Performance evaluation of closed-loop supply chain in bottled water industry: a case study

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Abstract. The closed-loop supply chain has been identified as an efficient and effective strategy for sustainable practices in manufacturing companies. An evaluation is essential to achieve a successful closed-loop supply chain. This study aims to evaluate the closed-loop supply chain performance in the bottled water industry using a fuzzy rule-based system. A case study is conducted to PT X, a bottled water company in West Sumatra. The results show the overall closed-loop supply chain performance of PT X is at a fair level. Nine measures in the forward chain are at a good level. In contrast, one measure (i.e., product characteristics) is classified into a poor level. Based on the results, the company needs to conduct improvements related to product characteristics. In terms of the reverse chain, two measures (i.e., material features and supplier commitment) are at a fair level, while four measures are at a good level. The company has to pay more attention to material features and supplier commitment. Improvements to those measures can increase the reverse chain's performance, which indirectly increases the overall performance of the closed-loop supply chain.

1. Introduction
Over the last decades, the environmental burden associated with industrial activities has become an important global issue. Awareness about the impact of human activities on global environments has promoted environmental degradation prevention practices, such as industrial ecology, green supply-chain management, and product life-cycle management [2]. Green supply-chain management can be described as screening suppliers for their environmental performance and only allowing only satisfactory suppliers to enter into business agreements with manufacturers [3]. The totality of this green purchasing, if combined with green manufacturing and material management, green distributor, marketing, and reverse logistics can be defined as a closed-loop supply chain [4].

Closed-loop supply chain (CLSC) is a method for designing and/or redesigning a supply chain that combines metal and plastic recycling, repair and reuse of parts and components to produce new goods, and remanufacture and/or repair of all discarded products to be used as used goods [4]. The operations and potential flow of material in a closed-loop supply chain must combine the forward and reverse chains [4]. Forward logistics handles and manages the flow of goods downstream in the supply chain from suppliers to customers, while reverse logistics manages the flow of returned goods upstream [5]. Reverse logistics is the movement of products or materials in the opposite direction to create or recapture value or proper disposal [6]. It means that CLSC includes the manufacture and distribution.
of new products and the return of used products from customers back to the factory through reprocessing operations and back to suppliers.

Closed-loop is a strategy to achieve a sustainable supply chain. The closed-loop will involve changing in the philosophy of manufacturing organization, such as finding and selecting suppliers, evaluating suppliers, environmental performance, modifying and managing processes, reducing packaging and waste, developing more environmentally friendly products, reducing carbon emissions related to manufacturing and transportation of goods, etc. [4]. Therefore, continuous efforts and improvements are needed in the supply chain. Some researchers have conducted researches on the closed-loop supply chain. [1] developed a new model for closed-loop supply chain performance measurement for the automobile industry. Meanwhile, [4] measure the automobile industry's performance using the evaluation framework adopted from [1]. On the other hand, [10] presented the specific implementation of closed-loop supply chain management in the food industry. To overcome the lack of knowledge regarding international reverse supply chains as assessment, [11] established a performance measurement system to assess the international reverse supply chains. The study aims to support the circular economy and the remanufacturing industry with an approach to optimize international reverse supply chains and become more sustainable.

Although leaving waste, bottled water is favored by the public because of the convenience offered and the company's relatively affordable prices. The waste produced by bottled water is plastic. Plastics are lightweight, strong, cheap, and easily adapted into different shapes and colors. Plastics are commonly used for single-use items [7]. Because of these reasons, many industries in this world produce more plastics. However, excessive use of plastic can pollute the environment because of the character of plastic is difficult to decompose, about 50 – 100 years. The Indonesian Olefin and Plastic Industry Association (INAPLAS) and Badan Pusat Statistik (BPS) stated that plastic waste in Indonesia reaches 64 million tons every year, and 10 billion plastic bags or as many as 85,000 tons are disposed of into the environment every year [8].

PT X is a bottled water company located in West Sumatra. Nowadays, PT X promotes plastic wise campaign that concern to the environment and commit to reusing the waste, which is plastic bottles. Starts from 2015, 25% of the plastic bottle materials are using recycled materials. Conducting the recycling process to plastic bottles can mean PT X has implemented reverse logistics in its supply chain [9]. The company is working with the waste banks to collect plastic bottles that have been used for recycling into the new ones. Currently, a new bottle making factory has built in the PT X area and start the operation in early 2020. The purpose is to reduce paper usage. Bottles are usually sent using 450 boxes every day. With the development of a new bottle making factory in PT X area, the use of disposable boxes can be stopped and replaced with baskets that can be used repeatedly. PT X has applied a closed-loop supply chain since 2015. Based on the interviews with the company staff, the company does not know how well the closed-loop supply chain is performing. Thus, it is essential for the company to evaluate its closed-loop supply chain performance.

