Circular Economy in Plastic Pallet Manufacturer (PPM) using Nano Level Material Circularity Indicator (MCI)

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ABSTRACT

The circular economy concept is an industrial system concept with a restorative and/or regenerative design, which is closely related to the material flow. The implementation of a circular economy in a system begins with an initial design based on an assessment of the circularity of the existing system. Of several circularity assessment tools, the Material Circularity Indicator (MCI) was chosen because the assessment is quantitative. The object of this research is Plastic Pallet Manufacturer (PPM) with its main product, namely plastic pallets where the product characteristics are unique, namely between functional products and innovative products. The Nano Level model is implemented to capture material flow at the operational level where PPM has two different flows, namely open and closed in its manufacturing program. Implementing the Nano Model to MCI to conduct an assessment requires adjustments, namely changing the goal from previously assessing a product to assessing a production as a whole. In this study, the implementation of Nano Level MCI succeeded in assessing the production in the latest PPM with an average index of 0.79 which means that the system in PPM is quite circular. Then, the recommendation for improvement with the addition of workstations resulted in an increase in the average index to 0.80.

KEYWORDS

Circular Economy, nano level model, Material Circular Indicator (MCI), circularity, plastic pallets

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1 INTRODUCTION

As humans, we should be concerned about the utilization of most of the resources that still use the take-make-dispose system, which according to Bocken et al, the system can burden and pressure businesses with increased material costs due to scarcity [1].

The Circular Economy concept is proposed as an alternative industrial system that has a restorative/regenerative purpose and design. This concept replaces the 'End of life' with a more effective and efficient cycle system [2].

Saidani et al stated that the Circular Economy model is usually implemented in three-level systems, namely macro level, meso level, and micro level. However, the more specific and detailed the model used, the more relevant it is to the essence or essence of the circular economy, which focuses on the circulation of materials and products [3]. So, Saidani et al, propose a fourth level, namely the Nano Level which can see up to the operational level with material and product flows.

The author takes the object of research at Plastic Pallet Manufacturer (PPM) which produces plastic pallets and several other types of plastic houseware. A pallet is one of the material handlings that serves as a medium between the product and its loading. Pallets are widely used throughout the industry, especially for product delivery [4]. Plastic pallets themselves have unique characteristics as a product because they include several characteristics of functional products and innovative products. And, because there has been no research on circularity in plastic pallet companies, it becomes a bigger reason for the author to carry out this research.

This study aims to evaluate the circularity system in PPM using the Material Circular Indicator (MCI) which has a numerical or quantitative output with a scale of 0 to 1. The nano-level model is also applied in this study to see a clearer picture of the flow of materials and products at the operational level. which company also has two programs with two different types of streams, namely open streams on a regular program, and closed streams on makloan program.

This research is interesting because it is different from previous studies where the circularity assessment using an adjusted MCI does not measure the material flow of the product but the material flow of overall production. So, it is hoped that the results of the circularity assessment can provide an accurate picture of the condition of PPM and can be the basis for providing recommendations for improvement or increasing the circularity scale for the company.

2 LITERATURE REVIEW

Circular Economy according to the Ellen MacArthur Foundation (2015) is an industrial system with a restorative and/or regenerative design, which can replace the linear concept (take-use-throw away) or the 'end-of-life' concept [2]. Meanwhile, according to Geissdoerfer, et al. Circular Economy is a regenerative system that minimizes resources and waste, as well as emissions and other energy leakages

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by slowing, closing, and narrowing the flow of materials and energy [5].

The concept of a circular economy is related to material flows economically and considering the economic conditions that cause these flows [6]. Industry players need to get the right methodology and tools, including the measurement indicators [7].

The need for the development of a framework to track the progress of the Circular Economy was stated by the European Commission in 2018. How the framework is built is to take into account the aspects of the material, product, and service life. And, the framework must contain a set of indicators, which are as follows.

- Production and consumption.
- Waste management.
- Secondary raw materials.
- Competitiveness and innovation.

The implementation of the Circular Economy strategy has the potential to grow the economy, create jobs, and reduce the impact of environmental damage, including carbon emissions [2].

2.1 Circular Business Model

The circular economy concept aims to minimize waste through designing the use of materials, products, etc. through a business model. So that both companies, institutions, and researchers agree that there is a need for an assessment of circularity and indicators that are recognized in industrial practice.

The company's strategic steps should be based on a strong scientific basis. The more specific or detailed the level, the more relevant it will be to the core or essence of a circular economy, which focuses on the circulation of products and materials. So, Saidani et al, propose a fourth level, namely Nano Level, which has a deeper implementation scope. The scope of the Nano Level Model is in operations and products including materials. The introduction and implementation of the Nano Level Model, it is expected to provide a more specific picture for managers.

