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Waste Management Model for Personal Care Products Based on Reverse Logistics in Sustainable Supply Chains

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ABSTRACT

Waste management of personal care products in Indonesia faces complex issues. The widely single-use nature of product packaging results in resource inefficiency and environmental pollution, contaminating soil and water due to its non-biodegradable properties. With limited landfills, increasing environmental impacts, and long-term risks to human health, effective waste management has become an urgent strategy to mitigate environmental pollution. This study aims to design a strategic framework for personal care product waste management improve supply chain sustainability in the Fast-Moving Consumer Goods (FMCG) sector. The research began with the study of the supply chain from the perspective of reverse logistics and then developed a structural model to represent interlinkages among driving factors. A mixed-methods approach, integrating qualitative exploration and quantitative validation, was employed to derive a representative model. The data analysis using the integrated DEMATEL–ISM–MICMAC method provided a hierarchical structure of the relationships between factors. The findings indicate that all the factors considered have influence in the management of personal care products' waste in the reverse logistics process. The three most crucial factors that are revealed to be significant for policymakers are Recycling Infrastructure and Technology (IT), Consumer Participation (CP), and Communication, Information, and Education (CIE). Optimizing these three crucial factors can heighten the development of a more effective, environmentally friendly, and economically advantageous reverse logistics system. Thus, this approach not only helps in the removal of waste but also supports the long-term sustainability of supply chain performance.

1. INTRODUCTION

Sustainability has become a major concern in the global manufacturing industry, driven by increasing awareness of the environmental impacts of production and consumption [1]. Rising industrial demand for raw materials has led to the depletion of essential resources such as clean water, fossil energy, and minerals, thereby threatening supply security and production continuity [2]. According to the IPCC [3], industrial and consumer activities contribute significantly to global emissions that accelerate global warming and climate change. This situation highlights the need for a shift towards more responsible consumption and production patterns, as mandated by Sustainable Development Goal (SDG) 12 of the United Nations, which emphasizes resource efficiency, waste reduction, and sustainability throughout the value chain.

One policy approach that has gained attention in supporting industrial sustainability is Extended Producer Responsibility (EPR). EPR requires that producers are responsible for the entire product lifecycle, including managing post-consumer waste [4]. This framework shifts some of the responsibility for waste management from governments to industries. It encourages producers to design recyclable products and set up systems for collecting post-consumer packaging [5]. As a result, many companies have begun to integrate sustainability principles into product design, material selection, and post-consumer waste management [6].

Waste management has become a critical global challenge, particularly in Indonesia, the world's fourth most populous country. High population density leads to increased industrial activities and consumption, resulting in more waste generation [7]. The limited landfill capacity and the long-term health effects make it essential to imply effective waste management strategies. In Indonesia, Law No. 18/2008 mandates producers to take responsibility for packaging and non-compostable products. This supports Presidential Regulation No. 97/2017, which sets targets to reduce waste by 30% and improve waste handling by 70% by 2045. The FMCG industry, particularly the personal care sector, is a major contributor to packaging waste [8]. The adoption of EPR in Indonesia is outlined in the Ministry of Environment and Forestry Regulation No. 75/2019, which requires FMCG producers to develop and report a packaging waste reduction plan.

The peak development of the EPR framework in Indonesia is marked by the release of the 'Waste Reduction Roadmap' under the Ministry of Environment and Forestry Regulation No. 75/2019. This policy requires producers to actively manage post-consumer waste as part of their responsibility. In practice, producers must create step-by-step waste reduction plans and report their progress to the government. These initiatives include packaging take-back programs, recycling, and the reuse or disposal of materials [9]. To put this regulation into action, strong cooperation among the government, producers, and society is essential to ensure effective and sustainable waste management in Indonesia.

Plastic waste, particularly from the FMCG sector, is a major issue. Indonesia ranks third in the world as a generator of plastic waste [10]. Personal care products such as soap, shampoo, toothpaste, and deodorant often come in single-use plastics such as jars, tubes, bottles, and sachets. This packaging contributes significantly to plastic waste [11]. Table 1 presents the types of personal care waste commonly found in final disposal sites.

Table 1. Types of personal care waste and their plastic content

Personal Care Products	Material
 Jar	1. Polyethylene (PET) 2. Polypropylene (PP) 3. Acrylonitrile butadiene styrene (ABS)
 Tube	1. High Density Polyethylene (HDPE) 2. Low-Density Polyethylene (LDPE) 3.Multiplayer Plastic (MLP)
 Bottle	1. Polyethylene (PET) 2. High Density Polyethylene (HDPE) 3. Polypropylene (PP)
 Sachet	1. Multiplayer Plastic (MLP)

Although plastics have downsides, they also significantly help in promoting circular economy strategies. The EPR concept, which has been strongly developed in the FMCG sector, is expected to play a significant role in reaching the national waste reduction goal of 30% by 2029, as required by Indonesian Ministerial Regulation of Environment and Forestry No. 75/2019. Therefore, teamwork among the government, industry stakeholders, and consumers is crucial to improve EPR implementation by creating integrated, efficient, and sustainable waste management systems.

Waste management of personal care products in Indonesia has complex challenges, making it an important area of study. By examining the major factors influencing personal care product waste management, a structural model can be created to develop focused strategies. A case study in the FMCG sector highlights the challenges and opportunities associated with collecting, processing, and reusing post-consumer packaging. This provides a foundation for developing management models that support national waste reduction objectives.

This study aims to develop a structural model of factors influencing personal care waste management in Indonesia, with a focus on reverse logistics. This integrates DEMATEL, ISM, and MICMAC analysis to provide a comprehensive understanding of the influence, interrelationships, and classifications of these factors. The findings are expected to help FMCG stakeholders in formulating targeted, efficient, and sustainable waste management policies and strategies.

