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Circular Supply Chain Model for Reducing Food Waste in Local Bakery Industry: A Case Study in Yogyakarta Tourism Small and Medium Enterprises (SMEs)

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Abstract

Food waste is a critical issue in the bakery industry due to perishable raw materials, short product shelf life, and demand uncertainty. This study aims to develop and validate a circular supply chain model to reduce food waste in a bakery SME in Yogyakarta, Indonesia. The research integrates the Supply Chain Operations Reference (SCOR) model, Value Stream Mapping (VSM), Root Cause Analysis (RCA), and Discrete Event Simulation (DES). SCOR analysis indicates low material utilization efficiency, with Material Utilization Rate values below 0.78 and total food waste reaching 612 kg per day, resulting in a waste cost of IDR 9,678,000 per day. VSM analysis reveals that Non-Value Added activities occur in the production process due to waiting time. Root Cause Analysis identifies demand-misaligned production planning, manual process variability, and the lack of utilization of residual material as the main drivers of food waste. Based on these findings, a circular supply chain model is proposed through redesigned process flows, a reuse-and-recycle supply chain, optimized process facilities, and improved synchronization of material and information flows. Projection using DES based on BPMN shows elimination of waiting time, stabilization of cycle time with a prevalence reduction of 19%, and reduction of total food waste cost to IDR 7,044,638.

Keywords
Bakery SMEs, Circular Supply Chain, Discrete Event Simulation, Food Waste Reduction, and Value Stream Mapping

1. Introduction
Food waste has become an increasingly urgent global concern as supply chains struggle to balance efficiency, sustainability, and resource scarcity. Recent global studies show that one-third of all food produced continues to be lost or wasted, representing substantial economic, social, and environmental burdens (UNEP, 2022). Beyond representing lost nutritional value, the generation of food waste accelerates greenhouse gas emissions and strains the environmental capacity of food systems (Dou et al., 2024). As global food demand rises, reducing waste throughout the supply chain has become one of the most impactful strategies for improving sustainability performance (Ni et al., 2026). The issue is particularly pressing in Indonesia, which consistently ranks among the world's largest generators of food waste. The Indonesia Food Loss and Waste Baseline Study during 2021–2022, conducted by the Ministry of Development Planning, estimates that the country produces approximately 115–184 kg of food waste per capita annually, significantly higher than regional averages (Bappenas, 2021). Much of this waste originates from food processing and distribution activities, including micro and small food enterprises that form the backbone of Indonesia's culinary economy (Farahdiba et al., 2023). Food waste in Indonesia not only inflates production and

operational costs but also reflects structural inefficiencies in supply chains, inadequate forecasting, and limited adoption of data-driven operational systems.

Within the manufacturing sector, the food and bakery industries are widely recognized as high-waste environments due to the perishability of inputs, short shelf life of finished goods, fluctuating consumer demand, and batch-oriented production systems. Several pieces of evidence consistently highlight that breads, pastries, and confectionery products remain among the most frequently discarded categories in small-scale manufacturing due to overproduction, unsold inventory, quality deviations, and process losses (M. S. Rahman et al., 2025). These challenges are intensified in enterprises that rely on manual planning, non-digitalized production control, and traditional decision-making practices, which are characteristics typical of micro and small industrial units in Indonesia (Dabral et al., 2025). The Bakpia SMEs ecosystem in Yogyakarta represents a relevant and critical case within this context. Bakpia production involves manual dough preparation, variable product sizing, short shelf life, and demand patterns that fluctuate along tourism cycles (Ariutama et al., 2026). These conditions frequently lead to unsold finished goods, leftover raw materials, and rework-related losses. Recent field studies on Indonesian small food producers indicate that the absence of structured supply chain frameworks, such as SCOR-based process mapping or value stream identification, can create visibility gaps that obscure where, when, and why food waste is generated along the chain (dos Santos et al., 2022).

The persistence of food waste in these settings is strongly associated with the dominance of linear production and consumption models, which continue to follow a Take–Produce–Dispose orientation. Some literature emphasizes that linear systems create structural lock-ins that normalize inefficiency, discourage resource recovery, and overlook opportunities for regenerative processes (Svartebekk et al., 2025). As a result, small-scale bakery supply chains, especially those operating with limited technological maturity, struggle to minimize waste or repurpose by-products effectively (Bonte et al., 2026). In contrast, the transition toward a circular production and consumption paradigm offers promising opportunities for improving resource efficiency and reducing waste across bakery supply chains. Circular supply chain models emphasize material recirculation, improved demand–supply synchronization, and closed-loop recovery mechanisms for surplus products (Zhang et al., 2026). Recent literature highlights how applying circular principles within supply chain frameworks can significantly reduce food waste while enhancing operational resilience and competitiveness (Tian et al., 2026). Integrating these principles with industrial engineering tools such as the SCOR model, Value Stream Mapping, Root Cause Analysis, and Discrete-Event Simulation enables systematic diagnosis of inefficiencies and evaluation of circular interventions in realistic operational contexts. Therefore, advancing a circular supply chain model tailored for Bakpia SMEs in Yogyakarta presents a strategic opportunity to address food waste challenges at their roots. By combining structured supply chain analysis with simulation-based evaluation, this research aims to contribute both practical solutions for local industries and theoretical insights for the broader sustainability and industrial engineering community.

1.1 Objectives

This research aims to develop a circular supply chain model capable of significantly reducing food waste within the local bakery industry in Yogyakarta by integrating structured supply chain analysis and simulation-based projection. The study specifically seeks to generate a comprehensive understanding of where and why food waste occurs across the end-to-end SCOR processes, quantify inefficiencies and losses embedded in the current production value stream, and uncover systemic drivers of waste through rigorous root-cause analysis. Building on these analytical insights, the research intends to formulate a circular supply chain design tailored to the characteristics of bakery production. The ultimate objective is to evaluate the operational, economic, and sustainability impacts of this circular model through discrete-event simulation, providing empirical evidence of its effectiveness in reducing waste, improving resource utilization, and enhancing overall supply chain performance.

2. Literature Review

Food waste remains a major global sustainability and operational problem. Although much public attention is focused on household waste, the food industry, particularly focused on processing and distribution activities, contributes significantly to total food loss and waste through production processes, returns, and product quality failures (Lo & Choi, 2025). Food waste at the manufacturing and distribution stages generates direct economic losses, increases waste management costs, and contributes to greenhouse gas emissions when organic waste is disposed of in landfills (Kunszabó et al., 2025). Preventive measures undertaken upstream often have greater environmental and economic impacts than interventions at the household or retail level (Faour-Klingbeil & Todd, 2020).