2. Methodology
The methodology of this research consists of development of performance measures and metrics, collecting data, and determining the closed-loop supply chain performance.

2.1. Development of performance measures and metrics
The performance measures and metrics are adopted from the evaluation framework by [1]. The framework consists of a two-in-one performance evaluation approach consisting of the forward chain and the reverse chain. The chains are divided into external and internal evaluations, as presented in Figure 1.
The validation is then performed to confirm the practicability of measures and metrics of the closed-loop supply chain performance in PT X for both the forward chain and the reverse chain. The validation is conducted through a questionnaire sending to three staff of PT X consist of the plant manager, logistic manager, and logistic staff. The experts are asked to determine the importance of the closed-loop supply chain performance measures and metrics. Based on the validation results, all the measures and metrics are important and thus can be used to assess the closed-loop supply chain performance in PT X. In terms of the metrics related to costs, the company suggests using secondary data because the company is not willing to provide the cost related data.

2.2. Collecting data
A questionnaire was developed to evaluate the closed-loop supply chain performance of PT X. The questionnaire is filled by PT X staff consist of the plant manager, logistic manager, and logistic staff. The questionnaire contains the performance measures and metrics that will be assessed by the manager and staff. A ten-point Likert scale is used ranged from 1 = highly poor to 10 = excellent [4]. Each metric scores in the measures of responsiveness, flexibility, and traditional supply chain cost are converted from a percent scale to a ten-point Likert scale [12], ranged from 1 = 1%-10% to 10 = 91%-100%. The measures related to costs (greening cost and recycling cost) are conducted inversely converted scale on each metric.

2.3. Determining the closed-loop supply chain performance
The closed-loop supply chain performance is then calculated using the fuzzy rule-based system. The linguistic variables used in the performance evaluation were limited to three: poor, fair, and good, or low, moderate, and high. The linguistic variables and fuzzy numbers can be seen in Table 1.
Table 1. Linguistic variables and fuzzy numbers [4]

| Importance Weight | Fuzzy Numbers  | Performance Rating | Fuzzy Numbers  |
|--------------------|----------------|--------------------|----------------|
| Low                | (0.0, 0.2, 0.4) | Poor               | (0, 2, 4)     |
| Moderate           | (0.3, 0.5, 0.7) | Fair               | (3, 5, 7)     |
| High               | (0.6, 0.8, 1.0) | Good               | (6, 8, 10)    |

The fuzzy rule-based system stages are determining fuzzy sets and fuzzy inputs, implementing fuzzy operators, implementing function implications, composing all outputs, and defuzzification. The fuzzy rule-based system is using IF-THEN rules and AND rules. IF statements are called the premises, while the THEN part is called a conclusion. The fuzzy AND is applied to combine the premise variables. Based on the number of measures, each group has a rule base equal to $x^n$. $X$ is the number of linguistic variables and $n$ is the number of measures for that particular group. For example, the external measures of the reverse chain has 9 rules and the quality of the forward chain has 81 rules. An example of the rules is: if flexibility is poor, responsiveness is poor, quality is poor, and traditional supply cost is poor, then traditional supply chain measures are poor. The rules are presented in Table 2.

Table 2. Rules for measures/metrics [4]

| Measures/Metrics | Poor (P) | Fair (F) | Good (G) |
|------------------|----------|----------|----------|
| Poor (P)         | P        | P        |          |
| Fair (F)         | P        | F        | F        |
| Good (G)         | F        | F        | G        |

### 3. Results and discussions

#### 3.1. Determining fuzzy sets and fuzzy inputs

The first stage of the procedure of the fuzzy rule-based system method is the formation of a fuzzy set, known as fuzzification. Fuzzification is a process carried out by transforming crisp set inputs into fuzzy sets. This is performed because the input used initially is in firm numbers (real) from a firm set (crisp). This fuzzy set is based on its linguistic level, which is grouped into a fuzzy variable. The average score is acted as a fuzzy input. Fuzzy sets and fuzzy inputs can be shown in the form of the membership function. The type of membership function used in this study is the triangular membership function. Triangular membership function was chosen because the widely fuzzy number used in a real system is the number of fuzzy triangular membership functions. The membership function of management commitment is shown in Figure 2.