2. LITERATURE REVIEW AND PROBLEM STATEMENT

2.1 Factors influencing personal care waste management

The study adopts a reverse logistics perspective, focusing on the return, recovery, and recycling of products in order to create more environmentally friendly and competitive supply chains [12]. This approach provides both economic and environmental benefits, enabling companies to strengthen their competitive advantage [13].

Based on the literature, observation, and the expert's input, the following key factors influencing personal care waste management were identified:

1. Consumer Participation (CP)—Consumer participation is a critical part of managing personal care waste. Most waste occurs after consumption. Changing habits from using single-use products to collecting and returning used packaging is essential for building a sustainable waste management system [14].
2. Communication, Information, and Education (CIE) shapes awareness and encourages responsible consumer behavior. Well-planned CIE initiatives can inform consumers about the environmental effects of personal care waste and the need to return packaging for recycling. This approach helps promote responsible and sustainable consumption behavior [15].
3. Collection Points (CPt)—Accessibility and convenience directly impact consumer participation. Collection points are important for making it easier for consumers to return used packaging. Having strategic, affordable, and visible drop-off locations boosts consumer participation in recycling. Without sufficient collection systems, recovering waste remains ineffective, even if consumer awareness is

high [14].
4. Collection Strategy (SC)—Incentives such as discounts or rewards increase return rates. These incentives provide clear motivation, turning passive consumer behavior into active involvement in waste return programs [15].
5. Packaging Design (PP)—Determines ease of recycling; eco-design improves efficiency. Designs that overlook environmental elements—such as the mixing of product residues, labels, and materials—make recycling harder, requiring more time and labor. Packaging should focus not only on function and looks but also on waste management, eco-friendly materials, and sustainability principles to support effective and responsible waste management [16].
6. Recycling Infrastructure and Technology (IT)—Enables handling and processing of small, complex materials. Advances in technology improve the efficiency of separating and processing complicated packaging materials, increasing recycling potential [16].
7. Government Regulations and Policies (LT)—Provide legal frameworks such as EPR implementation [17]. For example, Ministerial Regulation No. 75/2019 requires producers to take responsibility for reducing packaging waste through EPR. Such policies encourage changes in industry behavior, enhance accountability, and create more measurable, transparent, and sustainable waste management systems. Without regulatory support, waste management efforts may become inconsistent and ineffective.
8. Operational Efficiency (OE)—Ensures integrated and cost-effective waste handling processes. Improving operational efficiency affects waste management by ensuring that every stage—from collection to sorting and processing—is optimized and integrated. Efficiency saves resources, reduces unprocessed waste, and speeds up recycling. Beyond cutting costs, operational efficiency enhances sustainability by promoting eco-friendly and consistent practices across the supply chain [14].
9. Circular Business Model Profitability (CB)—Economic viability ensures long-term scalability [18]. Profitability in circular business models is not just an added benefit; it is also crucial for ensuring the sustainability and growth of waste management in the personal care sector. When circular models are economically viable, industries are more likely to implement proactive, efficient, and environmentally friendly waste management systems.
10. Partnerships (Pr)—Collaboration among stakeholders enhances system effectiveness. Partnerships unite different stakeholders—producers, government, recyclers, and consumers—within a collaborative framework. They enable the sharing of resources, knowledge, and infrastructure, creating more efficient and impactful waste management systems. Strong collaboration helps tackle challenges such as waste collection, consumer education, and advancements in recycling technology in a more integrated and sustainable way [14].

2.2 Problem statement

The FMCG industry in Indonesia accounted for 43.5% market share in 2022, with nearly 50% from personal care products. These products rely heavily on single-use plastic packaging, leading to significant waste generation. Current waste management systems struggle to address the complexity of these materials, resulting in burning or landfilling, which worsens environmental impacts.

Previous studies on EPR in waste management have largely focused on specific industries, including electronics, paper, tires, automobiles, electric vehicles, plastics, and packaging. While previous studies have examined EPR in sectors such as electronics, paper, automotive, and general plastics [19-23]. However, little research has addressed personal care waste management from a supply chain and reverse logistics perspective. To date, no studies have explored the interrelationships among influencing factors in reverse logistics, which highlights a significant research gap. This research addresses this gap by applying DEMATEL–ISM–MICMAC to develop an integrative framework for personal care waste management.

3. RESEARCH METHODS

The study applied a mixed-methods approach, beginning with qualitative exploration and followed by quantitative validation. A pairwise comparison-based approach was implemented in line with the primary objective of the study, namely to map the causal structure and strategic roles of factors within the reverse logistics system of the FMCG sector. Accordingly, the analysis relies on structured expert judgment from the FMCG sector to ensure the validity of the results. Expert consensus was adopted due to the limited availability of EPR data in Indonesia, particularly in the FMCG personal care segment. The internal mechanisms of the reverse logistics system have not yet been fully established, as EPR policies for plastic packaging in Indonesia will only become mandatory in 2029. Therefore, the research method is divided into three stages, as outlined below:

Step 1: Identified Research Factors and Questionnaire

Factors were identified through literature review, field observations, and expert interviews. These factors were subsequently validated by experts. The experts involved in this validation included specialists from the FMCG personal care sector, logistics practitioners, and waste management operators. Then, a structured questionnaire was developed for constructing the model of interrelationships among waste management factors (WMF) for personal care products. This implies the integration of DEMATEL–ISM–MICMAC analysis. The questionnaire was designed in the form of pairwise comparisons to capture expert assessments regarding causal relationships, hierarchical structures, as well as the driving and dependence power among the identified factors. The validation process ensured that the identified factors were relevant, accurate, and reflective of real-world conditions.

