JRSSEM, Vol. 6, No. 2, September 2026
pp. 1239-1249
E-ISSN: 2807 – 6311
DOI: 10.59141/jrssem.v6i2.1737

Simulation Model of a Waste Loop Based on The Closed Loop Logistics Method for Food Waste Management in The Free Nutritious Meal (MBG) Program in Bandung City

Abelio Try Kanda GM, Irfaan Ardhi Nurfadhiilah, Yasmina Frahnaz Nasywa, Muhamad Rafi Arban, Noneng Nurjanah*
Universitas Logistik dan Bisnis Internasional, Indonesia
Email: noneng.nurjanah@ulbi.ac.id*

Keywords:
Closed Loop Logistics; Food Waste; System Dynamics; Hermetia Illucens; Circular Economy.

Abstract

Food waste generated by Indonesia's Free Nutritious Meal (*Makan Bergizi Gratis* [MBG]) Program presents an environmental and logistical challenge, particularly in urban areas with limited waste-processing capacity. This study aimed to formulate a Waste Loop model based on closed-loop logistics for managing food waste generated by Nutrition Fulfillment Service Units (*Satuan Pelayanan Pemenuhan Gizi* [SPPGs]) in Bandung City. A qualitative approach supported by empirical measurements and a field perception survey was employed. Organic waste generation was measured over five consecutive working days at three purposively selected SPPGs. Questionnaires were administered to 77 operational personnel, while interviews and observations were conducted to identify workflow processes, infrastructure constraints, and institutional readiness.The three SPPGs generated 940.07 kg of organic waste, with an average generation rate of 188.01 kg per day. Plate waste accounted for 64.92% of total organic waste, while food preparation residues accounted for 35.08%; vegetables represented the largest waste component. Respondents identified limited processing facilities and the absence of reverse logistics procedures as major barriers, despite strong support for circular waste management practices. The resulting causal loop diagram connected organic waste management with black soldier fly larvae bioconversion through two reinforcing pathways: vegetable cultivation using larval residue and poultry production using larval biomass. The proposed model provides a conceptual basis for reducing landfill disposal, recovering resource value, and strengthening circular food supply chain resilience within the MBG Program.

INTRODUCTION

The issue of food waste has developed into an urgent environmental and economic challenge in urban areas of Indonesia, particularly in Bandung City. Food waste accounts for more than 40% of total municipal waste generation (BPS, 2020), while the city's waste management capacity can accommodate only around 160 tons per day out of a total waste generation of approximately 1,500 tons per day (DLH Kota Bandung, 2025). This issue is further complicated by the implementation of the Free Nutritious Meal (*Program Makan Bergizi Gratis* [MBG]) Program, which is estimated to generate up to 3,500 tons of food waste per day nationally (KLHK, 2025). In Bandung City, 242 Nutrition Fulfillment Service Units (*Satuan Pelayanan Pemenuhan Gizi* [SPPGs]) registered with the National Nutrition Agency (Nasional, 2026) serve as the primary nodes for daily food distribution (Kehutanan, 2025) . However, most SPPGs still rely on direct disposal to Temporary Waste Disposal Sites (*Tempat Penampungan Sementara* [TPS]) or Final Processing Sites (*Tempat Pemrosesan Akhir* [TPA]) without an integrated reuse or recovery scheme (Bandung, 2020) .

The closed-loop logistics approach has demonstrated potential for maximizing product value through the reuse of waste materials within supply chains (Simonetto et al., 2022). As described by (Morana & Seuring, 2007) and (Rogers & Tibben-Lembke, 2001) , closed-loop logistics integrates forward logistics and reverse logistics to minimize waste disposal and return residual materials into productive cycles (Annita et al., 2023). Furthermore, (Blomsma & Brennan, 2017) emphasized that the circular economy framework aims to replace inefficient linear production systems with closed-loop systems in which waste is minimized or transformed into valuable inputs (Lybaws et al., 2025) . Although closed-loop logistics has been successfully applied in industrial sectors, its implementation for fresh food products (perishable food) presents significant challenges related to quality preservation (Chaerul & Zatadini, 2020) . Literature on fresh-product supply chains highlights that maintaining product quality and extending the shelf life of fresh produce, dairy products, and meat require precise time management and strict operational control (Simonetto et al., 2022).

