A Comprehensive Evaluation of Closed-Loop Manufacturing and Reverse Logistics for Sustainable Engineering Management

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Abstract— The modern business landscape has witnessed a transformative shift in supply chain management, marked by the transition from the traditional "classic supply chain" approach to the emergence of sustainable practices. Sustainability, a concept now permeating various fields, has led to the development of Sustainable Supply Chain Management, characterized by a closed-loop methodology. This approach integrates forward and reverse supply chain activities, emphasizing the creation, use, and recycling or disposal of products within a closed system. While Reverse Logistics deals with the return and environmentally responsible management of end-of-life products, Closed-Loop Supply Chain Management encompasses the entire supply chain, with the primary objectives of minimizing production costs and environmental impact, predominantly through the promotion of reuse and recycling. This abstract underscore the differences between these concepts, elucidating their individual roles in achieving a more sustainable and environmentally conscious business ecosystem. With a growing emphasis on closed-loop supply chain management, industries and researchers alike are increasingly recognizing its potential to drive sustainability and reduce waste, making it a focal point for future endeavors.

***Index Terms*— Manufacturing, Reverse Logistics, Closed-Loop, Supply Chain, Sustainable.**

1. Introduction

Over the past years, the forward supply chain was called the 'classic supply chain' approach. It does not feel any obligation towards end-of-life consumer products. At that point, the reverse logistics tries to represent end-of-life consumer products in the most natural friendly manner possible [1].

Manuscript revised October 15, 2023; accepted October 16, 2023. Date of publication October 18, 2023.
This paper available online at www.ijprse.com
ISSN (Online): 2582-7898; SJIF: 5.59

Sustainability has been known to many fields including, supply chain, technology, and management. The widely known definition of Sustainable Supply Chain Management is the one where products which are being consumed are created, used, and recycled or disposed of in the Closed-loop Method [2].

Closed-loop Supply Chain considers both forward and reverse flows activities in a supply chain. While Reverse Logistics is the process of moving or transporting goods from its final forward destination for capturing value or for proper disposal. These two terms are sometimes used to refer to each other, they have their differences [4].

Reverse Logistics includes the processes for sending new or utilized items for repair, reuse, resale, recycling, scrap or salvage. The consumer products in a turn Reverse Logistics systems are normally returned to a central location for processing. Reverse Logistics also includes transport, reception, assessment and testing, and the arrangement of return materials to its supposed reprocessing part. The execution of Reverse Logistics can be done by a third-party logistics company or the company itself [5]. The Closed-loop Supply Chain is accurately designed as the combination of both process flows. Closed-loop Supply Chain is focused on lessening the production cost and the environmental impact of the producer to the environment. A main objective is for everything to be reused or recycled. Closed-loop Supply Chain Management has been gaining attention in industries and researches in the past years [4].

2. Methodology

The study made use of the descriptive research design, in order to examine the characteristics and properties of the companies that implement any of the said strategies: Closed-loop Manufacturing and Reverse Logistics. Along the observation of the company, the effects of implementation and

also the extent of the achievement of Green Supply Chain of Closed-loop Manufacturing and Reverse Logistics will also be observed and analyzed. The basis of the conclusion will be further strengthened by the results of this chapter that will analyze the results of the data gathered [1].

The study used a survey questionnaire that was prepared by the researchers which consists of 4 questions relating to the objectives of the study. The questionnaire aims to measure and rate four observed aspects of Green Supply Chain based on the values given by the surveyed. The survey will also be used to determine the effects of implementation of Closed-Loop Manufacturing and Reverse Logistics and their corresponding environmental impacts [4].

The 4 observed aspects that the researchers identified have been determined by previous studies and researches [1]

Production Cost – production cost refers to the costs that a business incurs when manufacturing a good or providing a service. It includes expenses such as labor, overhead costs, and other costs that are involved during production.

Material Cost – refers to the total costs of materials used to manufacture a finished good whether direct or indirect.

