutical companies.

According to Sterman, J. D. (2018) [3], dynamic systems modeling is an approach used to understand, represent, and analyze the behavior of complex systems that change over time. This approach combines principles of control theory, mathematical modeling, and computer simulation to study the dynamic interactions between various system components. Dynamic systems modelling is widely applied in multiple fields, including management, economics, ecology, engineering, and the social sciences, to predict and manage the impact of changes in system variables.

According to Montgomery, D.C., et al. (2021) [2], multiple linear regression is a statistical technique used to analyze the relationship between one dependent variable (or response variable) and two or more independent variables (or predictor variables). The primary goal of multiple linear regression is to understand how well the independent variables can predict the dependent variable, as well as to measure the strength and direction of the relationship between each independent variable and the dependent variable.

III. RESEARCH METHODE

A. Data Variables for GSCM Affecting Operational Cost Efficiency

Data collection in this research includes primary data, which involves direct observation of the research object. Data collection is carried out through questionnaires. The respondents selected are stakeholders directly involved in the implementation within the company and experts who are planners of GSCM. This approach is used to gain insights into the ongoing implementation of GSCM. The questionnaire contains statements that represent the research variables. Each statement is designed to gather information from respondents in the context of GSCM variables, using a 5-point Likert scale. A scale of 1 represents "Strongly Disagree," and a scale of 5 represents "Strongly Agree" with the given statements.

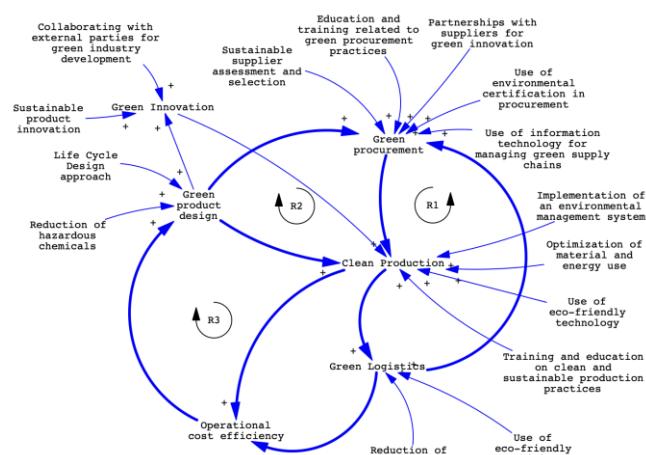
B. Conceptualization of the Model

This conceptual model is designed to illustrate the interactions between variables and sub-variables, based on literature studies and expert validation. In this research, the experts referred to are the team leader or professionals with expertise in GSCM planning at PT. XYZ. The process of conceptualising the model involves creating a Causal Loop Diagram (CLD), performing structural equation modelling with multiple linear regression, and developing a Stock and Flow Diagram (SFD).

IV. RESEARCH RESULTS AND DISCUSSION

A. Causal Loop Diagram (CLD)

According to Wilson, A.T., et al. (2022), a Causal Loop Diagram (CLD) is a graphical tool used to depict cause-and-effect relationships between various elements within a system. CLDs are often used in dynamic systems analysis to help understand how different components of a system interact and how changes in one part of the system can impact other parts. A positive sign on an arrow indicates a direct relationship, where an increase in one variable leads to a rise in the affected variable. Conversely, a negative sign on an arrow indicates an inverse relationship, where an increase in one variable leads to a decrease in the affected variable. The initial CLD model and the CLD model verified by experts are shown in Figure 1.



[Fig.1: CLD Model]

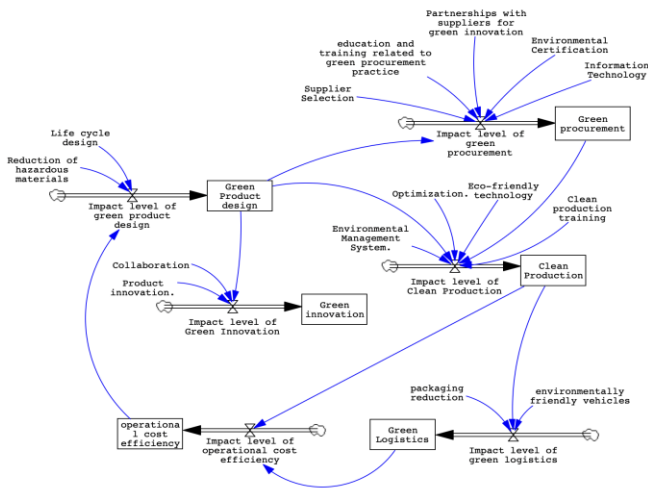
B. Structural Equation Modeling with Multiple Linear Regression and Stock and Flow Diagram (SFD)

The processing of multiple linear regression statistics is used to obtain the SFD equation. In this process, two types of variables are used: predictor variables and dependent variables. Predictor variables are factors that influence changes in other aspects, while dependent variables are the factors affected by these predictors. The relationship between predictor and dependent variables is analyzed and expressed in the form of an equation. This equation is then used to create the dynamic system model.