![Figure 2. Membership function of management commitment](image-url)
The yellow, green, and red lines show the average score of measure management commitment metrics. Based on the data collected, three different average scores consist of 8.2, 8.4, and 8.8. The score of 8.2 is indicated by the yellow line with the metrics consist of the level of management effort to enlighten customers on sustainability, and availability of environmental reward systems. The score of 8.4 is indicated by the green line with the metric of the level of management effort to motivate suppliers. The score of 8.8 is indicated by the red line with the metrics consist of the level of management effort to motivate employees, availability of environmental evaluation schemes, availability of environmental auditing systems, availability of mission statements on environmental sustainability, and the number of environmental management initiatives. The triangular membership function is given by [13]:

\[
\mu(x) = \begin{cases} 
0 & \text{if } x < \alpha \\
\frac{x - \alpha}{\beta - \alpha} & \text{if } \alpha \leq x \leq \beta \\
\frac{\gamma - x}{\gamma - \beta} - \frac{x - \alpha}{\beta - \alpha} & \text{if } \beta \leq x \leq \gamma \\
0 & \text{if } x > \beta 
\end{cases}
\]  

Equation (1) is used to the management commitment fuzzification process. The membership function for each score of management commitment is shown in Table 3.

| Metrics                                           | Score | µ(x) | Fuzzy sets |
|---------------------------------------------------|-------|------|------------|
| Level of management effort to motivate employees  | 8.8   | 0.6  | Good       |
| Availability of environmental evaluation schemes  | 8.8   | 0.6  | Good       |
| Availability of environmental auditing systems    | 8.8   | 0.6  | Good       |
| Availability of mission statements on environmental sustainability | 8.8   | 0.6  | Good       |
| Number of environmental management initiatives     | 8.8   | 0.6  | Good       |
| Level of management effort to enlighten customers on sustainability | 8.2   | 0.9  | Good       |
| Availability of environmental reward systems      | 8.2   | 0.9  | Good       |
| Level of management effort to motivate suppliers  | 8.4   | 0.8  | Good       |

The value of µ(x) is influenced by the type of membership function chosen. In Figure 2, it can be seen that there are three triangles with three different peaks. These peaks can be interpreted as the highest value of each fuzzy set. For the poor category, the highest value is obtained when the metric score is 2, for the fair category is 5, and for the good category is 8. The line cut by the score determines the value of µ(x). Figure 4.1 shows that if a line is drawn perpendicular to the score, then the score of 8.2, 8.4, and 8.8 will cut the lines in the good categories. If the score is 6 or 7, the categories will be fair and good, while if the score is 3 or 4, the categories will be poor and fair [14].

3.2. Implementing fuzzy operators

The second stage is implementing fuzzy operators. The fuzzy operators are logical structure consisting of a collection of premises and one conclusion. The fuzzy operators are used to determine the relationship between premises and conclusions. In this fuzzy rule-based system, it is using IF-THEN rules and AND rules. The rules are adopted from [4]. The rules for management commitment are if MC1 is good, MC2 is good, MC3 is good, MC4 is good, MC5 is good, MC6 is good, MC7 is good, and MC8 is good, then management commitment is good. The α value of management commitment is the minimum value of membership function that equals to 0.6.
3.3. Implementing function implications
The value of α from the previous stage is used to obtain the output value in the third stage. The implication function of management commitment is shown in Figure 3. The question mark is the output value (x). The output value means how the score of management commitment with the membership function of 0.6. The output value is determined using the same formulas in the first stage. The output is a fuzzy set that reflects the contribution of each proposition. The output value of management commitment is 7.2 and 8.8.

![Implication Function of Management Commitment](image)

**Figure 3.** Implication function of management commitment

3.4. Compose all outputs
All outputs are areas that are truncated by alpha values. Figure 4 shows the graph of all outputs of management commitment.

![Compose All Output of Management Commitment](image)

**Figure 4.** Compose all output of management commitment

Based on Figure 4, the formula for each line is as follows:

$$
\mu(x) = \begin{cases} 
0 & \text{if } x \leq 6 \text{ or } x \geq 10 \\
\frac{x-6}{8} & \text{if } 6 \leq x \leq 7.2 \\
\frac{10-x}{10-8} & \text{if } 8.8 \leq x \leq 10 \\
0 & \text{if } 7.2 \leq x \leq 8.8 
\end{cases}
$$

(2)
3.5. Defuzzification

The last stage is the defuzzification. The defuzzification process is used to interpret fuzzy membership values into certain decisions or real numbers. Defuzzification is conducted by divided the moment with the area of implication. Figure 5 shows the implications of management commitment. The formula for defuzzification is as follow:

\[
Z^* = \frac{\int \mu(z)z \, dz}{\int \mu(z) \, dz}
\]

(3)

Figure 5. Area of implication of management commitment

There are three areas of implications. The area value of AI is 0.36, AII is 0.96, and AIII is 0.36. The moment value of AI is 2.50, AII is 7.68, and AIII is 3.21. After obtaining the area and moment values of each area of implication, then a defuzzification calculation is conducted. It is resulting in the score of management commitment is 7.97. The score of each measure is then calculated based on the calculation stage above. Table 4 presents a summary of the score calculation using the fuzzy rule-based system. The scores of each measure can be described as an evaluation framework shown in Figure 6.