Waste – refers to the left-over materials from a production process. Also refers to processes or materials that does not add value to the good or service.

Environmental Impact – refers to the possible effects caused by a development, industrial or infrastructural project or by the release of substances in the environment [7].

The respondents of the study consisted of various companies who are currently implementing one of the observed production methods namely: Closed-loop Manufacturing and Reverse Logistics.

Selection of the respondents was done through purposive sample for the sole purpose of determining which of the various manufacturing companies present in the area are currently implementing any of the observed production methods.

From each of the respondents, the following data was obtained from companies that implement any of the said production methods: Closed-loop Manufacturing and Reverse Logistics. The data are ratings provided by the observed companies on each of specified categories given by the researchers. Each company gives their own rating based on how effective the applied production method is on their company. After that, the data are tallied and compared to the other method to show which is more effective on various industries. Also, to support the ratings given by the respondents, the researchers also made the respondents justify their ratings on the given aspects of the study.

The responses of the companies were analyzed by getting the average ratings of the observed benefits being shown in implementing Reverse Logistics along with their given justifications supporting their ratings. Data was also presented by percentages, graphs, and charts to further elaborate the results of the survey.

Table 1
Respondent Details

Company Observed	Type of Industry	Strategy Implemented	Implementation Period
Golden Dragon Apparel Inc.	Garments	Reverse Logistics	< 6 months
ON Semiconductor	Semiconductor	Closed-Loop Manufacturing	<6 months
Vivere Lifestyles Co. Inc.	Furniture	Reverse Logistics	1 year - 2 years
PCPPI	Food and Beverages	Reverse Logistics	> 2 years
IM Digital Phil.	Semiconductor	Closed-Loop Manufacturing	>2 years

3. Result And Discussion

Table 2
Reverse Logistic Survey Summary

Company	Processing Cost	Material Cost	Less Waste	Less Envi. Impact
GDAI	4	6	8	7
Vivere	5	7	7	7
PCPPI	2	10	10	10
TOTAL:	11	23	25	24
AVERAGE:	3.7	7.7	8.3	8
PERCENTAGE:	13%	28%	30%	29%

This table appears to provide information about four different companies (GDAI, Vivere, PCPPI) and their performance across four different metrics: Processing Cost, Material Cost, Waste Reduction, and Environmental Impact. Here's an interpretation of the table

Company this column lists the names of the three companies (GDAI, Vivere, and PCPPI) being evaluated.

Processing Cost this column represents the processing costs incurred by each company. Lower numbers indicate lower processing costs. For instance, GDAI has a processing cost of 4, Vivere has a cost of 5, and PCPPI has the lowest processing cost of 2.

Material Cost this column represents the material costs incurred by each company. Similarly, lower numbers indicate lower material costs. In this case, PCPPI has the highest material cost of 10, while GDAI and Vivere have material costs of 6 and 7, respectively.

Less Waste This column appears to indicate how effectively each company minimizes waste in its processes. Higher

numbers indicate a better performance in waste reduction. PCPPI has the highest score of 10, which means it's the most efficient in waste reduction, followed by GDAI with a score of 8 and Vivere with a score of 7.

Less Environmental Impact this column suggests the environmental impact of each company's operations. Higher numbers mean less environmental impact. PCPPI has the highest score of 10, indicating the least environmental impact. GDAI and Vivere both have a score of 7.

The "TOTAL" row provides the sum of each metric for all the companies. In this case, the sum of Processing Cost for all three companies is 11, the sum of Material Cost is 23, the sum of Waste Reduction is 25, and the sum of Environmental Impact is 24.

The "AVERAGE" row gives the average value of each metric across the three companies. The average Processing Cost is 3.7, the average Material Cost is 7.7, the average Waste Reduction is 8.3, and the average Environmental Impact is 8.