Bakery products, particularly bakpia, have characteristics that make them vulnerable to waste, consist of perishable ingredients and finished products, batch-based production with yield variability, and strong fluctuations in consumer demand (Börühan & Ozbiltekin-Pala, 2021). Empirical studies in the food chain show that the pastry or bakery category often tops the list of wasted products due to a combination of overproduction, quality defects, and mismatches between production and sales (Malefors et al., 2026). For traditional bakery SMEs, this problem is exacerbated by manual production management practices, low use of information systems, and minimal integration between actors in the local supply chain, creating a clear need for a practical, scalable, and easily adopted solution framework (Blum, 2020). Furthermore, circular food supply chain solutions feature models that combine forward and secondary flows to handle surpluses and returns and convert by-products into value (Bhajan et al., 2022). These models demonstrate opportunities to reduce waste while creating new revenue streams, presenting a highly relevant approach for bakpia, which generates leftover dough, unsold products, and organic waste. However, many studies have developed this model at the macro level or in large companies. Research that formalizes and simulates the circular model for the context of bakery SMEs is still relatively limited, so the impacts are not felt.

This gap should be filled by developing a circular supply chain model built from several frameworks, which offers significant potential for further research. One approach is the Supply-Chain Operational Reference (SCOR) method. SCOR provides a Plan–Source–Make–Deliver–Return process structure and a set of performance metrics that enable researchers and practitioners to map end-to-end supply chain activities and identify weak performance areas in industrial processes (M. Rahman et al., 2026). SCOR is often used as the backbone of supply chain analysis in the agrifood and food manufacturing sectors to establish baseline metrics and organize operational interventions, including the integration of reverse flows at the Return stage when designing circular models (Alexander et al., 2017). SCOR also facilitates the development of KPIs that can be measured before and after interventions (De Angelis et al., 2018). In addition to SCOR, Value Stream Mapping (VSM) can also be used to measure value creation at every stage of the supply chain. VSM is a lean tool proven effective in visualizing the flow of materials and information at the production process level (Chauhan et al., 2021). For the food industry, researchers not only measure lead time and non-value-added time but also calculate the impact of materials, energy, and operational waste points (Haque et al., 2025). The VSM approach is also used as a primary diagnostic step before designing circular solutions because it extracts the quantitative data needed for simulation and cost-benefit analysis (Dinis-Carvalho et al., 2019).

Once waste hotspots are identified, a root-cause analysis method using a fishbone diagram is used to explore the root causes. Practical literature on the food industry and case studies of SMEs show that fishbone diagrams are effective in organizing field findings and linking symptoms to systemic causes (Kalemkerian et al., 2024). Root cause analysis forms the basis for designing circular elements (Abideen et al., 2021). Discrete Event Simulation (DES) subsequently enables quantitative evaluation of process redesigns, including the introduction of reverse logistics, by-product processing, and changes to production policies (Dhiman, 2020). DES can also be used to simulate waste reduction scenarios across the food chain and report metrics such as total waste, lead time, machine utilization, and cost of waste (Cramer, 2020). DES is particularly well-suited to the food industry because of its batch production, discrete process times, and easily modelled variations in order arrivals (Bag & Rahman, 2023). Using DES, strategies can be tested across multiple scenarios and generate robust numerical evidence.

Table 1. State of The Art

No.	Author (Year)	Study Object	Method				Main Focus	Research Gap
			SCOR	VSM	RCA	DES		
1	Adwiyah et al. (2024)	Palm oil supply chain	✓				Performance & sustainability	Food waste was not analyzed
2	Çıkmak et al. (2024)	Blockchain-enabled SC	✓				Performance measurement	No FLW focus
3	Masoomi et al. (2026)	Humanitarian SC	✓				Performance & policy	Non-food context
4	Yadav et al. (2022)	Agro-food SC	✓				SC design & metrics	Limited operational insight

No.	Author (Year)	Study Object	Method				Main Focus	Research Gap
			SCOR	VSM	RCA	DES		
5	El Kihel et al. (2023)	Industry 4.0 SC	✓				KPI reliability	Waste not addressed
6	De Steur et al. (2016)	Food supply chain		✓			Food loss reduction	No simulation
7	Dinis-Carvalho et al. (2019)	Food manufacturing		✓			Waste identification	No impact quantification
8	Kalemkerian et al. (2024)	Circular production		✓			Circular VSM	No SCOR integration
9	Ciccullo et al. (2021)	Agri-food SC		✓			Circular economy	No performance
10	Massaro & Galiano (2020)	Food factory		✓			Process improvement	Limited FLW focus
11	REALPE et al. (2024)	Food systems			✓		FLW root causes	No SC flow analysis
12	Balaji & Arshinder (2016)	Perishable food SC			✓		Causes of waste	No digital approach
13	Faour-Klingbeil & Todd (2020)	Food safety systems			✓		Risk & waste causes	Lacks quantification
14	Chauhan et al. (2021)	Food SC review			✓		FLW framework	Limited practical use
15	Alexander et al. (2017)	Global food system			✓		System inefficiencies	Not process-specific
16	Fusto et al. (2025)	Agri-food production				✓	Waste reuse optimization	No root cause analysis
17	Ni et al. (2026)	Hospital foodservice				✓	Waste quantification	Limited context
18	Haque et al. (2025)	Export SC				✓	SC efficiency	FLW not central
19	Abideen et al. (2021)	Circular SC	✓				Circular business	Lack of empirical cases
20	Fusto et al. (2025)	Food production				✓	Process simulation	No SCOR linkage
21	**This Study**	**Circular SC for SMEs**	✓	✓	✓	✓	**Circular Supply Chain for reducing food waste**	**Applicative framework for Food SMEs**

From Table 1 above, several gaps emerge that this research will address. The circular supply chain literature offers many conceptual models or network optimization at a large level, while studies combining SCOR, VSM, Root-Cause Analysis, and DES in the context of bakery SMEs are relatively few. This gap is particularly evident in studies that combine microprocess diagnostics with circular design specifically for short-life perishable products and validate the model through realistic scenario simulations using SME field data. By closing this gap, the research can provide practical and theoretical contributions, namely an implementable framework that is measurable and replicable in other food SMEs in developing countries.

3. Methods

This study adopts a stepwise analytical framework to investigate and reduce food waste in the bakpia supply chain. The analysis begins with the SCOR model to map structural processes, followed by Value Stream Mapping to capture operational flow and identify waste-generating activities. Root Cause Analysis using a Fishbone diagram is then applied to uncover the underlying drivers of inefficiency. These insights guide the development of a circular supply chain scenario, which is projected through Discrete Event Simulation to measure its operational and waste-reduction impact.