The food-waste hierarchy developed by (Papargyropoulou et al., 2014) places prevention and redistribution above recycling, recovery, and disposal because preventing surplus food generally provides greater environmental and social benefits. Nevertheless, not all food waste can be prevented, particularly in large-scale food-service operations where preparation residues and unavoidable leftovers are continuously generated (Kehutanan, 2025) . For these residual waste streams, circular recovery is preferable to landfill disposal. Papargyropoulou et al. demonstrated that a systematic hierarchy can support decision-making by distinguishing edible surplus from unavoidable waste and assigning each stream to an appropriate treatment pathway. Subsequent studies have also emphasized that reducing plate waste in institutional food services requires coordinated interventions involving menu planning, portion control, employee training, and beneficiary awareness rather than relying solely on end-of-process disposal solutions (Lins et al., 2024).

Closed-loop logistics provides an appropriate framework for integrating waste prevention and recovery strategies. Unlike conventional forward logistics, which ends when meals are delivered to beneficiaries, closed-loop logistics connects forward material flows with reverse flows that collect, sort, process, and return residual materials to productive use. Rogers and Tibben-Lembke (2001) defined reverse logistics as the movement of goods or materials from their typical final destination to recover value or ensure proper disposal. In the food sector, however, reverse logistics processes are more complex because organic materials are perishable, heterogeneous, biologically unstable, and highly sensitive to delays and contamination.

Therefore, an effective closed-loop system for SPPGs must coordinate waste segregation, temporary storage, collection frequency, processing capacity, food safety requirements, and redistribution of recovered outputs. These interconnected activities cannot be adequately evaluated through static waste-volume calculations alone.

One promising recovery technology is the bioconversion of organic waste using black soldier fly larvae (BSFL), scientifically known as Hermetia illucens. Diener et al. (2009) found that BSFL can convert organic materials into protein-rich larval biomass, creating opportunities to partially replace conventional feed ingredients. (Čičková et al., 2015) similarly demonstrated the ability of BSFL to process organic waste, while subsequent studies confirmed that conversion performance depends significantly on substrate composition, moisture content, feeding rate, and environmental conditions. The resulting larvae can potentially be processed into animal-feed ingredients, while the residual material, commonly referred to as frass or larval residue, may be utilized as a soil amendment after appropriate treatment and quality assessment. Thus, BSFL bioconversion enables value recovery through two interconnected outputs; however, its operational and biological performance should not be assumed to be consistent across all waste streams.

Previous research has provided a strong scientific foundation for food-waste prevention, reverse logistics, and BSFL processing; however, these research areas remain insufficiently integrated within the context of public nutrition programs. Studies on school and institutional meal services have generally focused on measuring plate waste, evaluating menu acceptability, optimizing portion sizes, and modifying consumer behavior. Conversely, BSFL studies have primarily examined larval growth performance, substrate suitability, waste-reduction efficiency, biomass composition, and fertilizer potential under laboratory or small-scale operational conditions. Research on closed-loop supply chains has largely focused on manufacturing, retail, and commercial food networks rather than decentralized government meal-service units. Although these studies demonstrate the value of individual interventions, they do not adequately explain how daily SPPG operations, waste accumulation, reverse collection, bioconversion capacity, agricultural outputs, and food-supply requirements interact dynamically over time.

Accordingly, an important research gap concerns the lack of an empirically grounded dynamic model that connects food-waste generation within the MBG distribution system with circular resource recovery at the SPPG level. Existing studies rarely integrate measured kitchen and plate waste, stakeholder readiness, reverse logistics requirements, BSFL processing, vegetable cultivation, and poultry production within a single feedback structure. Addressing this gap is essential because interventions introduced without considering system capacity may merely shift existing problems. For example, collecting larger volumes of organic waste without adequate sorting or bioconversion capacity may create additional risks related to storage, odor, contamination, and transportation. System dynamics is therefore relevant because it captures causal relationships, delays, feedback loops, and capacity constraints that influence system behavior. A causal loop diagram can identify reinforcing and balancing mechanisms before the model is further developed into a quantified stock-and-flow simulation for scenario analysis.