Step 2: Data Collection via Questionnaire

Data collection was carried out using the pairwise comparison questionnaire designed to map the causal relationships among factors. A total of 15 experts evaluated the degree of influence between waste management factors for personal care products using a five-point influence scale: “0” indicating no influence, “1” low influence, “2” moderate influence, "3" high influence, and "4" very strong influence. The questionnaire was distributed online via Google Forms. A total of 15 experts with diverse backgrounds, including academics, industry practitioners, and policymakers, who possess extensive experience and knowledge in personal care waste management participated in the survey. The assessments provided by the experts did not involve right or wrong answers; rather, they were subjective judgments used solely for research purposes.

Step 3: Structural Model Development

The integrated method of DEMATEL-ISM-MICMAC was applied:

Method 1: DEMATEL is used to identify cause–effect relationships and distinguish *driving factors* (factors influencing many others) and *dependent factors* (factors primarily influenced by others). The results of DEMATEL serve as the basis for subsequent ISM analysis.

Method 2: ISM Methodology is implied to build hierarchical structures of factors. ISM maps factors into a hierarchical structure through three steps: (a) developing the initial and final reachability matrices, (b) constructing the level partitions matrix, and (c) generating the ISM-based model. The resulting hierarchy positions fundamental factors at the lower levels as the foundation of the system, progressing to higher-level factors that represent outcomes of underlying influences.

Method 3: The MICMAC is used to categorize elements in order to make strategic decisions. Based on their capacity for dependence and motivation. Four quadrants are used to group factors: Dependent (low influence, high dependence), Linkage (high influence, high dependence, unstable), Autonomous (low influence, low dependence), and Driving (high influence, low dependence—key factors) are the first four categories.

Specifically, the DEMATEL–ISM–MICMAC sequence was selected to represent a logical and systematic investigation for analyzing complex systems, as demonstrate in previous studies [24, 25]. DEMATEL was first applied to identify and quantify the cause-effect relationships among factors, which then served as the basis for constructing a hierarchical structure using ISM. Finally, MICMAC analysis was employed to classify the factors according to their driving power and dependence, derived from the ISM reachability matrix. This sequential approach is designed to support the FMCG personal care sector prioritizing reverse logistics strategies, thereby enabling more effective planning and the achievement of sustainable competitive advantage.

4. RESULTS

4.1 Overview of waste management in the Fast-Moving Consumer Goods supply chain for personal care products

The supply chain in the FMCG sector producing personal care products operates under a push production system, in which production planning relies on demand forecasting. Figure 1 illustrates the supply chain structure of an FMCG company in the personal care sector. The company serves end customers distributed across Indonesia. Waste management begins at the consumer level, where personal care product packaging is discarded into waste bins after use. This waste is subsequently collected either by sanitation workers or by third parties such as waste pickers and waste banks.

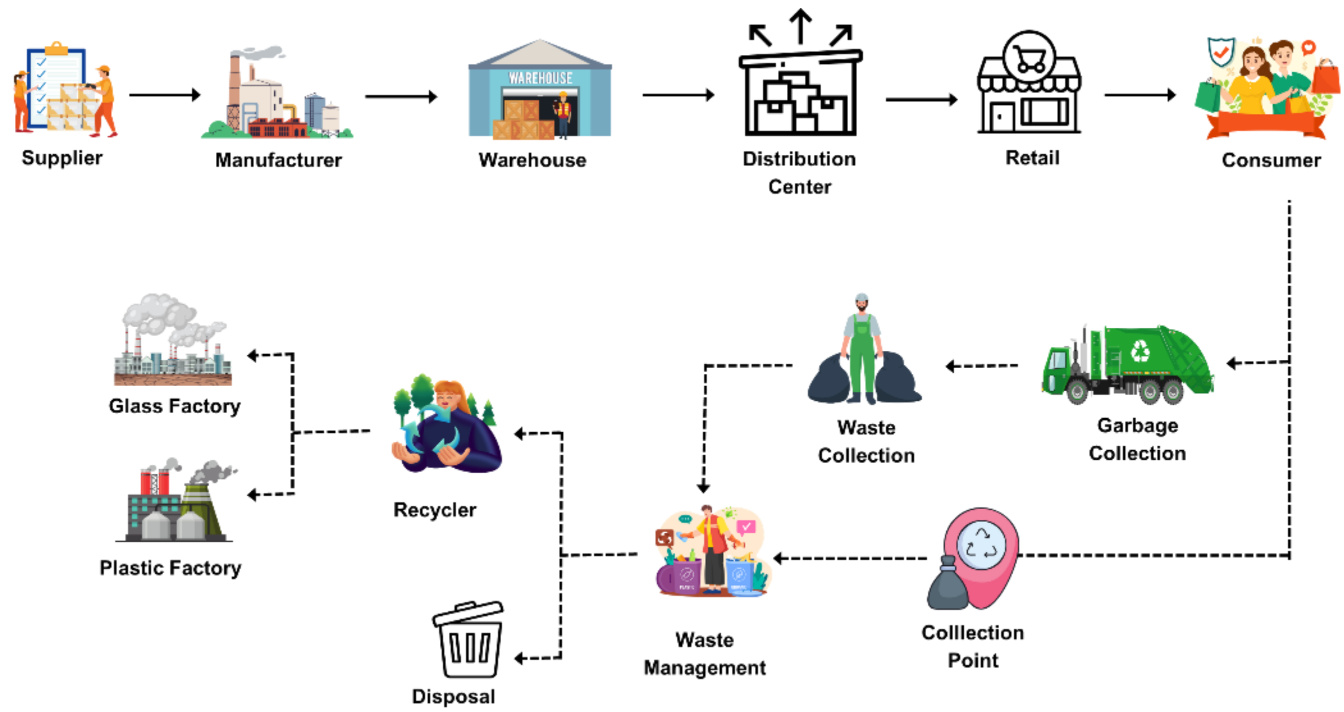


Figure 1. Supply chain in the Fast-Moving Consumer Goods (FMCG) sector for personal care products