3.1 Supply-Chain Operational Reference (SCOR)

The Supply Chain Operations Reference (SCOR) model is a standardized framework that companies use to measure and improve supply chain performance through five core processes consist of Plan, Source, Make, Deliver, and Return (Çıkmak et al., 2024). This model serves as a map that depicts the comprehensive flow of materials, information, and activities, making it easier for companies to identify weak points and design appropriate improvements (Masoomi et al., 2026). In this study, the SCOR framework is applied by emphasizing Asset Management Efficiency as the primary performance attribute to evaluate material utilization within the bakery production system. The analysis focuses on the Material Utilization Rate, calculated as the ratio between actual material usage and total material input, as the main metric to quantify food waste generation across production stages (El Kihel et al., 2023).

$$\text{Material Utilization Rate} = \frac{Total\ Input - Waste}{Total\ Input}$$

This metric is selected because it directly reflects the effectiveness of raw material usage, which is the core indicator of asset efficiency in the SCOR model. To complement this assessment, the Cost attribute is used to translate material losses into economic impact through waste cost calculation (Adwiyah et al., 2024). By combining these two SCOR-based metrics, the study ensures that performance evaluation remains quantitatively measurable, operationally relevant, and fully aligned with the standardized SCOR 12.0 framework.

3.2 Value Stream Mapping (VSM)

Following the high-level diagnosis, Value Stream Mapping (VSM) is employed to analyze the physical production flow of bakpia at the shop-floor level. VSM facilitates the visualization of both material movement and information triggers, capturing how value is created and where non-value-added activities accumulate (Astill et al., 2019). The current-state VSM documents cycle times, processing times, takt time alignment, changeover durations, queue lengths, defect rates, and inventory buffers across each workstation (Balaji & Arshinder, 2016). Attention is given to time-sensitive steps, which consist of dough resting, shaping, and baking, where improper synchronization often leads to drying, over-fermenting, or burning of the product, ultimately causing material spoilage (Ciccullo et al., 2021). The map also uncovers flow disruptions such as waiting for batching delays or misaligned production scheduling, that cause overproduction and unsold inventory (Yadav et al., 2022). Information flow from the front-end retail demand to the back-end production team is evaluated to determine whether signaling is timely and stable or prone to distortions that generate excess output. The outcome of the VSM analysis identifies explicit waste categories, which is processing excess and waiting time that serve as the basis for deeper causal exploration (De Steur et al., 2016). By providing a granular view of the internal flow structure, VSM bridges the abstraction of SCOR with the operational realities that directly contribute to daily food waste.

3.3 Root-Cause Analysis

To understand the fundamental mechanisms that generate the inefficiencies identified in SCOR and VSM, the study conducts Root Cause Analysis (RCA) using a Fishbone (Ishikawa) diagram. This method categorizes potential causes into several domains (Parfitt et al., 2010). By mapping the interplay between these causes, the Fishbone diagram reveals that food waste is not driven by isolated operational errors but by a systemic convergence of planning inaccuracies, material instability, process variability, and environmental constraints (REALPE et al., 2024). This causal clarity provides the theoretical and practical foundation for formulating a Circular Supply Chain model that addresses waste not merely at the symptom level but at its root, structural and behavioral origins.

3.4 Discrete Event Simulation

The final methodological stage uses Discrete Event Simulation (DES) that based on Business Process Model and Notation to evaluate the performance of the proposed circular interventions in a controlled, model-based environment

(Fusto et al., 2025). This simulation approach is selected to map the sequence of activities, calculate the accumulation of waste costs, and evaluate the valorization system, rather than to model stochastic queuing behaviors. The simulation begins with constructing a baseline system, replicating the existing workflow and raw data identified in the VSM (Massaro & Galiano, 2020). The simulation process is carried out using the Bizagi modeler tool with a framework based on the Business Process Model and Notation. To ensure structural accuracy, this baseline model undergoes observational validation (conceptual validity), in which SME management confirmed that the mapped process accurately represents their actual sequence of operations. The redesigned circular scenario is then incorporated by modifying system parameters—specifically by introducing product recirculation loops and using waste materials to produce secondary products. This future state is simulated under theoretically ideal conditions to project the maximum potential impact of the proposed framework. Through this approach, the study quantifies how circular redesigns can minimize waste costs and demonstrates the conceptual feasibility of reducing food waste in the bakpia supply chain.

3.5 Flowchart Diagram

Figure 1 illustrates the structured and sequential research methodology, starting with the identification of problems related to food waste in the supply chain, followed by a literature review to build a theoretical foundation and identify research gaps.

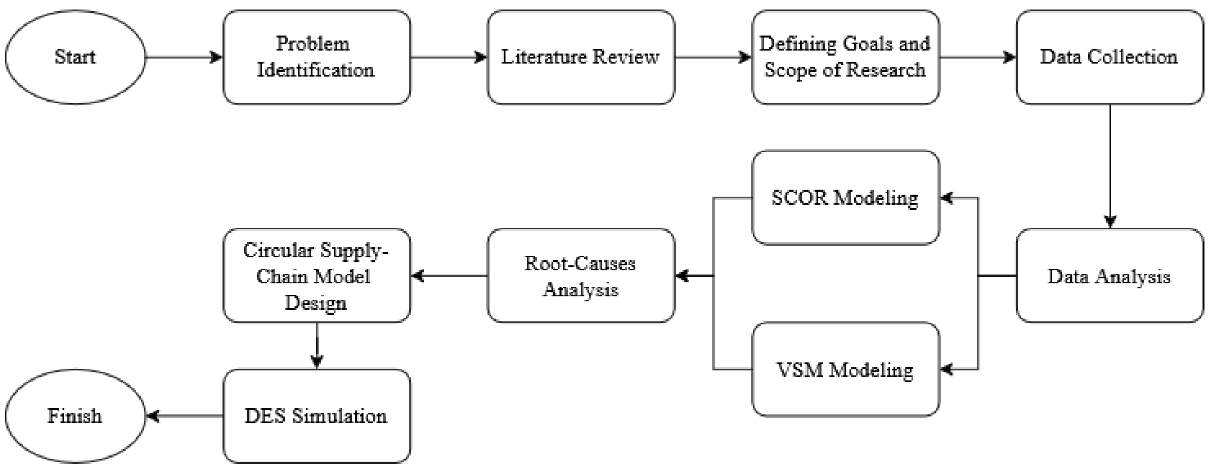

Figure 1. Research Flowchart

The researcher then established the objectives and scope of the study before entering the data collection phase of the operational processes studied. The obtained data then underwent a data analysis process, which formed the basis for two parallel modeling approaches, consisting of SCOR Modeling to analyze supply chain performance and structure at the macro level, and VSM Modeling to map the production process flow at the micro level and identify waste points. The findings from these two models provided input for RCA, which mapped the underlying factors that led to waste. The results of the root cause analysis were then used to design a Circular Supply Chain Model that offers improvement mechanisms based on circular principles. The final stage was a Business Process Simulation utilizing a BPMN framework via Bizagi Modeler. Rather than modeling stochastic queuing behavior, this simulation projected the proposed circular scenarios under theoretically ideal conditions to evaluate their potential impact on waste cost reduction and the workflow of the valorization system before the study was concluded.