This study aimed to formulate and examine a Waste Loop model based on closed-loop logistics for managing food waste generated by the MBG Program in Bandung City. Its novelty lies in integrating empirical waste measurements from three SPPGs, perceptions of 77 operational personnel, reverse logistics processes, and BSFL bioconversion into two proposed circular pathways: returning processed residues to vegetable cultivation and utilizing larval biomass in poultry and egg production. The research objectives were to characterize the volume and composition of SPPG organic waste, assess institutional readiness and operational barriers, map causal relationships among key system variables, and develop a dynamic framework for returning recovered resources to the SPPG food supply chain. Theoretically, this study extends closed-loop logistics applications into the public nutrition service context; methodologically, it connects field evidence with system dynamics modeling; and practically, it provides SPPG managers, BGN, local governments, waste processors, and agricultural partners with a decision-support framework for reducing landfill disposal, strengthening local resource circulation, and improving the environmental sustainability of the MBG Program.

METHOD

Research Design

This study employed a qualitative approach supported by empirical waste generation measurements and field perception surveys (Sterman, 2000; Syafril, 2024). System modeling was conducted using a System Dynamics approach to map causal relationships among variables within the SPPG food-waste management system. The qualitative framework was applied to develop the Causal Loop Diagram (CLD) structure of the proposed closed-loop logistics model.

Population and Sample

This study was conducted at three main SPPG locations in the City of Bandung, namely SPPG Sarijadi 1, SPPG Sarijadi 3, and SPPG Gerlong 2 (DT) over five consecutive SPPG working days. Location selection was performed using purposive sampling based on the criteria of SPPGs that actively produce and distribute food under the MBG Program and regularly generate organic waste. Survey respondents comprised N=77 operational personnel directly involved in the SPPG production and distribution chain, including leadership elements (Head of SPPG), Nutrition Supervisors, Financial Supervisors, Cooks, Food Ingredient Preparation Personnel, Portioning Personnel, Dishwashing Personnel, Cleaning Personnel, Security Personnel, and Field Assistants (Pretest SPPG, 2026).

Data Analysis Techniques

The data in this study consists of primary data obtained through the measurement of food waste volume at SPPGs within the MBG Program. Data collection was carried out using three main techniques:

1. Physical Waste Generation Measurement: Direct volume and weight (kg) measurements of raw material residues (production waste) and leftover food (plate waste) were conducted over 5 consecutive working days across 4 main menu categories: carbohydrates, proteins, vegetables, and fruits (Data Sampah SPPG, 2026).
2. Field Perception Survey: Distribution of questionnaires using a 5 point Likert scale (Strongly Disagree/STS=1 to Strongly Agree/SS=5) to evaluate the operational staff's perceptions regarding food waste trends, facility constraints, reverse logistics readiness, and the potential of the Waste Loop scheme.
3. In depth Interviews and Observation: Qualitative interviews were conducted with SPPG managers to identify operational workflows, standard waste handling procedures, and

institutional barriers.

Research Location and Time

This study was conducted in the City of Bandung as the data collection site, considering that the research data sources originated from 3 SPPGs located in the area (SPPG 1, SPPG 2, and SPPG 3). The implementation period of the research spanned from June to September 2026

RESULTS AND DISCUSSION

Food Waste Generation Characteristics as the Model Database

Empirical measurements of organic waste generation over five working days across three sample SPPGs yield a detailed overview of organic waste accumulation, separating raw material preparation residues (kitchen waste) from unconsumed food left by beneficiaries (plate waste). The summary of waste generation from all three SPPGs is presented in Table 1.