In several cases, FMCG companies have initiated post-consumer packaging collection systems as part of their EPR initiatives. Through collaboration with logistics partners or NGOs, companies have developed reverse logistics schemes by establishing waste stations as collection points to retrieve used packaging from consumers for recycling or reuse. The collected waste is then transported to either final disposal sites (landfills) or recycling facilities, depending on the type and condition of the waste. This system extends the supply chain beyond the consumer level into a closed-loop supply chain, aiming to reduce environmental impacts and enhance resource efficiency.

4.2 Factors influencing waste management of personal care products

A review of research articles and interviews with stakeholders in personal care waste management identified eleven factors in reverse logistics that influence the management of personal care product waste (Table 2).

Ten factors were derived from the literature review, and one factor, Return Flows Uncertainty, was identified through expert feedback. According to the expert, the variation in volume, timing, and condition of returned packaging makes planning difficult. Uncertainty in reverse flows affects the efficiency of waste management, as it complicates planning and logistics for recycling. Variation in the amount, timing, and condition of returned packaging can disrupt collection and processing efficiency. This affects operational costs, capacity at recycling plants, and the continuous supply of recycled material.

These factors were validated by three experts: one from the FMCG personal care manufacturing sector, one from the logistics sector of FMCG personal care, and one from the waste management sector. The validation process ensured that the identified factors were relevant, accurate, and consistent with real-world conditions.

The pairwise comparison questionnaire for the eleven factors was distributed digitally. A total of 15 experts participated in completing the questionnaire, most of whom held middle management positions within their respective companies. The data from these 15 respondents, who are experts in waste management within the FMCG personal care sector in Indonesia, are presented in Table 3.

Table 2. Factors influencing the waste management of personal care products

Factors	Code	Author
Consumer Participation	CP	[14, 26]
Communication, Information, and Education	CIE	[15, 26]
Collection Point	CPt	[14]
Strategy Collection	SC	[15]
Packaging Design	PP	[15, 16, 18]
Recycling Infrastructure and Technology	IT	[15, 16, 26]
Government Regulations and Policies	LT	[17, 18]
Operational Efficiency	OE	[14]
Circular Business Model Profitability	CB	[14, 15]
Partnerships	Pr	[14, 15, 16, 18, 26]
Return Flow Uncertainty	RU	Expert's feedbacks

Table 3. Characteristics of the experts

Respondent	Position	Category	Years of Experience
1	Lecturer	Academia	11–15
2	Senior Logistics Manager	Logistics	26–30
3	Research & Development Manager	Manufacturing	16–20
4	Sales Manager	Manufacturing	16–20
5	Production Manager	Manufacturing	11–15
6	Project Manager	Manufacturing	11–15
7	Warehouse Manager	Logistics	11–15
8	Quality Assurance Manager	Manufacturing	16–20
9	Engineering Manager	Manufacturing	16–20
10	SVP of Business Growth & Partnerships	Waste Management	16–20
11	Import and Warehouse Manager	Logistics	21–25
12	Quality Control Manager	Manufacturing	11–15
13	Head of Business Development	Waste Management	16–20
14	Plant Manager	Waste Management	11–15
15	Lecturer	Academia	16–20

4.3 DEMATEL method

The data obtained from the questionnaires were analyzed using the DEMATEL method, following these steps:

4.3.1 Constructing the direct-relation matrix (Matrix A)

The relationships among the eleven factors in reverse logistics influencing personal care product waste management were measured through pairwise comparison matrices. The evaluation scale ranged from 0 to 4, as adopted from Torbacki and Kijewska [27]. The results of the pairwise comparison questionnaire are represented in the direct-relation matrix (Matrix A), as shown in Table 4.

4.3.2 Normalization of the direct-relation matrix (Matrix X)

The normalization of Matrix A was carried out using Eqs. (1) and (2) as follows:

$$X = k.A \qquad (1)$$

$$k = \min\left[\frac{1}{max\sum_{j=1}^{n}|X_{ij}|}, \frac{1}{max\sum_{i=1}^{n}|X_{ij}|}\right];\ j,i = 1,\ldots, n \qquad (2)$$

The results of the normalization process (Matrix X) are presented in Table 5.

4.3.3 Construction of the Total-Effect Matrix (Matrix T)

The total-effect matrix (T) was derived from the normalized direct-relation matrix (X) using Eq. (3):

$$T= X(I - X)^{-1};\ I = \text{identity matrix} \qquad (3)$$

Table 6 presents the results of the total effect matrix (Matrix T).