The Stock and Flow Diagram (SFD) can be used to illustrate the interactions between variables such as



Green Product Design, Green Innovation, Green Procurement, Clean Production, Green Logistics, and Operational Cost Efficiency. This diagram also shows how stocks and changes occur over time in simulations. The initial CLD model and the CLD model verified by experts are shown in Figure 2.



[Fig.2: SFD Model]

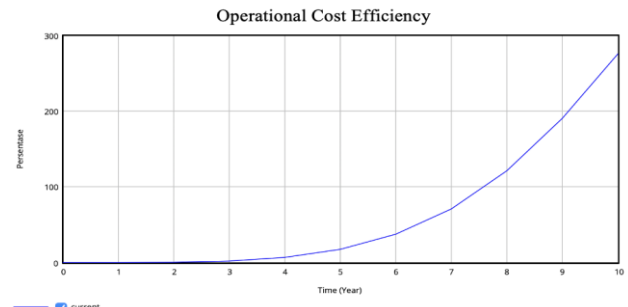
Statistical processing using multiple linear regression is employed to obtain the System Dynamics Model (SFD) equation. In this process, two types of variables are used: predictor variables and dependent variables. Predictor variables are the factors that influence changes in other variables, while dependent variables are the factors that are influenced by these predictor variables. The relationship between predictor variables and dependent variables is analyzed and expressed in the form of an equation. This equation is then used to create a dynamic systems model. A summary of the equations showing the influence between factors obtained from data processing using multiple linear regression is presented in Table 1.

Table-I: Results of Data Processing with Multiple Linear Regression Equation

No	Variables	Multiple Linear Regression Equation
1	Green Product Design	$GPD = 7,1154 + (-0,750 * 0,067) + (-0,3269 * 0,067)$
2	Green Innovation	$GI = -2,000 + (0,5625 * 0,048) + (0,9375 * 0,084)$
3	Green Procurement	$GP = 3,250 + (0,250 * 0,072) + (0,6250 * 0,072) + (0,0625 * 0,077) + (-0,4063 * 0,077) + (-0,4063 * 0,067)$
4	Clean Production	$CP = 3,250 + (0,250 * 0,046) + (0,625 * 0,074) + (0,0625 * 0,074) + (-0,8125 * 0,067)$
5	Green Logistics	$GL = -2 + (0,05625 * 0,061) + (0,9375 * 0,058)$

C. Result of System Dynamics Simulation

The results of the dynamic systems simulation using Vensim provide essential insights into the behavior of the relationship between the implementation of GSCM and cost efficiency over a specific period. The simulation was conducted to observe changes in Cost Efficiency, which is the primary focus of this research. The time unit used in this simulation is years. However, it is essential to note that the term 'years' in this context does not represent conventional calendar years, but rather a time unit defined according to the specific needs of the dynamic systems model. The results of the simulation are displayed as follows:

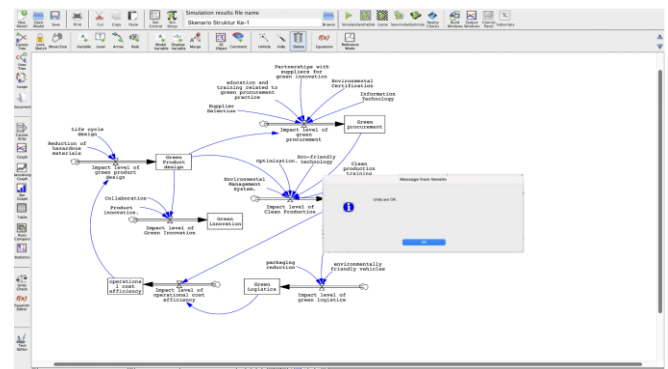


[Fig.3: The Result of the Simulation]

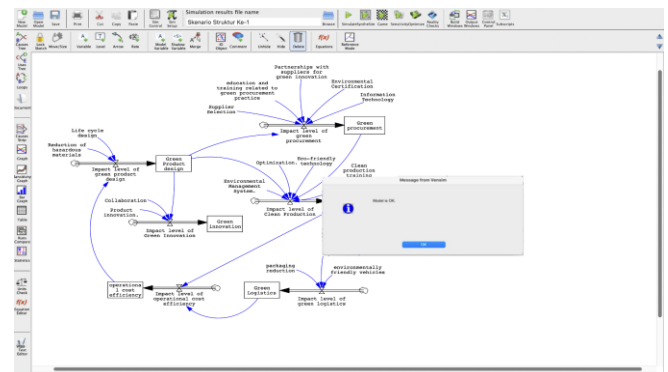
The graph illustrates how the implementation of Green Supply Chain Management (GSCM) impacts cost efficiency over time. The horizontal axis represents the time units used in the study, which are measured in years. The vertical axis shows the Cost Efficiency value. This graph provides a clear visualisation of the trends and patterns in operational cost efficiency changes from year to year. Based on the simulation data above, it is observed that the implementation of GSCM in the company does not show a significant impact during the first 6 years. In the 7th year, GSCM implementation resulted in a 70.63% increase in cost efficiency. The maximum result occurred in the 8th year, where the increase reached 113.02%.