Table 1. Recapitulation of Organic Waste Generation across 3 SPPGs (5 Working Days)

SPPG Name	Raw Material Residues (Kg)	Leftover Food (Kg)	Total Organic Waste (Kg)	Daily Average (Kg/Day)
SPPG 1	76.80	222.85	299.65	59.93
SPPG 2	191.80	143.55	335.35	67.07
SPPG 3	61.12	243.95	305.07	61.01
Total Accumulation	329.72	610.35	940.07	188.01

The weighing results indicate that within a period of 5 operational days, the total organic waste generated by the three SPPGs reached 940.07 kg, with an average daily accumulation of 188.01 kg (Data Sampah SPPG, 2026). Leftover food from consumers (plate waste) dominated the total generation, accounting for a proportion of 64.92% (610.35 kg), while raw material preparation residues contributed 35.08% (329.72 kg). This aligns with the findings of Papargyropoulou et al. (2014) and (Kim et al., 2021) , which indicate that in mass catering systems, the final consumption node is often the largest contributor of organic waste. To understand the structure of the discarded materials, a breakdown analysis was conducted across four main food menu components (Carbohydrates, Protein, Vegetables, and Fruits). The waste composition data based on the type of food ingredient is presented in Table 2.

Table 2. Composition of Organic Waste Generation Based on Food Components

Food Component	Raw Material Residues (Kg)	Leftover Food (Kg)	Total Waste (Kg)	Percentage of Total (%)
Carbohydrates	0.00	233.25	233.25	24.81%
Protein	55.25	125.91	181.16	19.27%
Vegetables	141.87	213.45	355.32	37.80%
Fruits	132.60	37.74	170.34	18.12%
Total Accumulation	329.72	610.35	940.07	100.00%

A deeper analysis reveals distinct behavioral dynamics between kitchen waste and plate waste. In raw material residues, vegetables (141.87 kg) and fruits (132.60 kg) are the dominant contributors due to the high volume of inedible parts discarded during initial cleaning (preprocessing). Conversely, in leftover food (plate waste), carbohydrates (233.25 kg) and vegetables (213.45 kg) recorded the highest figures. The high amount of discarded carbohydrates with zero raw material residues indicates that the rice cooking process in the kitchen is efficient, yet a mismatch exists between the standardized carbohydrate portion sizes served and the acceptance capacity of beneficiaries. As reviewed by (Ravandi et al., 2024) , uniform portions without adjustments for individuals' actual needs are frequently the primary trigger for high plate waste in school food programs.

Stakeholder Perception and Reverse Logistics Readiness Analysis

A survey involving N=77 SPPG operational staff respondents confirms internal perceptions regarding current waste management conditions as well as the acceptance level of the closed-loop logistics scheme (Pretest SPPG, 2026). The evaluation results of the questionnaire are presented in Table 3.

Table 3. Frequency Distribution of SPPG Operational Staff Perceptions (N=77)

Survey Statement Indicator	STS (%)	TS (%)	S (%)	SS (%)	Dominant Category
Food waste management at the SPPG is currently not optimal	1.3	48.1	39.0	11.6	Not Optimal
Lack of facilities is the primary obstacle in waste management	0.0	32.5	39.0	28.5	High Facility Obstacles
Absence of understanding/SOP regarding reverse logistics	0.0	22.1	55.8	22.1	High Need for SOP
Integration of food waste with a reverse logistics system is highly needed	0.0	1.3	44.2	54.5	Highly Supportive (98.7%)
Implementation of the Waste Loop can increase management efficiency	0.0	7.8	54.5	37.7	Strongly Agree (92.2%)

Survey data indicates that the primary obstacles to waste management at SPPGs are structural and operational in nature (Pretest SPPG, 2026). In line with research by (Walker et al., 2019) regarding supply chain management barriers in developing countries, physical facility limitations (67.5% agreed) and the absence of reverse logistics Standard Operating Procedures (SOPs) (77.9% agreed) serve as the primary institutional impediments to implementing independent waste management. Nevertheless, there is remarkably high institutional support for the Waste Loop concept: 98.7% of respondents agreed with integrating a reverse logistics system, and 100% of respondents agreed that this circular model would reduce the burden of waste accumulation at municipal TPSs.

Dynamic Model Formulation of the Waste Loop (Causal Loop Diagram)

Based on the synthesis of empirical waste generation data and the operational perception map, a dynamic modeling framework based on the Waste Loop Causal Loop Diagram (CLD) was formulated (Syafril, 2024). This model integrates the reverse chain of waste processing using Black Soldier Fly (BSF / Hermetia illucens) maggot bioconversion (Čičková et al., 2015; Kim et al., 2021). The structure of inter-variable relationships within the system is modeled through two reinforcing feedback loops (reinforcing loops R1 and R2) like in Figure 1.