2.2 Circularity Indicator

The Circular Economy concept, which has direct and indirect advantages, must be measurable so that it can be used as the basis for making future strategies. Therefore, a set of indicators is needed to measure the efficiency of the Circular Economy. Several indicators have been discovered and continue to be developed to help management design their products and systems to be more circular, such as REPRO2, Circular Economy Toolkit (CET), and Circular Economy Indicator Prototype (CEIP), and Material Circularity Index (MCI).

Material Circularity Indicator (MCI) proposed by the Ellen MacArthur Foundation (2015), combines restorative flow measures, with complementary impacts, and risk indicators to create a comprehensive picture. The input to MCI is the product Bill of Materials (BOM) [8]. That is used to measure the extent to which linear flow is minimized and restorative flow is maximized for materials, components, and their duration of use, which are presented in Figure 1. Therefore, MCI uses a rating scale of 0 to 1, because in practice most products will fall between these two extremes.

The variables used in MCI are as follows [2]

1. Amount of pure raw material/virgin(V)
2. The total amount of material that cannot be recovered (W)

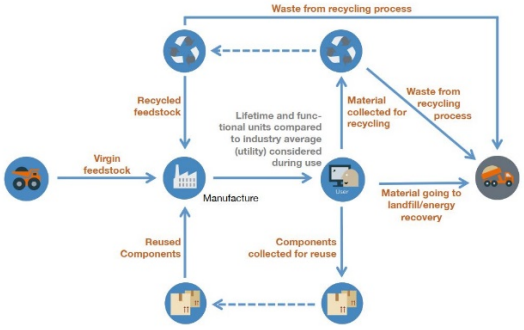

Figure 1: Material Flow Diagram (Ellen MacArthur Foundation, "Circularity Indicators: An Approach to Measuring Circularity," 2015)

3. The proportion of material flow is linear as measured by the Linear Flow Index (LFI) with a scale of 0-1
4. Utility factor (X) which takes into account the phase of product use, and the intensity of product use

2.3 PPM

A product is anything that can be offered in the market to satisfy a want or need, whether in the form of physical goods, services, experiences, events, people, places, properties, organizations, information, and ideas [9].

A company needs to pay attention to several things in designing its products. First, product design must reflect customer or market aspirations. So, there is a need for market research that underlies the making of the design. Second, the designed product needs to take into account the availability and characteristics of raw materials. So, it is necessary to pay attention to who will be the key suppliers. Third, the designed products can be produced economically as much as possible, which is related to the production facilities owned or to be built. Fourth, the product must be designed by considering storage, distribution, and other activities which will also incur costs [10].

Marshal Fisher 1997 divided products into two categories, namely functional products and innovative products. Functional products are products with standard configurations (with few variations) and have long life cycles. Thus, the demand for this product is relatively stable from time to time, making it easy for companies to forecast customer demand in the future. A brief overview of the differences between functional and innovative products is shown in Table 1 [10].

A pallet is a product base/base/holding of goods and/or piles of goods as a medium of transfer and storage in logistics, warehousing, and other activities. Previously, pallets were products made of wood. However, now plastic pallets have become known and are starting to shift the position of wooden pallets. Plastic pallets are considered to have various advantages over wooden pallets.

PPM is one of the companies in Indonesia that is engaged in manufacturing plastic pallets and other houseware products made of plastic, such as plastic baskets, plastic chairs, and so on. The main products from PPM are plastic pallets with various variations,

Table 1: Difference between Functional Products and Innovative Products

Aspect	Functional Products	Innovative Products
Life cycle	> 2 years	Short, 3 months – 1 year
Variations per category	Few, 10-20 variants	Many, thousands
Volume per production	High	Low
Demand Forecasting	Relatively easy, high accuracy	Difficult to predict, high error rate
Stock out rate	1-2%	10-40%
Excess inventory at the end of sales	Rarely, because the sales period is relatively long	Often
Markdown	Almost 0%	10-25%
Profit margin per unit	Low	High

Table 2: Product Characteristics of PPM's Plastic Pallet

Aspect	Functional Product	Innovative Product
Life cycle	X	
Variations per category		X
Volume per production	X	
Demand Forecasting		X
Stock out rate		X
Excess inventory at the end of sales		X
Markdown	X	
Profit margin per unit	X	

both in size, strength, color, and others. PPM has around 30 main product variants that they offer. The variants presented do not include custom requests, such as adding customer identity with spray paint, hot stamps, and so on. So that the characteristics of PPM products are unique because they have the characteristics of functional products and innovative products, as presented in Table 2.