The "PERCENTAGE" row appears to represent the percentage contribution of each company's score to the total. For example, GDAI's Processing Cost of 4 is 13% of the total Processing Cost (11), Vivere's Processing Cost of 5 is 28% of the total, and PCPPI's Processing Cost of 2 is 59% of the total. Overall, this table provides a comparative analysis of these three companies in terms of their processing cost, material cost, waste reduction, and environmental impact. It shows that PCPPI generally performs well in waste reduction and environmental impact, but it has the highest material cost. GDAI and Vivere have somewhat similar performance in most metrics but differ in processing and material costs.

Table 3
Closed- Loop Manufacturing Survey.

Company	Processing Cost	Material Cost	Less Waste	Less Envi. Impact
ON Semiconductor	9	8	10	10
IM Digital Phil.	10	9	9	9
TOTAL:	19	17	19	19
AVERAGE:	9.5	8.5	9.5	9.5
PERCENTAGE:	26%	22%	26%	26%

The table presents a summary of a closed-loop manufacturing survey for two companies, ON Semiconductor and IM Digital Phil. The key metrics measured are Processing Cost, Material Cost, Waste Reduction, and Environmental Impact. Here's a summary of the table:

ON Semiconductor Processing Cost: 9 Material Cost: 8 Waste Reduction: 10 Environmental Impact: 10 IM Digital Phil.: Processing Cost: 10 Material Cost: 9 Waste Reduction: 9 Environmental Impact: 9

The "TOTAL" row represents the sum of these metrics for both companies, which is 19 for Processing Cost, 17 for Material Cost, 19 for Waste Reduction, and 19 for Environmental Impact.

The "AVERAGE" row provides the average values of these metrics, with both companies having an average score of 9.5 for all four metrics.

The "PERCENTAGE" row shows the percentage contribution of each metric to the total. Each metric contributes 26% to the overall total, indicating that both companies have similar performance in all four categories.

The table is labeled "Table 3.3 Closed-loop Manufacturing Survey Summary," suggesting that it's a summary of survey results related to closed-loop manufacturing practices for these two companies.

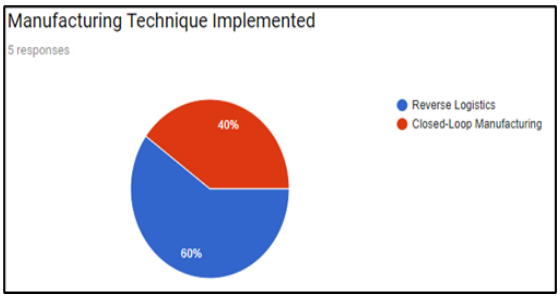

Fig.1. Manufacturing Technique Implemented

In this figure the Reverse Logistics got 60% and Closed-Loop Manufacturing got 40% which means in terms of manufacturing technique Reverse Logistics is effective.

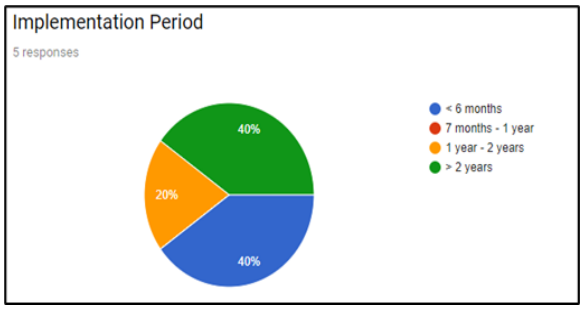

Fig.2. Implementation Period

In this figure the implementation period most effective is < 6 months the same with > 2yrs and followed by 1yr to 2 years.