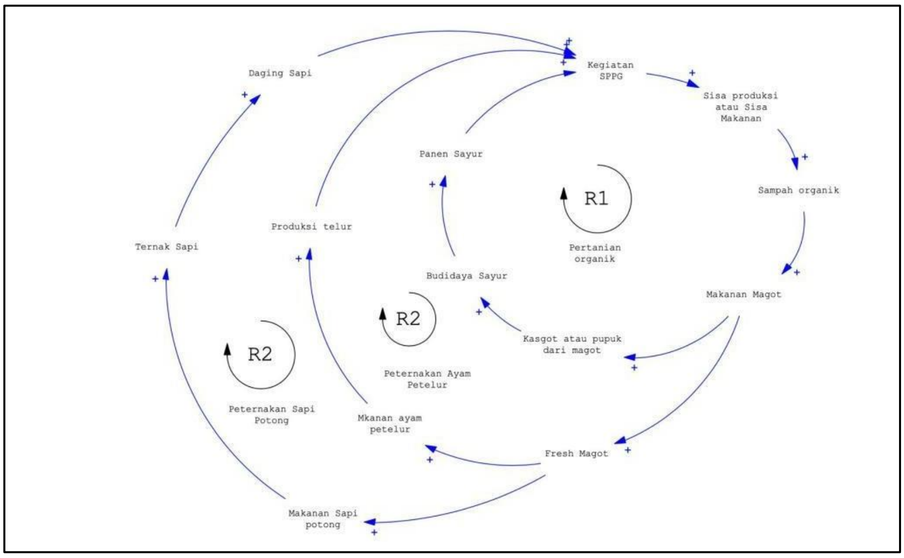

Figure 1. Dynamic Model of the Waste Loop

The causality flow structure of the Waste Loop system encompasses the following components:

1. Daily operations at the SPPG Activities node directly generate Production Waste and Leftover Food. The accumulation of this waste flows to become Organic Waste. The sorted organic waste is then allocated as the primary feed input (Maggot Feed) for BSF larvae bioconversion facilities.
2. Reinforcing Loop 1 (Loop R1 - Vegetable Cultivation Cycle): The organic waste digestion process by BSF larvae produces nutrient-rich organic residue called Kasgot (maggot compost fertilizer) (Zurbrűgg et al., 2018) . Kasgot is distributed to urban farming units to support Vegetable Cultivation activities. Increased cultivation efficiency yields a higher volume of Vegetable Harvest. The Vegetable Harvest is supplied back as a fresh raw material supply for menu provisions in SPPG Activities. This closed cycle forms Loop R1 (Reinforcing Loop 1), where the increase in SPPG activity progressively enhances the supply of organic fertilizer and local vegetable harvests.
3. Reinforcing Loop 2 (Loop R2 - Poultry and Egg Farming Cycle): In addition to producing kasgot, waste bioconversion yields live larval biomass (Fresh Maggot) with high protein content reaching 40–60% (Gligorescu et al., 2019; "Reassuring Insect Farming Ensures Waste Minimization and Future Food Security," 2025) Fresh Maggot is processed and formulated into high-quality Chicken Feed substitution. The use of maggot feed increases the rate of Egg and Chicken Production in local partnership farms. The supply of poultry products is sent back to meet protein requirements in SPPG Activities. This cycle forms Loop R2 (Reinforcing Loop 2), directly connecting food waste management with the independence of the SPPG's animal protein supply (Syafril, 2024).

The causality flow structure and feedback mechanisms of this Waste Loop system are summarized in Table 4.