PPM uses two types of plastic as its main base material, namely High-Density Polyethylene (HDPE) and Polypropylene (PP). Both HDPE and PP have different characteristics that cause them to have their own advantages and disadvantages.

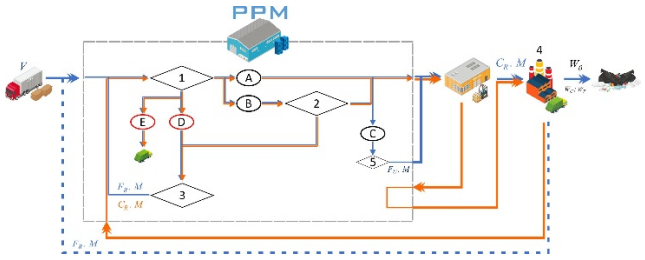

Figure 2: PPM's Nano Level MCI Model

3 METHODOLOGY

This paper attempts to answer the research questions:

1. How do assess the condition of circularity in PPM?
2. What are the recommendations for improving the circularity value for PPM?

To address that questions, Material Circularity Indicator (MCI) was chosen as a research tool because of its quantitative nature. While the Nano Level model is implemented to capture material flow at the operational level where PPM has two different programs. Thus, in this study, an assessment of the circularity of PPM using Nano Level MCI was carried out where the MCI was adjusted not to measure the flow of product material but rather the material flow of overall production. However, the order of assessment still follows the MCI presented by EMF.

4 RESULT

PPM is a plastic pallet manufacturing company. PPM has shipped its products both domestically and abroad. PPM operates on an order basis or MTO, which only works when the customer has placed an order through 2 programs, namely regular and makloan.

PPM has 2 products, namely basic and modified products. Basic products are products that are only processed by a molding machine. Modified products are products with the process of installing accessories, as well as reducing/cutting products according to customer requests. The entire production process at PPM is shown in Figure 2.

The basic pallet is the main component which can also be sold directly without the need to go through a modification process. The basic pallets can be made from raw materials which can be prime/virgin plastic pellets, crusher chips, and for some customized products, additional materials such as dyes, flexors, reinforcements, and so on are needed.

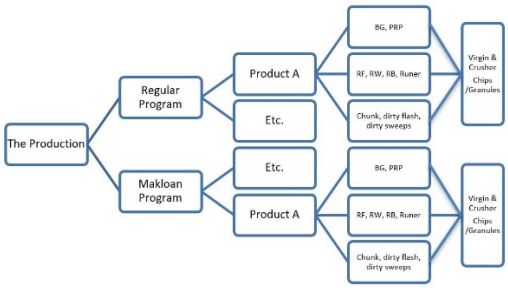

Figure 3: PPM's production

Although theoretically plastic-based products can be recycled and made repeatedly, there is always a heavy reduction in the waste recycling process which also depends on the capacity and efficiency of the recycling machine. So, in this study, the author tries to measure the company's MCI based on a manufacturing index per pallet type. This assessment is limited by the use of basic plastic pallet manufacturing data for the period 2021.

4.1 MCI Tools Adjustment

MCI as a tool presented by EMF in its circularity calculation methodology is widely used to measure the circularity index of a product. However, based to the Ellen MacArthur Foundation (2015), the methodology presented makes it possible to assess the circularity of a company. So that it is expected to be able to help the company to understand the condition of the company or the extent to which the company has transformed into a circular company.

PPM has many types of basic products, namely plastic pallets without accessories of various sizes, load-bearing capacities, and others. In addition, PPM also provides the option of adding accessories to meet customer needs. There are quite a several product types in PPM with various combinations of accessories offered, making it difficult to assess and draw conclusions that can accurately represent the conditions at PPM that are shown in Figure 3.

So, it is necessary to adjust the MCI tool to nano level to assess circularity in PPM through basic pallet production data. Thus, the adjustment of the tool to be more suitable for assessing accessible data from PPM is shown in Figure 3.

In this adjustment, the production results both in good condition and rejected are considered as components of the assessment. M, which is defined as the total mass of the product, is converted or considered as the total mass of production. This also applies to other assessment components, such as the recycled fraction, reused fraction, recycled feedstock fraction, and others.

4.2 MCI Measurement for Existing Condition

As previously explained, PPM has two main programs, namely the regular program and the makloan program. Thus, to see the actual condition of the PPM, each of these programs must be calculated using a predetermined assessment tool, namely the Nano Level MCI.