4.3.4 Calculation of Vector D and Vector R

Vector D was calculated as the row sums of Matrix T, while Vector R was calculated as the column sums of Matrix T. Vector D was obtained using Eq. (5), and Vector R was obtained using Eq. (6). The results of these calculations are presented in Table 6.

$$T = \left[t_{ij}\right]_{nxn};\ \text{i,j} = 1,2,\ldots,\text{n} \tag{4}$$

$$D = \left[\sum_{j=1}^{n} t_{ij}\right]_{nx1};\ \left[t_{ij}\right]_{nx1} \tag{5}$$

$$R = \left[\sum_{i=1}^{n} t_{ij}\right]_{1xn};\ \left[t_{ij}\right]_{1xn} \tag{6}$$

Table 4. Direct-relation matrix of waste management factors (WMF)

WMF	CP	CIE	CPt	SC	PP	IT	LT	OE	CB	Pr	RU
CP	0,000	3,067	3,400	3,467	2,867	2,867	3,067	2,867	2,800	3,000	2,400
CIE	3,133	0,000	3,267	3,267	2,933	3,000	2,933	2,733	2,933	3,067	2,867
CPt	3,267	3,133	0,000	3,333	2,800	2,600	3,133	2,800	2,733	3,133	2,667
SC	3,133	3,133	3,333	0,000	2,800	2,733	2,933	2,800	2,933	3,067	2,733
PP	2,867	2,867	3,000	2,800	0,000	2,733	2,733	2,733	2,600	2,600	2,800
IT	2,800	3,133	2,867	2,933	2,800	0,000	3,067	2,933	3,133	3,000	3,067
LT	3,000	2,867	3,133	2,933	2,667	3,000	0,000	2,733	2,667	2,867	2,867
OE	2,867	2,867	2,667	2,933	2,667	2,933	3,133	0,000	2,867	2,667	2,733
CB	2,933	2,800	2,933	2,867	2,933	2,667	2,733	2,733	0,000	2,867	2,733
Pr	2,667	2,467	3,267	2,800	2,667	2,533	2,933	2,933	2,867	0,000	2,933
RU	2,333	2,600	2,867	2,333	2,600	2,400	2,467	2,800	2,600	2,600	0,000

Table 5. Normalized direct-relation matrix (X)

WMF	CP	CIE	CPt	SC	PP	IT	LT	OE	CB	Pr	RU
CP	0,000	0,100	0,111	0,113	0,093	0,093	0,100	0,093	0,091	0,098	0,078
CIE	0,102	0,000	0,106	0,106	0,095	0,098	0,095	0,089	0,095	0,100	0,093
CPt	0,106	0,102	0,000	0,108	0,091	0,085	0,102	0,091	0,089	0,102	0,087
SC	0,102	0,102	0,108	0,000	0,091	0,089	0,095	0,091	0,095	0,100	0,089
PP	0,093	0,093	0,098	0,091	0,000	0,089	0,089	0,089	0,085	0,085	0,091
IT	0,091	0,102	0,093	0,095	0,091	0,000	0,100	0,095	0,102	0,098	0,100
LT	0,098	0,093	0,102	0,095	0,087	0,098	0,000	0,089	0,087	0,093	0,093
OE	0,093	0,093	0,087	0,095	0,087	0,095	0,102	0,000	0,093	0,087	0,089
CB	0,095	0,091	0,095	0,093	0,095	0,087	0,089	0,089	0,000	0,093	0,089
Pr	0,087	0,080	0,106	0,091	0,087	0,082	0,095	0,095	0,093	0,000	0,095
RU	0,076	0,085	0,093	0,076	0,085	0,078	0,080	0,091	0,085	0,085	0,000

Table 6. The total effect matrix of WMF

WMF	CP	CIE	CPt	SC	PP	IT	LT	OE	CB	Pr	RU
CP	1,267	1,354	1,435	1,395	1,299	1,289	1,362	1,312	1,313	1,350	1,288
CIE	1,370	1,274	1,442	1,401	1,312	1,302	1,369	1,319	1,327	1,362	1,311
CPt	1,354	1,346	1,325	1,382	1,289	1,273	1,354	1,302	1,302	1,344	1,287
SC	1,350	1,346	1,423	1,284	1,288	1,276	1,349	1,301	1,308	1,342	1,288
PP	1,269	1,265	1,336	1,292	1,134	1,206	1,269	1,228	1,227	1,256	1,219
IT	1,344	1,349	1,413	1,374	1,291	1,197	1,355	1,308	1,316	1,343	1,300
LT	1,312	1,305	1,381	1,336	1,252	1,251	1,227	1,266	1,267	1,303	1,259
OE	1,292	1,289	1,352	1,319	1,237	1,234	1,304	1,169	1,257	1,281	1,240
CB	1,288	1,281	1,353	1,312	1,239	1,221	1,287	1,245	1,166	1,281	1,235
Pr	1,275	1,266	1,355	1,303	1,225	1,211	1,286	1,245	1,245	1,189	1,234
RU	1,169	1,173	1,242	1,192	1,131	1,116	1,176	1,147	1,144	1,171	1,054

Table 7. Results of Vector D and Vector R

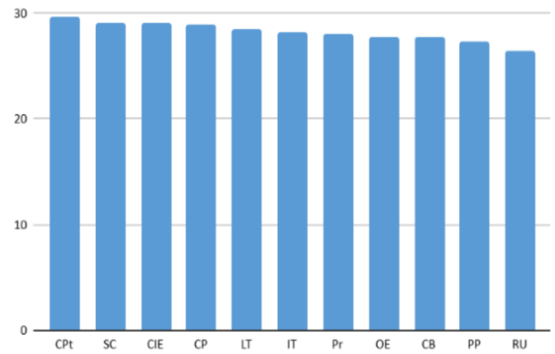
WMF	D	R	D+R	D-R	Relationship
CP	14,663	14,289	28,952	0,375	Cause
CIE	14,790	14,246	29,036	0,544	Cause
CPt	14,558	15,059	29,617	-0,501	Effect
SC	14,554	14,589	29,143	-0,035	Effect
PP	13,702	13,697	27,398	0,005	Cause
IT	14,590	13,575	28,165	1,015	Cause
LT	14,158	14,338	28,496	-0,179	Effect
OE	13,975	13,844	27,819	0,131	Cause
CB	13,909	13,874	27,782	0,035	Cause
Pr	13,834	14,223	28,057	-0,390	Effect
RU	12,715	13,716	26,431	-1,000	Effect

Subsequently, the values of Vector D and Vector R were used to derive the significance value (D+R) and the relation value (D−R). The (D+R) results indicate the level of importance of each factor in reverse logistics affecting the management of personal care product waste, while the (D−R) results reflect the degree of causal relationships among the factors within reverse logistics that influence personal care product waste management. Table 7 presents the results of Vector D and Vector R, as well as the level of each WMF relationship.