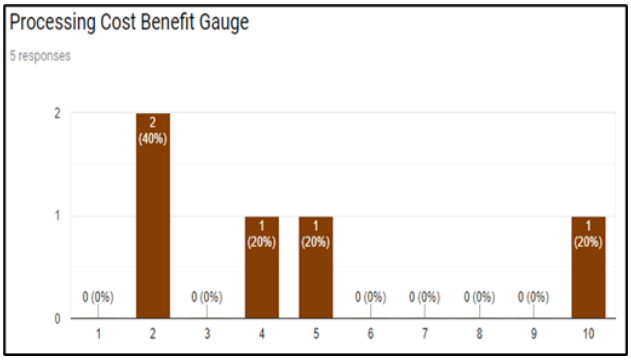

Fig.3. Processing Cost Benefit Period

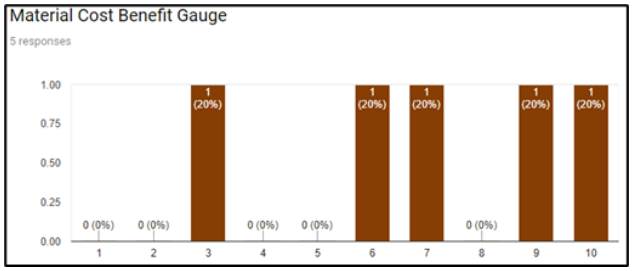

Fig.4. Materials Cost Benefit Guage

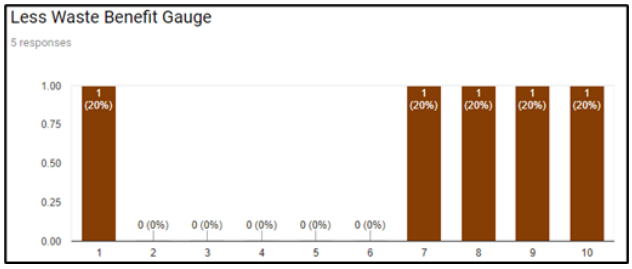

Fig.5. Less Waste Benefit Gauge

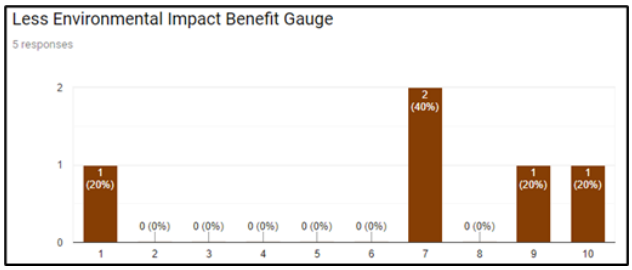

Fig.6. Less Environmental Impact Benefit Guage

Figure 5 & 6 shows the aspect ratings of Reverse Logistics & Closed-loop Manufacturing based on the average ratings given by the respondents. Under the Reverse Logistics, the benefit with the highest rating is the "Less Waste" aspect rated at (8.3), while the lowest rating is on "Less Production Cost" rated at (3.7). While on Closed-loop Manufacturing, the benefit with the highest rating is "Less Production Cost", "Less Waste", "Less Environmental Impact" rated at (9.5). The benefits with the lowest ratings is "Less Material Cost" rated at (8.5).

Table.4.
Average Ratings Based on Companies

Company Observed	Type of Industry	Strategy Implemented	Average Rating
Golden Dragon Apparel Inc.	Garments	Reverse Logistics	6.25
ON Semiconductor	Semiconductor	Closed-Loop Manufacturing	9.25
Vivere Lifestyles Co. Inc.	Furniture	Reverse Logistics	6.5
PCPPI	Food and Beverages	Reverse Logistics	8
IM Digital Phil.	Semiconductor	Closed-Loop Manufacturing	9.25

The table above shows the average ratings given by the companies on their respective strategies implemented. The average ratings are derived from the total ratings from all the aspects given on the survey. And as shown on the data above, Closed-Loop Manufacturing effects on the implementing company is noticeably very high compared to Reverse Logistics that is only somewhat high.