4. Data Collection

In the data collection stage, this study focused on mapping the overall bakpia production process flow to understand the relationship between operational activities, material flow, and potential waste generation. The approach used was business process modeling based on Business Process Model and Notation (BPMN), because it can systematically describe the interactions between activities, actors, and decision points. BPMN was chosen to ensure that the analyzed process is not only limited to production activities, but also includes supporting stages such as ordering, procurement, and quality control that contribute to material waste.

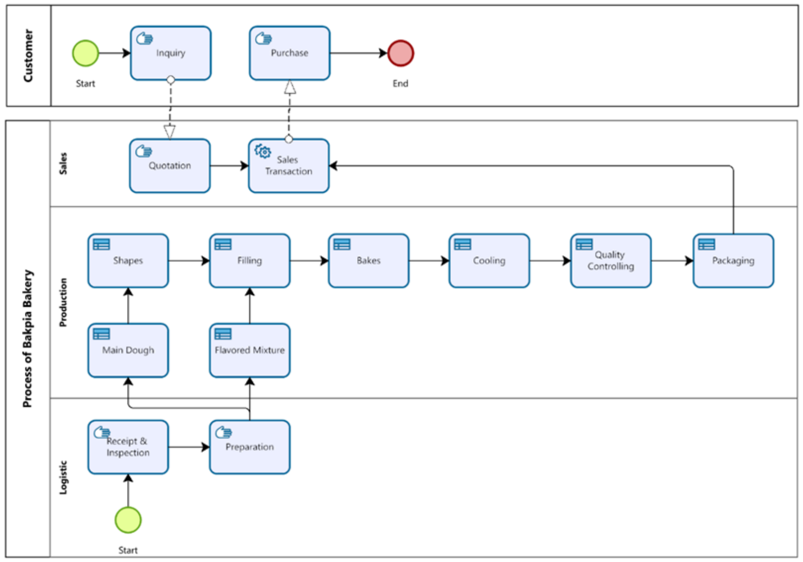

Figure 2. Initial BPMN

Figure 2 shows the bakpia production process, from raw material receipt, dough and filling preparation, shaping, baking, cooling, to packaging and sales. Each production stage is interconnected through material and information flows, so imbalances in one process can impact subsequent processes. This visualization helps identify critical points for food waste, particularly in the dough-making, filling, and baking processes, which are highly sensitive to variations in raw materials, time, and temperature.

Table 2. Food Waste Process Identification

Process	Input	Output	Food Waste
Dough	Flour, Water, Oil, Sugar	Main Dough	Dough excess
Filling	Mung Beans, Chocolate, Cheese, Milk Powder, Green Tea Powder, Cassava, Pineapple, Durian, Cappuccino	Flavor	Dough excess
Shaping	Main and Flavor Dough	Raw Bakpia	-
Baking	Raw Bakpia	Baked Bakpia	Burnt and Underbaked Bakpia
Cooling	Baked Bakpia	Cooled Bakpia	Broken Bakpia
Packaging	Finished Bakpia	Finished Product	Packaging Damage

Table 2 details each production stage, including the types of inputs, main outputs, and types of waste generated. This data shows that food waste in the bakpia industry includes not only damaged or unsalable products, but also includes leftover dough, excess filling, burnt or undercooked products, and mechanical damage during cooling and packaging. This table serves as a bridge between process mapping (BPMN) and quantitative material analysis, allowing for a direct link between process activities and the types of waste generated.

Table 3. Food Waste Number Identification

Material	Total Input (Kg/Day)	Utilized (Kg/Day)	Food Wasted (Kg/Day)
Flour	900	645	255
Sugar	210	150	60
Oil or Margarine	135	102	33
Mung Beans	320	240	80
Chocolate	95	70	25
Cheese	110	85	25
Cassava	180	135	45
Milk Powder	90	68	22
Cappucino Powder	45	28	17
Green Tea Powder	38	24	14
Durian	85	65	20
Pineapple	70	54	16

Table 3 illustrates the total use of primary raw materials in one production day of 75,000 bakpia, including the amount of utilized and wasted material. Utilization percentages below 80% for most materials indicate significant inefficiencies, particularly for powdered and flavored ingredients, which are susceptible to over-portioning and quality degradation. This quantitative information serves as an important basis for subsequent analysis, particularly in Root Cause Analysis and circular supply chain model design, as it provides a concrete picture of the potential for food waste reduction through improved planning, process control, and material reuse.

5. Results and Discussion

5.1 Numerical Results: SCOR Calculation

This sub-chapter presents the quantitative results of the bakpia supply chain performance evaluation using the SCOR approach, with a focus on the attributes of Asset Management Efficiency and Cost. The calculation was carried out by measuring the Material Utilization Index for each main raw material, which represents the ratio between materials that are effectively utilized and the total materials that enter the production system.

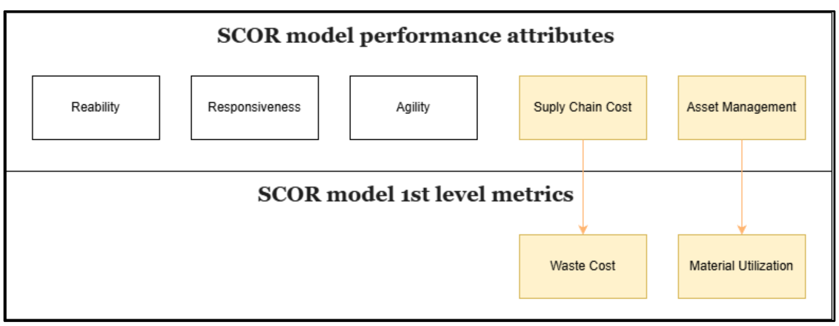

Figure 3. SCOR Attributes

Based on Figure 3, the both of indicator was chosen because it directly reflects the level of efficiency in the use of material assets and the amount of potential food waste that occurs in the daily production process. In addition, to provide an economic perspective, each quantity of material waste was converted into a cost unit based on the price of raw materials per kilogram, so that the financial impact of inefficiencies could be analyzed more comprehensively.