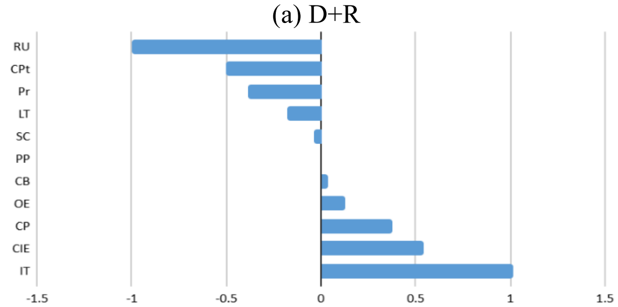
Figure 2 illustrates the cause (D−R) and effect (D+R) relationships of the factors in reverse logistics that influence the management of personal care product waste.

4.3.5 The Cause-and-Effect analysis of the factors

This section analyzes the cause-and-effect relationships among the factors in reverse logistics that influence the management of personal care product waste, based on the implementation of the DEMATEL method. The causal relationships of these factors were determined through calculations derived from the total-effect matrix (Table 6), which subsequently allowed for the identification of causal links as shown in Table 7. In addition, a causal-effect diagram is presented in Figure 2.



(a) D+R



(b) D-R

Figure 2. The causal-effect diagram for WMF by Expert

Based on the analysis of the (D+R) values, it was found that factors with higher (D+R) values exert a more significant impact on personal care waste management and play a crucial role within the overall system. As illustrated in Figure 2(a), the factors with the strongest influence are CPt, SC, CIE, CP, LT, IT, Pr, OE, CB, PP, and RU, in descending order of importance. The analysis of the (D−R) values was then used to classify factors into cause and effect categories, as illustrated in Figure 2(b). This study identified six factors in the cause category, as they have positive (D−R) values, indicating that they act as driving factors influencing other variables. These six factors are CP, CIE, PP, IT, OE, and CB. Conversely, the factors CPt, SC, LT, Pr, and RU fall into the effect category, as they have negative (D−R) values. These factors are influenced by other variables and represent the dependent effects within the reverse logistics system.

4.4 ISM methodology – MICMAC analysis

The next stage applied the ISM Methodology combined with MICMAC analysis to determine the hierarchical levels of the eleven factors in reverse logistics, based on the results obtained from the DEMATEL method. Given the methodological similarities between DEMATEL and ISM, integrating the two approaches provides a more accurate and robust analysis. The ISM Methodology was carried out through the following steps, building upon the DEMATEL results:

4.4.1 Generate the reachability matrix

To construct the reachability matrix, the total-effect matrix was converted into a binary matrix to identify the relationships between sub-factors. A value of 1 indicates the presence of a relationship between sub-factors, while a value of 0 indicates no relationship. This process is illustrated in Table 8.

To obtain the final reachability matrix, transitivity values were incorporated into the ISM methodology calculations. Table 9 presents the final reachability matrix, along with the driver power, derived from the total row sums, and the dependence power, derived from the total column sums.

Table 8. Initial reachability matrix

WMF	CP	CIE	CPt	SC	PP	IT	LT	OE	CB	Pr	RU
CP	0	1	1	1	1	1	1	1	1	1	1
CIE	1	0	1	1	1	1	1	1	1	1	1
CPt	1	1	1	1	1	0	1	1	1	1	1
SC	1	1	1	0	1	0	1	1	1	1	1
PP	0	0	1	1	0	0	0	0	0	0	0
IT	1	1	1	1	1	0	1	1	1	1	1
LT	1	1	1	1	0	0	0	0	0	1	0
OE	1	1	1	1	0	0	1	0	0	0	0
CB	1	0	1	1	0	0	1	0	0	0	0
Pr	0	0	1	1	0	0	1	0	0	0	0
RU	0	0	0	0	0	0	0	0	0	0	0

Table 9. Final reachability matrix with driver power and dependence power

WMF	CP	CIE	CPt	SC	PP	IT	LT	OE	CB	Pr	RU	Driving Power
CP	0	1	1	1	1	1	1	1	1	1	1	10
CIE	1	0	1	1	1	1	1	1	1	1	1	10
CPt	1	1	1	1	1	0	1	1	1	1	1	10
SC	1	1	1	1*	1	1*	1	1	1	1	1	11
PP	0	0	1	1	1*	0	1*	1*	1*	1*	1*	8
IT	1	1	1	1	1	1*	1	1	1	1	1	11
LT	1	1	1	1	1*	1*	1*	1*	1*	1	1*	11
OE	1	1	1	1	1*	1*	1	1*	1*	1*	1*	11
CB	1	1*	1	1	1*	1*	1	1*	1*	1*	1*	11
Pr	1*	1*	1	1	1*	0	1	1*	1*	1*	1*	10
RU	0	0	0	0	0	0	0	0	0	0	0	0
Dependence Power	8	8	10	10	10	7	10	10	10	10	10	