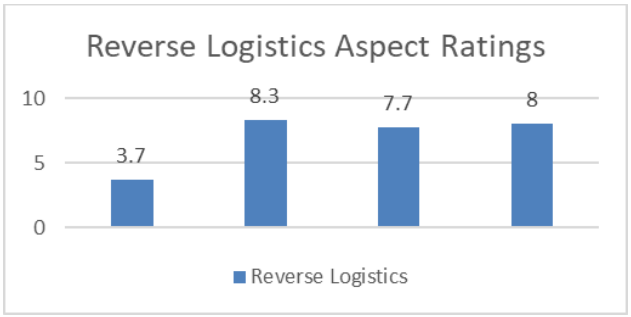

Fig.7. Reverse Logistics Aspect Ratings

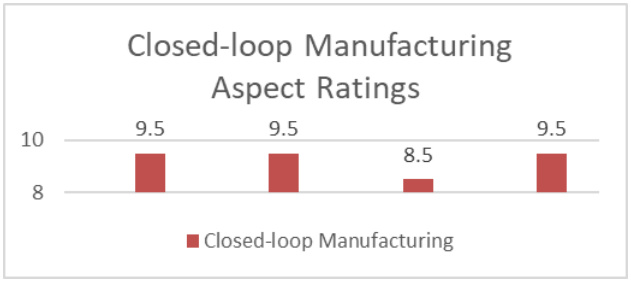

Fig.8. Closed-Loop Manufacturing Aspect Ratings

After the average ratings taken per company, the next data to analyze is the aspect rating based on the strategy implemented. This will show which of the 4 given aspects are prominent on each of the strategy being observed and studied. As shown on the graphs above, the strongest aspect of Reverse Logistics is on the "Lower Waste" aspect while its weakest is on the "Production Cost" aspect, while on the Closed-Loop Manufacturing strongest aspects are "Lower Waste", "Lower Production Cost", and "Environmental Impact" while having "Material Cost" aspect rating the lowest.

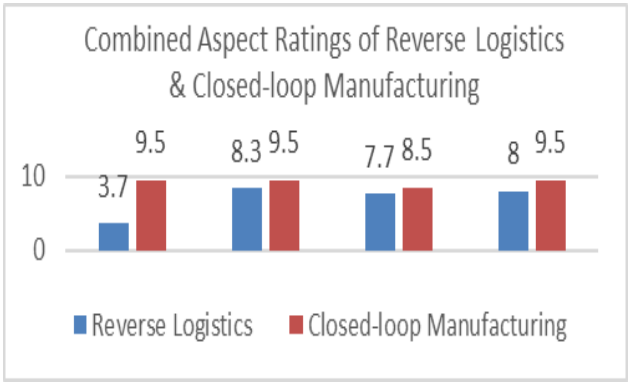

Fig.9. Combined Aspect Ratings

The combined aspect ratings show the comparisons of the 4 aspects being studied, it is shown that the Closed-Loop Manufacturing strategy shows better results compared to the Reverse Logistics but it is to be observed that based on the respondents that implements Closed-Loop Manufacturing, there is no second kind of industry that implements the said strategy, while on the Reverse Logistics, there are differing types of industry that applies the strategy. And based on the ratings on the Closed-Loop Manufacturing, it can be concluded that Closed-Loop Manufacturing is suitable for the semiconductor industry.

Figure10 and 11 shows the proportions of the benefits obtained in applying Reverse Logistics & Closed-loop Manufacturing respectively and as shown as a whole. In that way, it will be easy to observe and deduce which of the four observed aspects is the strongest and most prominent on each of the manufacturing techniques.

This will serve as a basis to conclude which of the techniques observed will be fit to be implemented on various kinds of industry. The effect on lowering the Waste is highly observed in Reverse Logistics (30%) while in Closed-loop Manufacturing it is (26%). On the other hand, the effect on the Material Cost (28%) & Environmental Impact (29%) is higher in the Reversed Logistics compared to Closed-Loop Manufacturing which is Material Cost (23%) & Environmental Impact (26%).