Table 4. Total Cost of Food Waste

Material	Material Utilized Rate	Waste (Kg)	Cost/Kg (IDR)	Total Cost (IDR)
Flour	0.716	255	9,000.00	2,295,000.00
Sugar	0.714	60	11,000.00	660,000.00
Oil or Margarine	0.755	33	15,000.00	495,000.00

Material	Material Utilized Rate	Waste (Kg)	Cost/Kg (IDR)	Total Cost (IDR)
Mung Beans	0.75	80	20,000.00	1,600,000.00
Chocolate	0.737	25	35,000.00	875,000.00
Cheese	0.773	25	35,000.00	875,000.00
Cassava	0.75	45	6,000.00	270,000.00
Milk Powder	0.755	22	25,000.00	550,000.00
Cappucino Powder	0.622	17	40,000.00	680,000.00
Green Tea Powder	0.631	14	35,000.00	490,000.00
Durian	0.765	20	30,000.00	600,000.00
Pineapple	0.771	16	18,000.00	288,000.00
Total		**612**		**9,678,000.00**

Table 4 shows that most raw materials have a Material Utilization Index below 0.78, indicating a relatively low level of material utilization and significant potential for food waste. Wheat flour recorded the highest amount of waste at 255 kg per day with a cost loss of IDR 2,295,000, making wheat flour the main contributor to the total waste cost. High-value ingredients such as chocolate, cheese, and beverage powder also showed low utilization rates with high waste costs despite their smaller physical volumes. In aggregate, total food waste reached 612 kg per day with a total cost loss of IDR 9,678,000. These findings confirm that the problem of food waste not only impacts operational efficiency but also creates a substantial economic burden, reinforcing the urgency of developing a circular supply chain model as a systemic solution.

5.2 Graphical Results: Value Mapping and Solving Process

The numerical calculations in Sub-chapter 5.1 show that the level of material utilization efficiency in the bakpia production system is still low, as reflected in the Material Utilization Index of less than 0.78 for all main raw materials and the high total cost of food waste. However, the SCOR results are aggregated and do not explain in detail how this waste is generated at the operational level. Therefore, the analysis continued using the VSM approach to visualize the flow of materials and information in the production process. VSM was used as a tool to bridge the macro findings of SCOR with the micro reality on the production floor, so that activities causing time wastage, process inefficiencies, and potential food waste could be identified in a more in-depth and structured manner (Figure 4).

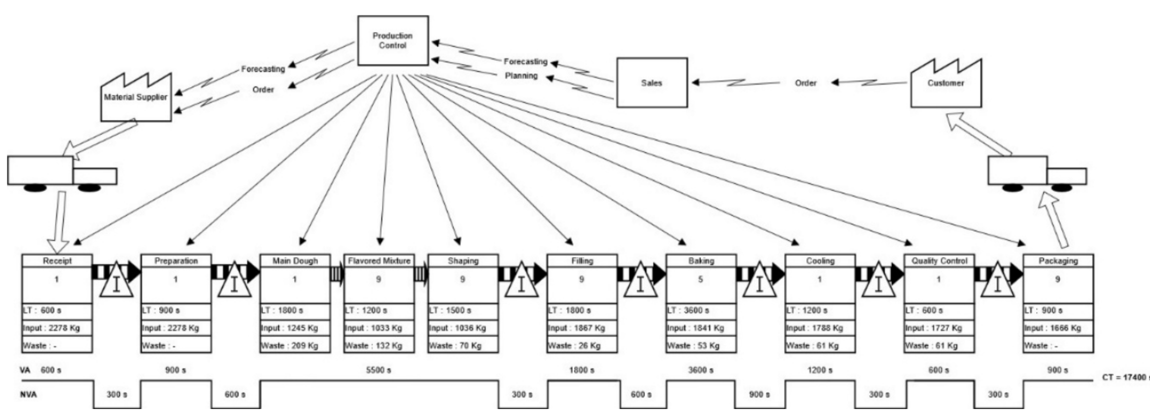

Figure 4. Current-State VSM

Figure 4 shows the entire bakpia production process flow, starting from the receipt of raw materials, preparation of the main dough and flavored dough, shaping, filling, baking, cooling, and packaging. From this map, the production flow is generally linear, but there are several critical points that indicate accumulated waiting times and unplanned additional activities. The lack of synchronization between the flow of demand information and the flow of materials causes excessive batching at the preparation and filling stages, which ultimately leads to overproduction and an increased risk of unsold products. This condition is directly correlated with SCOR's findings in Sub-section 5.1, where low material utilization efficiency is not only caused by defects in the final product, but also by imbalances in the process flow that occur from the early stages of production.

To quantify the contribution of each activity to value creation and waste, the activities identified in the VSM are then classified into Value Added (VA), Business Value Added (BVA), and Non-Value Added (NVA) categories. This classification aims to distinguish activities that directly increase the value of the product in the eyes of customers, supporting activities that are necessary for operational continuity, and activities that do not add value and have the potential to be a major source of waste of time and materials. With this approach, the analysis not only stops at identifying the location of waste but is also able to measure the proportion of time and activities that are structurally inefficient.

Table 5. Value Added Analysis

Stages	Activity	Time (s)	Category
Receipt Material	Receiving raw material	400	BVA
	Inspection of material quality	200	BVA
	Waiting for ingredient preparation	300	NVA
Preparation	Measuring and preparing raw material	900	BVA
	Waiting for the ingredients to be doughing	600	NVA
Main Dough	Kneading the main dough	1800	VA
Flavored Mixture	Extracts of flavor bakery	1200	VA
Shaping	Forming the dough	1500	VA
	Waiting for filling	300	NVA
Filling	Manual filling	1800	VA
	Waiting for baking	600	NVA
Baking	Baking the dough	3600	VA
	Waiting for cooling	900	NVA
Cooling	Cooling	1200	VA
	Waiting for Quality Control	300	NVA
Quality Control	Final inspection	600	BVA
	Waiting for Packaging	300	NVA
Packaging	Manual packaging	900	BVA
Total Time		**17400 s**	

Table 5 shows that although main activities such as kneading, shaping, filling, baking, and cooling are classified as value-added activities, the proportion of Non-Value Added activities is found in the overall process flow that includes waiting time between processes. The dominance of NVA activities not only extends production lead time but also increases product exposure to quality degradation risks, such as dough drying, filling leakage, and burnt or cracked products. These findings provide a strong operational explanation for the low Material Utilization Index in Sub-section 5.1, where material inefficiency is a direct consequence of NVA activities accumulated throughout the production process.