| No. | Forward chain measures        | Score  | No. | Reverse chain measures     | Score  |
|-----|------------------------------|--------|-----|----------------------------|--------|
| 1   | Management commitment        | 7.97   | 1   | Recycling efficiency       | 7.22   |
| 2   | Greening cost                | 7.97   | 2   | Recycling cost             | 7.97   |
| 3   | Level of process management  | 7.97   | 3   | Management commitment      | 7.97   |
| 4   | Product characteristics      | 2.00   | 4   | Material features          | 5.00   |
| 5   | Supplier commitment          | 7.22   | 5   | Customer involvement       | 7.53   |
| 6   | Customer perspective         | 7.53   | 6   | Supplier commitment        | 5.00   |
| 7   | Quality                      | 7.61   |     |                            |        |
| 8   | Responsiveness               | 7.22   |     |                            |        |
| 9   | Flexibility                  | 7.61   |     |                            |        |
| 10  | Traditional supply chain cost| 9.72   |     |                            |        |

Figure 6 shows the scores of each measure, but there are some measures that do not have a score. The score of the measure then calculated based on the previous calculation stages. Table 5 shows the calculation summary of the evaluation framework.
Closed-loop supply chain performance measurement

Forward chain performance evaluation

External measures
- 7.53

Internal measures
- 7.22

Green measures
- 7.61

Traditional SC measures
- 7.53

Reverse chain performance evaluation

External measures
- 5.00

Internal measures
- 7.97

Figure 6. Scores of evaluation framework

Table 5. Results of score of evaluation framework

| Measures                              | Rules                                                                 | Score |
|---------------------------------------|-----------------------------------------------------------------------|-------|
| Green measures                        | If management commitment is good, product characteristic is poor, the level of process management is good, and the greening cost is good, then the green measure is good. | 7.16  |
| Traditional supply chain measures     | If flexibility is good, quality is good, responsiveness is good, and the traditional supply chain cost is good, then the traditional supply chain measure is good. | 8.00  |
| Internal measures of forward chain    | If traditional supply chain measure is good and green measure is good, then internal measure of forward chain is good. | 7.60  |
| External measures of forward chain    | If supplier commitment is good and customer perspective is good, then external measure is good. | 7.49  |
| Forward chain performance evaluation  | If internal measure of forward chain is good and external measure of forward chain is good, then forward chain performance evaluation is good. | 7.09  |
| Internal measures of reverse chain    | If material feature is fair, management commitment is good, recycling efficiency is good, and recycling cost is good, then internal measure is good. | 7.49  |
| External measures of reverse chain    | If customer involvement is good and supplier commitment is fair, then external measure is fair. | 4.95  |
| Reverse chain performance evaluation  | If internal measure of reverse chain is good and external measure of reverse chain is fair, then reverse chain performance evaluation is fair. | 4.77  |
| Closed-loop supply chain performance measurement | If forward chain performance evaluation is good and reverse chain performance evaluation fair, then closed-loop supply chain performance measurement is fair. | 4.85  |
Based on Table 5, the closed-loop supply chain’s performance is at a fair level, with a score of 4.85. Nine out of ten measures in the forward chain have a score higher than 7, meaning that these nine measures have been classified as a good level, while one other measure only has a score of 2.00, which is classified into a poor level, i.e., product characteristics. Therefore, the company needs to conduct improvements related to product characteristics, specifically on the level of recycled materials in products, the level of products to be disposed of to landfills, the availability of eco-labeling, and the level of biodegradable contents in products.

In terms of the reverse chain, two of the six measures have a score of 5.00, which is classified into a fair level. In contrast, the other four measures are classified into a good level with a score higher than 7. The two measures are material features and supplier commitment. Improvements to both measures can increase the overall score of the reverse chain evaluation performance, which indirectly also increases the overall score for closed-loop supply chain performance. The evaluation framework is able to identify the strengths and weaknesses and can indicate where improvements need to be made [15]. It is hoped that the evaluation framework can assist the bottled water industry to continually improve its closed-loop supply chain performance to become efficient and effective.

4. Conclusions
This study has evaluated the closed-loop supply chain performance of the bottled water industry in PT X using the fuzzy rule-based system. Based on the results, the closed-loop supply chain performance of PT X is at a fair level, with a score of 4.85. The overall score is influenced by the scores of the forward chain performance evaluation (7.09) and the reverse chain performance evaluation (4.77). To obtain a better performance, the company needs to conduct improvements related to material features (MF) and supplier commitment (SC) measures on the reverse chain, as well as product characteristics (PC) in the forward chain. If the performance on the metric of each measure increases, the performance on that measure will also increase and indirectly will affect the overall performance of closed-loop supply chain performance. Future studies will implement the proposed improvements and reevaluate the closed-loop supply chain performance in the bottled water industry.

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