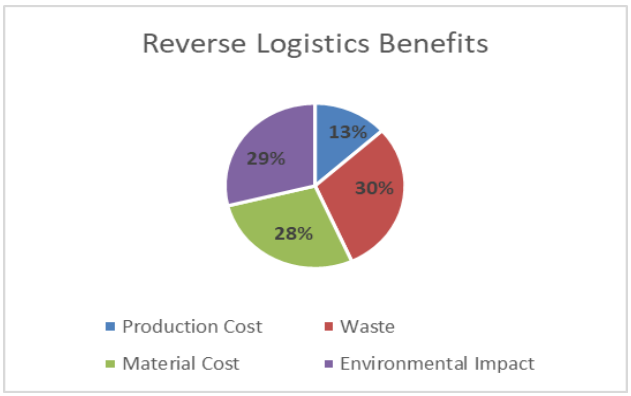

Fig.10. Reverse Logistic Benefits

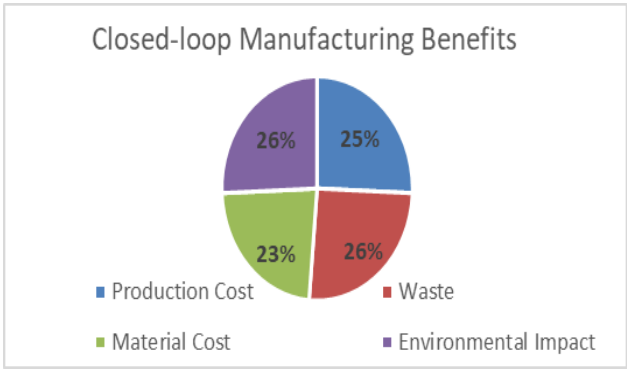

Fig.11. Closed-Loop Manufacturing Benefits

4. Conclusion

According to the respondents on Reverse Logistics, they chose Less Waste as the highest benefit because they can save up wastes (Rejected products/rejected materials) upon receiving by the end user or customers which can still be repaired, recycled, or reprocessed, they don't need to acquire new raw materials. The respondents also said that, old materials which are being re-used as raw materials of a new product has lower cost than that of purchasing new materials.

The respondents chose the Processing Cost on the Reverse Logistics as the lowest because it will add additional expense in the production line for the repairing/recycling process like additional manpower, electricity, overtime, etc. They suggest that the company should compute first using cost benefit analysis to conclude whether they really need to do the repairing/recycling process. Processing of recycled materials also depends on the quality of the recovered material.

Elaborating the observations and values, Reverse Logistics enjoys lower wastes as it is known that companies that implement Reverse Logistics recycles their materials that are already in the market and consumer side, due to this, there is a lower need for production of new materials that can possibly increase wastes. With the recycling from the consumer side, the processing cost will also increase as products that are acquired from the consumer side will undergo processes, this observation reflects on Reverse Logistics' weaker side which is on the Processing Cost aspect.

While on Closed-Loop Manufacturing, the biggest benefit is on the Waste & Environmental Impact aspect, as the said technique is exercising the practice of reprocessing and reusing materials that are once counted as waste from the previous manufacturing. Based on this practice, Closed-Loop Manufacturing lowest benefit is on the Material Cost aspect because the technique involves reprocessing of wastes/used materials to turn the waste into raw materials, it is expected that the production costs will also be higher and with the reprocessing of used materials to make them usable again on production, it will indirectly cause the cost of materials to become higher because of extra processing.

Overall, both techniques have their strengths and weaknesses and both are viable to be applied to achieve Green Supply Chain. To sum it up, Reverse Logistics focuses on outside the production facility and relies on the market and consumer side to carry out the technique. While on the other hand, Closed-Loop Manufacturing focuses inside the production facility and is not reliant on the consumer side to complete the technique.

Reverse Logistics focuses on a bigger population and on outside factors to achieve the objective of the technique; while on Closed-Loop Manufacturing focuses on inside the company itself and is not reliant on outside factors to achieve its objective.

With regards to the quality of recycled/reprocessed materials, there is no significant variation of the quality of materials because all processed and reprocessed products will undergo

Quality Control Phase that ensures the standard quality of the products whether the materials used are new or recycled.

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