D. Model Structure Analysis

Model structure analysis is conducted to identify and correct errors in the model, ensuring its reliability and suitability for further study. The following are some of the structural analyses performed:



[Fig.4: Unit Analysis Result]



[Fig.5: Model Analysis Result]

Based on the model structure analysis results, Figures 4 and 5 demonstrate that the dynamic system

model has been correctly constructed, with dimensional consistency achieved and no structural errors identified. This ensures that the model can be used for simulation and further analysis, as it accurately and logically represents the real system. This verification process is crucial to ensure the reliability and validity of the model, thereby ensuring that the simulation results can be trusted for informed decision-making.

E. Model Validation

Validating a dynamic system model with testing data is a necessary process to ensure the model's accuracy and reliability. By comparing simulation results with actual data and calculating accuracy metrics, we can evaluate the model's performance and make necessary adjustments to enhance its alignment with real-world data. The data compared between the model simulation results and testing data is shown in Table 2.

Table-II: Validation Results of Simulation Data against Testing Data

Time (Year)	Simulation Results of the Relationship between GSCM and Cost Efficiency (%)	Data Testing (%)
0	0	-
1	0	-
2	0.22	-
3	1.82	-
4	6.63	-
5	17.34	-
6	37.31	-
7	70.63	-
8 (max)	113.02	9466

The accuracy of the prediction can be obtained by calculating the Absolute Percentage Error (APE) based on Table 2, as follows:

$$APE = \frac{|yt' - y1|}{y1} \times 100\%$$

$$= \frac{94,66 - 113,03}{94,66} \times 100\% = 19,37\%$$

Thus, the prediction accuracy level = 100% - 19.37% = 80.63% (Good forecasting)

F. Parameter Scenarios

The parameter scenarios in this study involve changing the values of parameters in the dynamic system model without altering the model's fundamental structure. The goal is to observe how variations in parameters affect the system's output or behaviour. Simulations are conducted by adjusting the weight of each attribute in one variable to its maximum value (weight = 1). This assumes that the attribute becomes a priority in the company's management policies for improving cost efficiency. The scenarios that have been formulated are then simulated and analyzed to observe their impact on the model's output over the next 10 years. The results of the simulations for the three scenarios are presented in Table 3.

Table-III: Summary of Parameter Scenario Simulations and Their Impact on Cost Efficiency

Years	Initial	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
0	0	0	0	0	0	0
1	0	0	0	0	0	0
2	0.22	0.06	0.06	0.06	1.44	0.3
3	1.82	1.25	1.34	1.41	5.66	2.04
4	6.63	5.25	5.68	6.01	14.72	7.08
5	17.34	14.56	15.84	16.75	31.13	18.19
6	37.31	32.61	35.68	37.68	61.13	39.32
7	70.63	64.35	70.71	74.59	110.05	76.18
8	113.02	117.08	129.12	135.99	189.54	137.35
9	223.65	202.24	223.65	235.23	317.73	236.36
10	375.03	338.47	375.03	394	524.65	395.26

The results from the parameter scenarios show that Scenario 4 has the most significant impact on improving Cost Efficiency. Scenario 4 involves modifying the model's clean production attributes, which include implementing an environmental management system, optimising material and energy use, utilising environmentally friendly technology, and training in clean production practices simultaneously. This results in a cost efficiency value of 110.05% compared to the initial model's 70.63% in the 7th year. The percentage change is as follows:

$$\text{Percentage change for Scenario 4} = \frac{110.05 - 70.63}{70.63} \times 100\% = 55.81\%$$

V. CONCLUSION

The results of the dynamic modeling simulation of the relationship between elements of Green Supply Chain Management (GSCM) and the improvement of operational cost efficiency at PT. XYZ, using a dynamic system, yielded the following conclusions:

1. Fifteen sub-variables/attributes of Green Supply Chain Management (GSCM) were identified in the design of the Causal Loop Diagram (CLD) that influence the operational cost efficiency variable. These are detailed in the Stock Flow Diagram (SFD) as follows: 2 sub-variables for the green product design element, two sub-variables for the green innovation element, five sub-variables for the green procurement element, four sub-variables for the clean production element, and two sub-variables for the green logistics element.
2. The dynamic system modeling simulation of the relationship between GSCM elements and operational cost efficiency shows a trend of increasing influence from the 2nd year to the 10th year. The model's accuracy in predicting the relationship between GSCM elements and operational cost efficiency is 80.63% (Considered Good forecasting).
3. Scenario parameters involving changes in parameter values within the dynamic system model without altering the basic structure of the model. The element of Green Supply Chain

Management (GSCM) that most significantly impacts operational cost efficiency is the clean production element, with a 110.05% increase in the 7th year and a percentage change or improvement of 55.81% compared to the initial model.

DECLARATION STATEMENT

After aggregating input from all authors, I must verify the accuracy of the following information as the article's author.

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- **Ethical Approval and Consent to Participate:** The content of this article does not necessitate ethical approval or consent to participate with supporting documentation.
- **Data Access Statement and Material Availability:** The adequate resources of this article are publicly accessible.
- **Author's Contributions:** The authorship of this article is contributed equally to all participating individuals.

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