Although VSM and VA–NVA–BVA classification have successfully identified the location and form of waste, neither approach fully explains why NVA activities and food waste continue to occur repeatedly. Therefore, the analysis was continued with RCA using a Fishbone diagram to explore the underlying factors causing process inefficiencies and material waste. This approach was used to ensure that the solutions designed in the next stage not only address the symptoms but also target the systemic root causes of the problem.

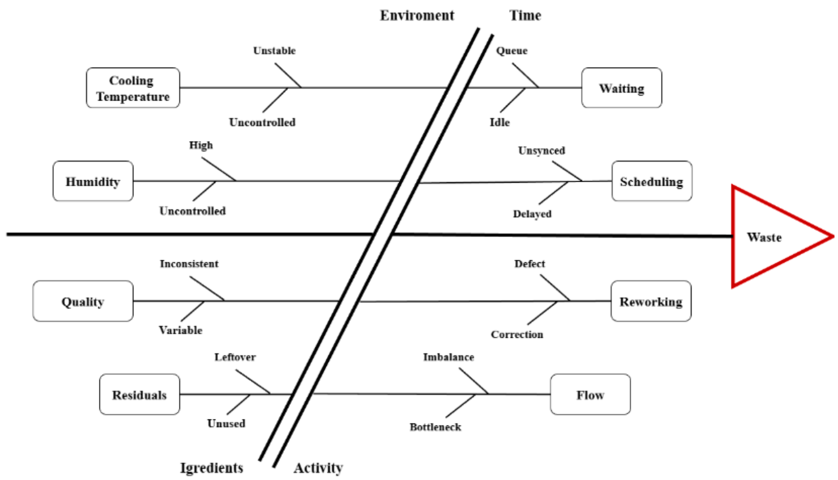

Figure 5. Fishbones Diagram

Figure 5 shows that food waste in bakpia production is the result of complex interactions between various factors, including work methods, materials, machinery, the environment, and time management. Production planning factors that are not based on actual demand, variations in raw material measurements due to manual processes, limited temperature and time control during the baking and cooling stages, and the absence of standards for the utilization of leftover materials emerge as the dominant causes. These findings confirm that food waste is not merely the result of individual operational errors, but rather a reflection of structural weaknesses in the process planning and control system, which is consistent with the pattern of material inefficiency identified through the previous SCOR analysis.

The results of the Root Cause Analysis show that the main sources of waste come from waiting time, rework, unnecessary additional processes, uncontrolled environmental conditions, and unused material potential. Each cause is linked to a solution that leads to the principles of a circular supply chain, such as improving capacity balance, standardizing work methods, controlling the production environment, and implementing mechanisms for reusing and recycling waste materials. Thus, the results in this sub-chapter not only serve as a diagnosis but also as a logical and empirical basis for the proposed improvements that will be discussed in detail in Sub-chapter 5.3.

5.3 Proposed Improvements: Circular Production and Supply Chain Mechanism

Based on the results of an in-depth analysis in Sub-chapter 5.2, it can be concluded that food waste in the bakpia production system is mainly triggered by the dominance of Non-Value Added activities, imbalances in material and information flows, and the absence of mechanisms for utilizing residual materials. These findings confirm that partial improvements will not be sufficient to significantly reduce waste levels. Therefore, this sub-chapter proposes a series of integrated improvements designed using the principles of a circular supply chain, with the main objective of closing the efficiency gaps identified through Value Stream Mapping and Root Cause Analysis. The improvement approach focuses on redesigning process flows, reducing NVA activities, and integrating material return flows into the production system, so that material waste no longer ends up as waste but is reused as a source of value.

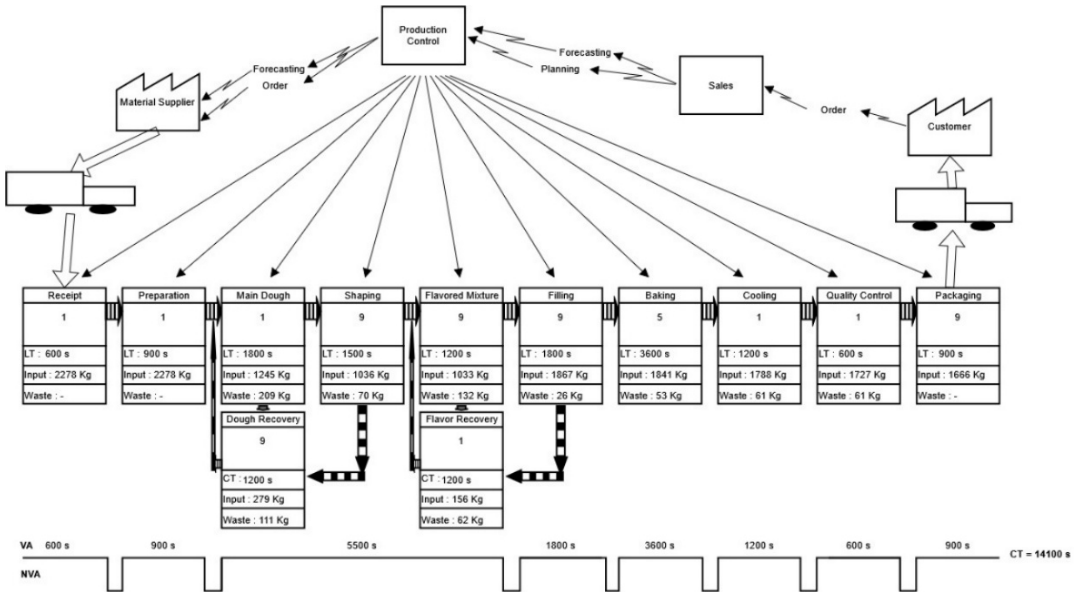

Figure 6. Future State VSM

Figure 6 illustrates the future state of the bakpia production system after implementing circular supply chain-based improvements. Compared to the initial VSM, this map shows a more streamlined process flow with fewer waiting times and additional activities that do not add value. Synchronization between the flow of demand information and the flow of materials is strengthened to prevent overproduction and excessive batching, while a mechanism for reusing leftover materials is integrated into the main production flow. These changes directly target previously identified sources of waste, thereby improving the Material Utilization Index and reducing the accumulation of food waste, as shown by the SCOR results in Sub-section 5.1.