Therefore, the MCI calculation is used to measure manufacturing performance in PPM. And, this calculation begins by grouping production data for the 2021 period which was previously per work shift into per product. Then, the data will be entered into the MCI calculation. Production data for the 2021 period through the regular program is shown in Table 3.

4.2.1 Calculating Virgin Feedstock. Virgin material is material that has not been used or consumed before [2]. Plastic pallets at PPM use plastic raw materials in the form of prime pellets and/or crusher chips that are recycled from reject products and processing residues, as well as additional materials such as dyes, reinforcements, flexors, and others. Prime materials and additives are included in the category of virgin materials.

The MCI calculation assesses material flow concerning mass. So, to carry out calculations using actual data in the field in the form of the total mass of production. And, with the nano model applied in this study, the fraction of recycled raw materials are taken from raw material data from internal PPM and from third parties that are already in a ready-to-use condition, while the fraction of reused raw materials is worth 0 because there is no raw material produced from reuse in the basic pallet molding process.

$$V = M - MF_R - MF_U \tag{1}$$

Based on the measurement, there are still virgin materials used in the Makloan program, but the virgin materials are not in the form of prime pellets but are changed to additional materials as reinforcement and flexibility according to customer needs which cannot be achieved if using 100% recycled materials.

4.2.2 Calculating Unrecoverable Waste. The advanced formula from MCI is a formula for calculating non-recoverable waste. This waste can arise due to the recycling and reuse of products, including during pre-process collection activities. In the pallet molding process, there are several by-products in the form of formation rejected pallet (RF), color rejected pallet (RW), weight rejected pallet (RB), and several types of afvalans.

In this research, C_R is the mass fraction of the product which is collected after the end of the usage period for recycling. Furthermore, the calculation of the quantity of waste in the recycling process is carried out with the W_C formula. To calculate the quantity of waste in the recycling process, a recycling process efficiency (E_C) value is needed, where the efficiency value is obtained from the historical performance of PPM's Crusher Machine so that based on the average it can be determined that the E_C is 0.997.

Whereas, the calculation of waste generated to produce any recycled used as feedstock (W_F) is carried out to calculate the efficiency of the recycling process, which in this study uses efficiency based on contract documents because the recycling process is carried out by third parties through services. So, E_F is 0.92.

The calculation of unrecoverable waste using the formulas below.

$$W_0 = M\ (1 - C_R - C_U) \tag{2}$$

$$W_c = M\,(1 - E_c)\,C_R \tag{3}$$

$$W_F = M\,\frac{(1 - E_F)\,F_R}{E_F} \tag{4}$$

4.2.3 Calculating the Linear Flow Index. The LFI measures the proportion of material flow linearly, including virgin material flows, and ends up partially as non-recoverable waste. So, based on the previous calculation, LFI can be calculated by dividing the amount

Table 3: Mass of production in the 2021 period

Product	M (ton)	Fr	Product	M (ton)	Fr
PT 1210AS	1577.48	.74	PF 1311	173.35	.84
PR 1512	1055.01	.17	CF 1210	144.87	.95
CF 1111	948.93	.97	TSH 1210	112.05	.37
PF 1210	597.24	.04	BST 1211	101.27	.10
2C1312	414.89	.04	PR 1311	91.12	.30
BST 1210	337.90	.17	B1110	75.65	.00
B325	332.88	.66	CPF 1111	69.45	.86
2C1513	315.36	.06	BT 1210	64.52	.75
B126	309.77	.64	C527	62.87	.21
B125v2	267.70	.57	TSH 1211	59.29	.15
PF 1111	196.23	.93	TSH 1210v1	47.08	.21
B113	190.62	.94	B1111	33.80	.73
PT 1212	189.19	.52	B1210	31.20	.53
C1513	184.97	.02	CB 1212	9.13	.03
CPR 1111	179.27	.84	PF1311 [M]	21.30	1.0
BSF 1210	173.50	.03	PT1210AS [M]	19.92	.97

of material flowing linearly by the amount of restorative flow. The index is worth from 1 to 0, where index 1 means the flow is completely linear while index 0 the flow is completely restorative.

$$LFI = Linear\ Flow\ Index = \frac{V + W}{2M + \frac{W_F - W_C}{2}} \tag{5}$$

4.2.4 Calculating the Utility Factor. The calculation of utility X consists of two components, namely the length of the phase of product used against the average use of similar products, and the intensity of product use against the average use of similar products. The two components are combined to calculate the formula X.

In this utility calculation, the pallet product itself cannot be determined by the maximum usage limit, so the factor of the intensity of use for both PPM products and the average of similar industrial products can be considered to be worth 1.