Table 10. Level partition matrix

Iteration	Description	Factor	Reachability Set	Antecedent Set	Interaction Set	Level
1	Packaging Design	PP	3,5,6	1,2,3,4,5,6	3,5,6	1
	Operational Efficiency	OE	1,2,3,4,5,6	1,2,3,4,5,6	1,2,3,4,5,6	1
	Circular Business Model Profitability	CB	1,2,3,4,5,6	1,2,3,4,5,6	1,2,3,4,5,6	1
2	Consumer Participation	CP	2,3	2,3	2,3	2
	Communication, Information, and Education	CIE	1,3	1,3	1,3	2
	Recycling Infrastructure and Technology	IT	1,2,3	1,2,3	1,2,3	2

4.4.2 Develop level partitions

The hierarchical levels of each factor were structured beginning from the top level (Level 1) in the ISM model. Subsequent levels were determined by separating the previously classified factors from the remaining ones. This partitioning process was repeated until all factors were assigned to their respective levels. In this study, six factors were grouped into two levels (Table 10). At Level 1, the factors included PP, OE, and CB, while CP, CIE, and IT were classified under Level 2. The factors CPt, SC, LT, Pr, and RU were excluded from further analysis, as their impact was considered low according to the DEMATEL results, indicated by negative R−C values.

4.4.3 Build the ISM-based model

The ISM-based model is a diagram that illustrates both direct and indirect relationships between factor *j* and factor *i*. This model represents the factors and their interconnections through nodes and edges. The hierarchical categorization highlights the interdependence among the factors. This approach is consistent with prior studies [28-30].

In this study, the ISM model, illustrated in Figure 3, presents a two-level hierarchical structure for the six selected factors. Factors PP, OE, and CB appear at Level 1, signifying their role as key elements influencing the overall system of personal care waste management. Meanwhile, CP, CIE, and IT are positioned at Level 2, indicating that their management depends on the key elements at Level 1.

4.4.4 Categorization of factors using MICMAC analysis

The purpose of MICMAC analysis is to classify the factors in reverse logistics that affect the management of personal care product waste into four categories. The classification is based on the driving power and dependence power values for each factor, as calculated in Table 8. The four categories in MICMAC analysis are independent, linkage, dependent, and autonomous.

Figure 4 Shows that no factors were classified as autonomous. This indicates that all factors involved in the study have an influence on personal care waste management from a reverse logistics perspective.

Based on their driving power and dependence power values, factors OE, CB, and PP fall into the dependent category. Factors in this category exhibit strong dependence power but weak driving power, indicating that their management relies heavily on other factors.

Meanwhile, factors IT, CP, and CIE are classified as linkage factors. Factors in this category tend to be unstable, as they have both strong driving power and strong dependence power. This implies that while they exert significant influence on the system, they are also highly dependent on other factors.

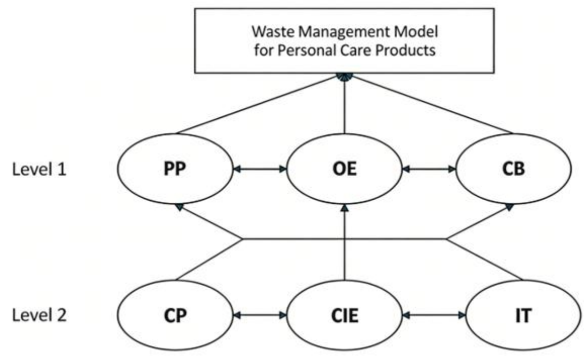


Figure 3. ISM model for WMF

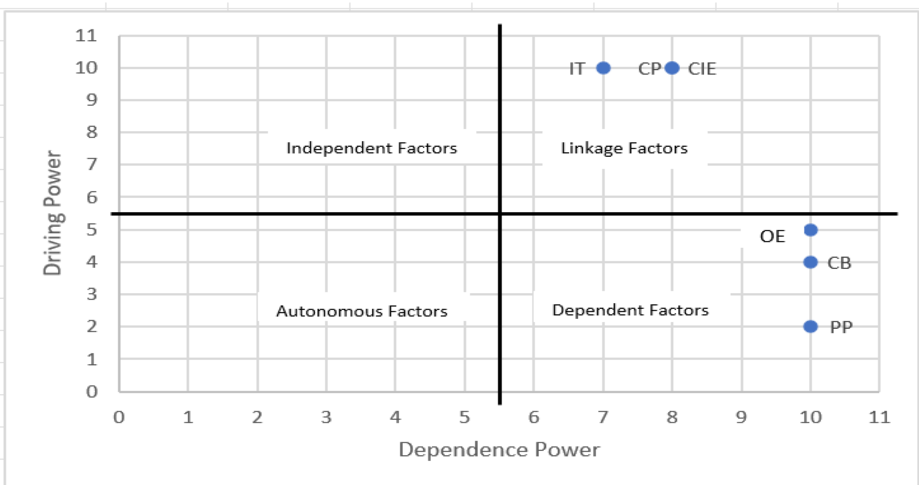


Figure 4. Driving power and dependence power diagram

5. DISCUSSION

5.1 Theoretical contribution

In terms of theoretical implications, this study contributes by providing an effective investigation of the factors influencing personal care product waste management, particularly from the perspective of reverse logistics. The urgency of managing personal care waste has been systematically outlined in earlier sections. The integration of DEMATEL-ISM-MICMAC methodologies proved useful in assisting decision-makers to address complex problems involving multiple interrelated factors. These methods enable the construction of a structured representation of factor relationships, making the system easier to interpret and analyze.

The findings indicate that IT, CP, and CIE serve as key elements for the successful management of personal care product waste from a reverse logistics perspective. This aligns with Fatimah et al. [31], who emphasize that active consumer participation is essential to ensure the viability of reverse logistics systems, where consumers include not only end users but also organizations, industries, and government actors. In Indonesia, companies operating in cities with better access to recycling infrastructure and supporting technologies show significantly stronger waste management performance than those in areas lacking such facilities. Recycling-related IT plays a pivotal role in enabling coordination, traceability, and operational efficiency [31, 32]. Furthermore, CP and CIE strengthen IT-driven initiatives by increasing public awareness and engagement in waste segregation and product return behaviors [33, 34].