Although the proposed VSM has conceptually described the future process flow, a more detailed representation of the process is needed to explain the interactions between activities, actors, and decision points operationally. Therefore, the proposed improvements were then translated into a Business Process Model and Notation model. BPMN is used to ensure that changes to the process flow are not only conceptually logical, but also practically implementable in the bakpia production environment. This model provides clarity regarding the sequence of activities, actor responsibilities, and decision-making mechanisms related to the reuse of waste materials and quality control.

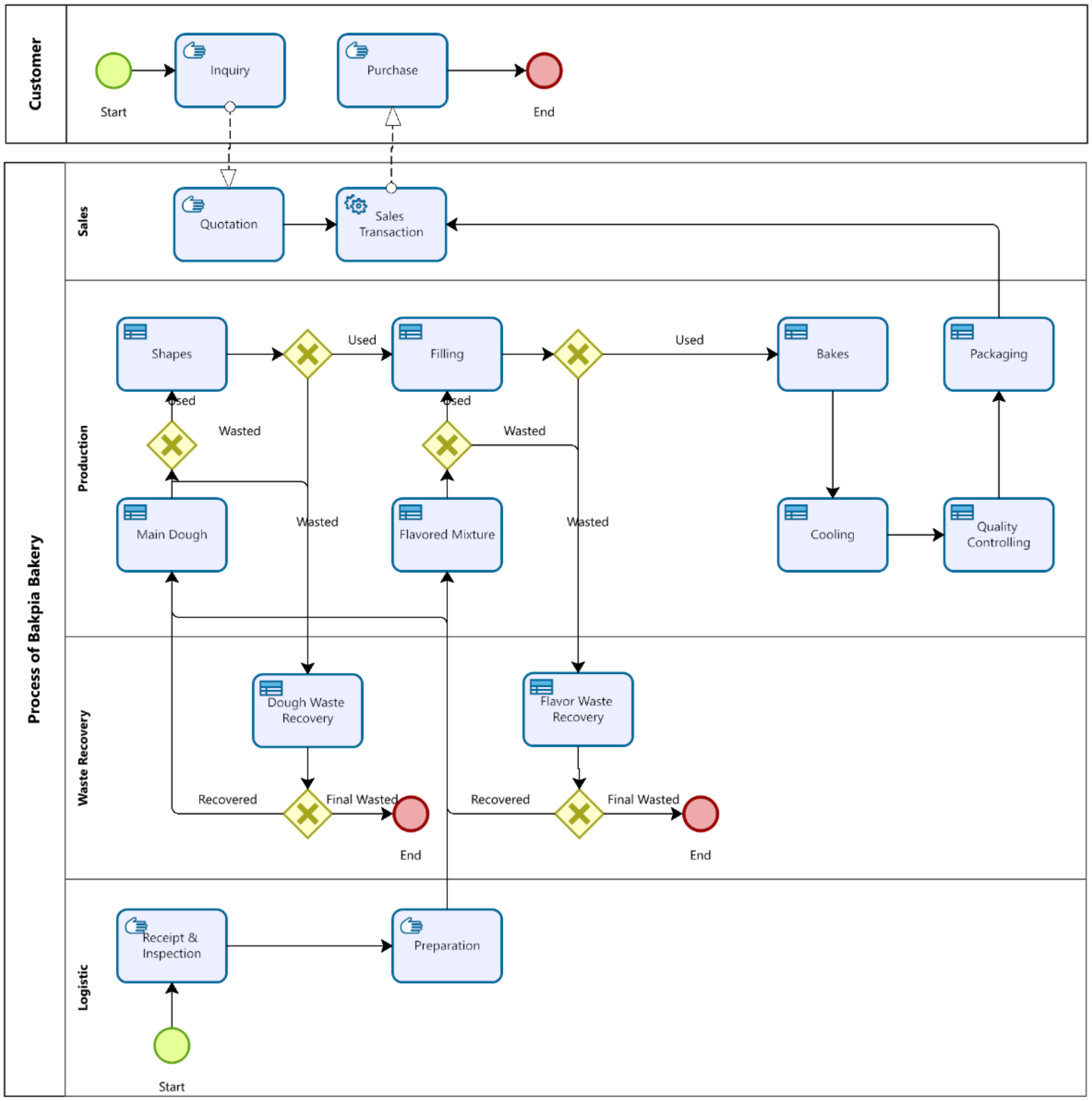

Figure 7. Future State BPMN

Figure 7 shows the restructured bakpia production process flow, which explicitly incorporates a circular supply chain mechanism. In this model, residual materials from the preparation and production processes are not immediately discarded, but are directed to reuse or processing into secondary products. In addition, quality control and production decision points are placed earlier in the process flow to prevent product defects from spreading to the next stage. This BPMN structure emphasizes that improvements are not only focused on reducing waste but also on increasing process control and production flow stability. Thus, the proposed BPMN serves as an operational implementation blueprint for the proposed VSM, as well as a basis for the quantitative projection stage.