Table 4. Synthesis of Causality Flows and Feedback Mechanisms of the Waste Loop Model

System Element	Causal Relationship / Feedback Mechanism	Operational and Ecological Impact
Primary Input	SPPG Activities to Production & Food Residues to Organic Waste	Diverts 188.01 kg/day of waste from landfill (TPA) disposal.
Bioconversion	Organic Waste to Maggot Feed (BSFL)	Rapid organic biomass processing without excessive greenhouse gas emissions.
Sub Cycle R1	Maggot Feed to Kasgot to Vegetable Cultivation to Vegetable Harvest to SPPG	Produces organic fertilizer for daily fresh vegetable supply efficiency.
Sub Cycle R2	Maggot Feed to Fresh Maggot to Chicken Feed to Egg/Chicken Production to SPPG	Reduces dependence on commercial feed and supplies quality protein.

Analysis indicates that the integration of the Waste Loop scheme based on closed loop logistics successfully transforms food waste from a negative externality into secondary economic capital (Geissdoerfer et al., 2017; Simonetto et al., 2022; Vasquez-Brust et al., 2018), a circular supply chain not only suppresses potential environmental damage but also creates value added efficiency within the production system. From a system dynamics modeling perspective, the existence of Loop R1 and Loop R2 creates a positive feedback effect that stabilizes the urban food supply chain (Sterman, 2000) . When a surge in waste generation occurs due to an increase in MBG distribution portions, the maggot bioconversion capacity proportionally absorbs this waste and returns it in the form of a larger supply of eggs and vegetables to the SPPG. This fundamentally breaks the linear urban waste chain and supports sustainable circular economy principles (Smetana et al., 2021) .

The primary advantage of this dynamic modeling lies in its ability to synchronize waste conversion speed with food ingredient supply needs. The short growth cycle of Hermetia illucens larvae (15–18 days) aligns remarkably well with the operational rhythm of the SPPG, which recurs every working day ("Reassuring Insect Farming Ensures Waste Minimization and Future Food Security," 2025) .Furthermore, substituting commercial livestock feed with maggot biomass can reduce operational costs for partner farms by up to 30%, while simultaneously lowering the carbon footprint of waste processing by up to 65% compared to conventional landfill disposal at TPAs. Thus, the Waste Loop scheme not only resolves downstream waste accumulation issues but also strengthens upstream raw material supply resilience.

CONCLUSION

This study formulated a Waste Loop model based on closed-loop logistics and System Dynamics to support food-waste management within the Free Nutritious Meal (*Makan Bergizi Gratis* [MBG]) Program in Bandung City. Measurements conducted at three Nutrition Fulfillment Service Units (*Satuan Pelayanan Pemenuhan Gizi* [SPPGs]) recorded 940.07 kg of organic waste over five working days, with an average generation rate of 188.01 kg per day. Plate waste represented the largest proportion at 64.92%, while preparation residues accounted for 35.08%, with vegetables and carbohydrate-based foods constituting the dominant components. A survey of 77 operational personnel identified limited processing facilities and the absence of reverse logistics standard operating procedures as the primary implementation barriers. Nevertheless, the high level of stakeholder acceptance indicated strong institutional potential for adopting the proposed model. The resulting causal loop structure connected SPPG organic waste with black soldier fly larvae (Hermetia illucens) bioconversion and established two reinforcing pathways: returning larval residue to vegetable cultivation and converting larval biomass into poultry feed. The model therefore provides a conceptual foundation for diverting organic waste from disposal facilities, recovering its productive value, and strengthening circular food supply relationships within SPPGs.

Future research should develop the causal loop diagram into a quantified stock-and-flow model incorporating waste generation rates, collection delays, BSFL processing capacity, conversion efficiency, operational costs, product demand, and environmental impacts. The model should be validated through longer observation periods, seasonal menu variations, and larger samples of SPPGs across diverse urban and rural contexts. Experimental or pilot-scale implementation is also required to evaluate biological performance, food and feed safety, frass quality, financial feasibility, greenhouse gas reduction potential, and the stability of partnerships among farmers and waste processors. Subsequent studies could compare the Waste Loop system with alternative treatment methods, including composting, anaerobic digestion, and conventional disposal, using life-cycle assessment and cost–benefit analysis. Researchers should also examine beneficiary preferences, menu acceptability, and adaptive portioning strategies because preventing plate waste should remain a priority before downstream recovery processes. These developments would strengthen the model’s predictive reliability and provide evidence for designing standardized reverse logistics procedures and scalable circular waste-management policies within the MBG Program.

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