From a theoretical perspective, the interaction among IT, CP and CIE strengthens their strategic role within reverse logistics systems for personal care products. CIE enhances consumer knowledge, environmental awareness, and social norms, which in turn encourage CP in packaging return activities. Higher levels of CP generate sufficient volume and regularity of return flows to achieve economies of scale, thereby enabling sustained investment in IT.

By improving consumer literacy and compliance with waste sorting practices, CIE also contributes to higher sorting quality and reduced contamination, which enhances process efficiency and material yield at recycling facilities (IT). At the same time, the availability of accessible and reliable IT increases consumer trust, further reinforcing CP. These interactions from a reinforcing feedback loop, in which improvements in CIE and CP enhance the effectiveness of IT, while successful IT implementation, in turn, strengthens CP.

5.2 Managerial contribution

The exploration of waste management for personal care products also contributes to supply chain sustainability and supports the achievement of SDG 12 on responsible consumption and production. In Indonesia, the FMCG sector faces significant challenges in adopting sustainability principles, particularly with regard to the implementation of EPR. The case study highlights the complex dynamics of EPR implementation, ranging from inadequate waste management infrastructure and low consumer awareness to opportunities for collaboration between industry players, government, and communities in developing more effective and sustainable systems.

The factors considered in this study were specifically developed from a reverse logistics perspective, which is designed to address product returns and enhance the environmental performance and competitiveness of conventional supply chains [12]. The integration of DEMATEL-ISM-MICMAC analysis reveals the hierarchical structure as well as the dependence and driving power among the factors influencing reverse logistics in waste management.

The findings are valuable for decision-makers in understanding the complexity of personal care product waste management. Moreover, structured guidance is provided to address these issues and improve sustainability performance in FMCG supply chains. The most critical and strategic factors identified are those classified in the linkage quadrant of the MICMAC analysis, namely IT, CP, and CIE. This reflects the structural characteristics of Indonesia's FMCG personal care sector. The dominance of multilayer plastic sachet packaging in personal care products increases reliance on adequate IT. In addition, reverse packaging flows are entirely determined by individual post-consumption behavior, making CP a key determinant of return flow volumes. Meanwhile, communication, information and education (CIE) influence material quality through proper waste segregation and contamination reduction [35].

Firstly, IT should be designed to be scalable and adaptable [16]. However, the feasibility of such investments is highly context-dependent. In Indonesia, recycling infrastructure and supporting technologies remain underdeveloped and unevenly distributed, with most facilities concentrated on Java Island, while firms face significant financial and human resource constraints that limit direct investment in advanced recycling technologies. Given Indonesia's archipelagic geography and the current structural limitations of the recycling ecosystem, strategic partnerships with third-party recycling organizations represent the most viable short- to medium-term pathway, alongside the gradual expansion of recycling facilities beyond Java, to strengthen reverse logistics systems.

Secondly, CP directly determines the volume of returned waste, thereby affecting the effectiveness of reverse logistics and recycling capacity. Companies must design effective consumer participation schemes, such as incentive programs or accessible packaging return systems. This factor is influenced by social trends, brand perceptions, and system convenience. Even minor changes in communication strategies or incentives can significantly impact consumer participation [14].

Lastly, CIE is fundamental because consumers play a central role in waste management within the FMCG sector. Companies must ensure consistent and massive communication through social media, product labeling, websites, educational campaigns, and community collaborations. This factor is highly sensitive to regulatory changes, shifting consumer values, and reputational risks. Ineffective communication may hinder reverse logistics performance even if adequate infrastructure is already in place [15].

Compared with developed countries that have mature waste sorting and recycling systems, Indonesia's reverse logistics infrastructure remains underdeveloped and unevenly distributed across the region. In countries such as Japan and Germany, waste management practices, starting from sorting to recycling and final disposal, are widely institutionalized and socially accepted [36]. Nevertheless, prior research indicates that these three factors remain critical in developed economies.

Recycling-related IT continues to be the most influential factor in implementation success by enabling system efficiency and coordination [37-39]. CP and CIE serve as essential complementary mechanisms, with their relative roles shaped by socio-cultural and regulatory contexts [38-40]. Despite institutional maturity, developed countries generate larger waste volumes, and public engagement with waste outcomes remains uneven [41], reinforcing the continued relevance of IT, CP, and CIE across contexts. Overall, this study highlights that improving sustainability performance in FMCG supply chains requires prioritizing these three key elements, which are IT, CP, and CIE as strategic drivers of reverse logistics.

6. CONCLUSION

This study provides managerial guidance for FMCG companies, particularly those producing personal care products, in prioritizing strategic efforts for waste management from a reverse logistics perspective. The findings reveal eleven influencing factors, categorized as either causes or effects within the system. Among these, three factors were identified as the most critical and strategic: IT, CP, and CIE.

The integration of DEMATEL, ISM, and MICMAC methodologies contribute in providing valuable insights for decision-makers by clarifying complex interrelationships among factors and providing a structured roadmap for successful waste management. Nevertheless, this research has limitations, particularly its focus on a single case study within a specific sector. Future research could address these limitations by: Expanding the number and diversity of respondents across institutional roles, incorporating fuzzy-based approaches to refine the model, and broadening the set of factors considered by integrating the latest references.

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NOMENCLATURE

A	the relationship between two factors
X	Normal matrix
T	Total relation matrix
I	Identity matrix
R	The sum of the rows of the matrix T
J	The sum of columns of the matrix T