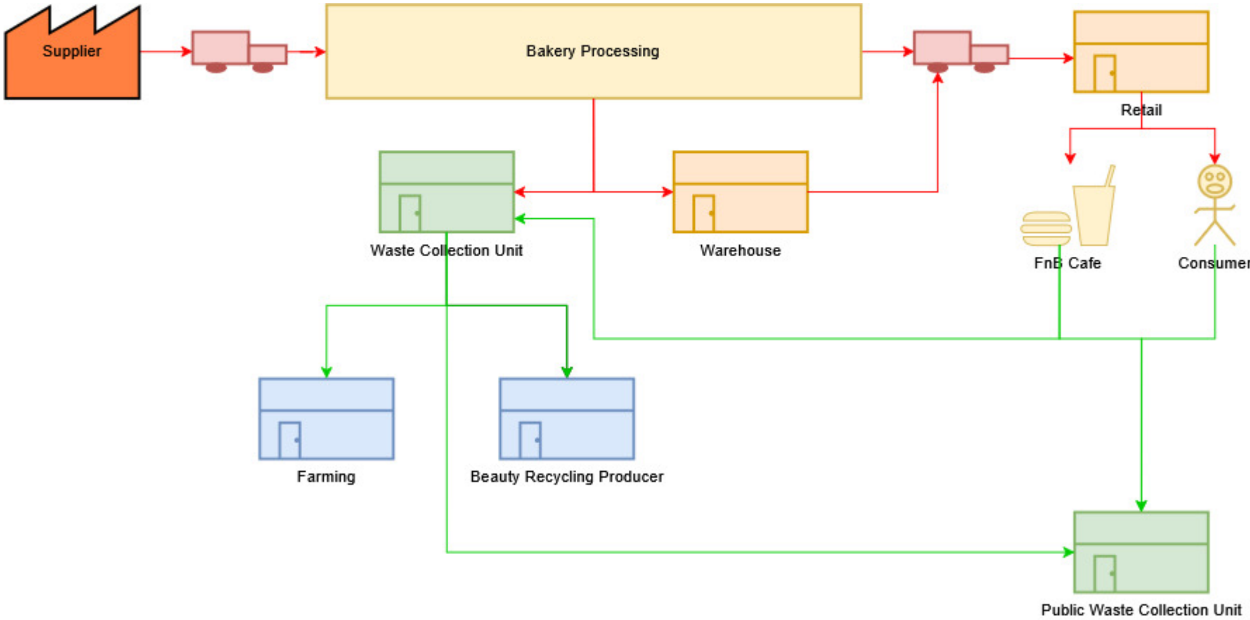

Figure 8. RPD of Circular Supply Chain Model

Figure 8 represents a proposed circular supply chain system for bakpia bakery production in Yogyakarta, where the red lines indicate the forward supply chain flow from suppliers through bakpia processing, warehousing, retail, and finally to consumers, ensuring that the product maintains its economic and consumption value until the point of use. Once bakpia products and by-products lose their primary value and become waste, the green lines illustrate the waste supply chain flow, which manages three specific types of bakery waste, consist of wet dough waste generated during mixing and forming, flavoring residue dough waste from filling and formulation adjustments, and dry post-baking dough waste originating from defects, unsold products, or quality rejection. Instead of being disposed of linearly, these waste streams are collected and redistributed to recovery pathways such as farming and non-food recycling industries, while non-recoverable residues are handled by public waste collection units, positioning this system as an escalation from a limited circular production approach to a fully integrated circular supply chain that reconnects production, consumption, and cross-industry valorization.

5.4 Projection

The proposed BPMN diagram shows the restructured bakpia production process flow, which explicitly incorporates a circular supply chain mechanism. In this model, residual materials from the preparation and production processes are not immediately discarded, but are directed to reuse or processing into secondary products. In addition, quality control and production decision points are placed earlier in the process flow to prevent product defects from spreading to the next stage. This BPMN structure emphasizes that improvements are not only focused on reducing waste but also on increasing process control and production flow stability. Thus, the proposed BPMN serves as an operational implementation blueprint for the proposed VSM, as well as a basis for the quantitative projection stage.

Table 1. Future State Prediction

Stages	Type	Total Time (s)	Waiting Time (s)	Food Waste Cost (IDR)
Receipt & Inspection	Task	600	0	
Preparation	Task	900	0	
Main Dough	Task	1800	0	
Shapes	Task	1500	0	1,295,000.00
Flavored Mixture	Task	1200	0	
Filling	Task	1800	0	1,680,888.00
Bakes	Task	3600	0	1,232,250.00
Cooling	Task	1200	0	1,418,250.00
Quality Controlling	Task	600	0	1,418,250.00

Stages	Type	Total Time (s)	Waiting Time (s)	Food Waste Cost (IDR)
Packaging	Task	900	0	
Total		**14100**	**0**	**7,044,638.00**

Table 6 shows that after implementing the circular supply chain model, all stages of production can be carried out without waiting time, indicating that the imbalance in the process flow previously identified in the initial VSM has been successfully overcome. The total production process time was recorded at 179 minutes, with a more stable distribution of time at each stage, reflecting a more controlled and coordinated workflow. From an economic perspective, the total cost of food waste was recorded at IDR 7,044,638, which shows a significant decrease compared to the initial conditions as reported in the SCOR results in Sub-chapter 5.1. This cost reduction mainly came from reduced waste in key stages such as dough preparation, filling, baking, and cooling, which were previously the biggest contributors to material waste. These findings validate that the integration of process improvements and systematic mechanisms for reusing residual materials can increase operational efficiency while reducing the economic impact of food waste, thereby supporting the feasibility of implementing a circular supply chain model in the bakpia industry at the SME level.

6. Conclusion

This study aims to develop and evaluate a circular supply chain model that can significantly reduce food waste in the SME-scale bakery industry, with a case study on bakpia production in Yogyakarta. Through the integration of the SCOR, VSM, RCA, and DES approaches as complementary analytical frameworks, this study successfully identified the sources, patterns, and main causes of material waste in the bakpia production system. The SCOR analysis results show that the level of material utilization efficiency is still low, with a Material Utilization Index below 0.78 for all main raw materials and significant total food waste costs, thus confirming the urgency of structural intervention in supply chain management. Further analysis using VSM revealed that material waste not only occurs in the final product but is formed gradually due to the dominance of Non-Value Added activities, imbalances in material and information flows, and weak process control at critical stages such as dough preparation, filling, baking, and cooling. Root Cause Analysis clarifies that food waste is the result of systemic factors, including production planning that is not based on actual demand, manual process variations, limitations in production environment control, and the absence of mechanisms for reusing residual materials. These findings confirm that conventional linear approaches are inadequate for addressing food waste in short shelf-life food products.

In response to these findings, this study proposes a circular supply chain model that integrates process flow redesign, reduction of Non-Value Added activities, and the application of reuse and recycle mechanisms for residual materials into the production system. The proposed model is visualized through future state Value Stream Mapping and clarified operationally using BPMN, providing a clear and applicable implementation framework for SME actors. Quantitative projection shows that the application of this model can eliminate waiting time between processes, stabilize production flow, and significantly reduce total food waste costs compared to the initial conditions. These results prove that the circular supply chain approach is not only conceptually feasible but also operationally and economically effective in the context of small-scale bakery industries. The main contribution of this study lies in the development of an integrated circular supply chain analysis and improvement framework based on SME field data, which has been relatively rarely discussed in previous literature. By combining SCOR, VSM, RCA, and simulation-based evaluation, this study provides a structured, measurable, and replicable approach for food products with a short shelf life. Practically, the results of this study can serve as a guide for bakery industry players and local policymakers in designing sustainable food waste reduction strategies. For further research, it is recommended that this model be tested on different scales and types of food products and combined with historical data-based demand analysis to improve the accuracy of production planning and long-term sustainability impacts.

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Muhamad Salimudin Paripurna is an undergraduate student of Industrial Engineering at the Faculty of Industrial Technology, Islamic University of Indonesia. His academic interests span product design, computer simulation, supply chain optimization, and sustainable manufacturing systems. Throughout his studies, he has actively participated in various competitions and contributed to national-level projects, including MSMEs economic empowerment and sustainable product innovation. In this research, he focuses on integrating SCOR modeling, value stream mapping, and discrete event simulation to reduce food waste in the supply chain of a local bakery, aiming to provide a practical and impactful approach for short shelf-life food products.

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