As for the product age factor for similar industrial products, PPM products are designed to be durable, which is more than five years. Thus, the age factor for both PPM products and the average of similar industries can be set to be worth 5 years. So, the pallet utility calculation is as follows.

$$X = \left(\frac{L}{L_{av}}\right) \tag{6}$$

4.2.5 Calculating the Material Circularity Indicator. MCI can be calculated after obtaining the LFI and F(X) values, which will affect the MCI value later. MCI has an index value of 0 to 1. However, according to EMF (2015), there is no truly linear industry, so calculating the maximum MCI rating starts from 0.1 [2]. Meanwhile, the equation used to calculate MCI is as follows. The MCI values for all products are shown in Table 4.

$$MCI = 1 - LFI \cdot F(X) \tag{7}$$

Based on Table 4, it is known that 25 of the 32 products have a manufacturing MCI value of more than 0.5 which can be said that manufacturing in PPM, in general, can be said to have been circular. If grouped by manufacturing program in PPM, then the Makloan program has a better average MCI score of 0.93, while the regular program has an average value of 0.66. So, overall PPM has an average MCI index of 0.79.

The production through the Makloan program has a relatively high MCI value. This is due to the dominant use of recycled materials, even PF 1311 Makloan uses 100% recycled materials. However, in its production there are still rejected products, so the index value is still 0.94. This means that the index can still be improved.

4.3 Circularity Index Improvement Proposal

In calculating the material flow for pallet production at PPM, several factors influence, and in the calculation of MCI production this time, there are still product rejects. The product with the lowest MCI value is C1513, which has a product reject percentage of 35.7% of the total mass production. Although the rejected products at PPM can be recycled, there is always shrinkage or loss in the collection and recycling process.

So, to increase the circularity index of production at PPM is by reducing the number of rejects or preventing the occurrence of rejected products. Meanwhile, RW or color rejects are the most likely to be repaired as the basis for increasing the MCI index. The main cause of RW is due to the use of crusher material, while RF and RB are more often caused by incorrect machine settings. To improve MCI through RW improvement, the author recommends adding a workstation with a color sorter investment. Plastic Color Sorter is a sorting device for plastic granules or pieces. The color sorter is placed before entering the injection machine area, or in the raw material warehouse for the re-bag process

However, to find out the possibility of RW reduction performance, a color sorter machine is selected according to the capacity of the crusher machine and various related matters such as electricity, space area, and so on. So, try to choose from the website wesortcolorsorter.com (accessed June 21, 2022) one product, namely the Seven-channel plastic color sorter. It is assumed that the sorting

Table 4: Result of MCI calculation

Product	MCI	Product	MCI
CF 1111	0.93	PR 1311	0.58
CF 1210	0.92	TSH 1210v1	0.57
B113	0,91	C527	0.57
PF 1111	0.89	TSH 1211	0.54
CPF 1111	0.87	BST 1210	0.54
CPR 1111	0.84	PR 1512	0.53
PF 1311	0.84	BST 1211	0.52
PT 1210AS	0.82	2C1513	0.50
BT 1210	0.80	2C1312	0.49
B325	0.77	B1110	0.49
B1111	0.76	PF 1210	0.44
B126	0.75	CB 1212	0.42
B125v2	0.71	BSF 1210	0.41
PT 1212	0.66	C1513	0.33
B1210	0.66	PF 1311 Makloan	0.94
TSH 1210	0.63	PT1210AS Makloan	0.92

accuracy of the color sorter is the ability to reduce RW, which is 99% according to the machine provider's claim.

The calculation of the improvement proposal in this research is to continue using the total production in the 2021 period. Only RW will be reduced by 99% of what is produced in that period. The calculation result of this scheme is quite good because it can increase the MCI index of the C1513 product from 0.33 to 0.42. Although, with this scheme, only one of the seven products can exceed the 0.5 indexes.

5 CONCLUSION

After going through the process of completing this research, the following conclusions can be drawn.

1. The MCI tool can be adapted to measure the product material flow index to measure the production/manufacturing material flow. So, with calculations using Nano Level MCI, it can measure the company's material flow seen from the basic manufacture of plastic pallets. And, the result of measuring the company's performance using MCI in the current condition is 0.79.
2. The improvement proposal to increase the index by reducing the quantity of color reject pallets (RW) by installing a pellet color sorter is quite capable, because it can increase the C1513 product index by 27%, from 0.33 to 0.42. And, overall increased the basic pallet production index in PPM from 0.79 to 0.80.

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