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Designing an Integrated Food Hub and Cold Chain Model to Optimize Raw Material Supply for the Free Nutritious Meal Program: A Case Study of 100 Nutrition Fulfillment Service Units (SPPG) in Three Regencies of Bali Province

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ABSTRACT

The Free Nutritious Meal Program (Makan Bergizi Gratis/MBG), coordinated by Indonesia's National Nutrition Agency, requires a reliable, safe, and cost-efficient food supply system to support the operation of Nutrition Fulfillment Service Units (SPPGs). However, the current decentralized procurement system exposes SPPGs to commodity price volatility, supply uncertainty, high food losses, and limited food safety control. This study aims to design and evaluate an integrated Food Hub and Cold Chain model for optimizing raw material procurement and distribution across 100 SPPGs operating in Buleleng, Gianyar, and Karangasem Regencies, Bali Province. A quantitative systems design approach was employed, using secondary data from 100 SPPGs, market price information, supplier capacity records, and regional logistics infrastructure. Demand forecasting, supply adequacy analysis, hub-and-spoke network design, cold-chain configuration, and economic feasibility assessment were conducted to evaluate the proposed model. The results indicate that the 100 SPPGs serve approximately 203,020 beneficiaries and require nearly 60 tons of food commodities per day. Existing supplier capacity is sufficient to meet aggregate demand; however, inefficiencies occur in procurement aggregation, storage, and distribution processes. The proposed Food Hub integrates centralized procurement, semi-processing facilities, temperature-controlled storage, and coordinated distribution. Economic analysis demonstrates that bulk purchasing and fewer intermediary transactions can lower procurement costs by 5–10%, while implementing cold chains can reduce food losses by 15–25%. Potential savings are estimated at IDR 10–20 million per SPPG per month, equivalent to IDR 1–2 billion per month across the system. Sensitivity analysis confirms the model's robustness to commodity price and demand fluctuations. The study concludes that the integrated Food Hub and Cold Chain model is technically feasible, economically viable, and scalable as a strategic infrastructure solution to strengthen the MBG program's sustainability, efficiency, and food safety performance. The proposed framework may serve as a replicable model for institutional feeding programs in other regions of Indonesia.

Keywords: Free Nutritious Meal Program; Logistics Optimization; Food Safety.

1. INTRODUCTION

The Free Nutritious Meal Program (MBG) is one of the national priority programs aimed at improving the nutritional status of school children, toddlers, pregnant women, and breastfeeding mothers in Indonesia. The implementation of this program is coordinated by the National Nutrition Agency (BGN) through the Nutrition Fulfillment Service Unit (SPPG) network, which functions as a food production kitchen unit at the sub-district and village levels. The success of the MBG program is highly dependent on the ability of each SPPG to obtain food raw materials in sufficient quantities, of guaranteed quality, and at efficient prices in a sustainable manner [1].

However, the current raw material procurement model is still decentralized. Each SPPG makes purchases independently, generally directly to the traditional market around the kitchen location. This pattern raises several structural problems. First, raw material prices fluctuate unpredictably, making it difficult to plan a menu within a fixed budget. Second, the absence of cold storage facilities causes fresh raw materials such as vegetables, fish, and meat to be easily damaged before processing, resulting in shrinkage that can reach 15-25% of total spending. Third, market stock availability is not always guaranteed, forcing sudden menu changes. Fourth, direct purchases from traders do not guarantee adherence to food safety standards such as Hazard Analysis and Critical Control Point (HACCP) and Good Manufacturing Practices (GMP) [1].

The concept of a food hub has been widely recognized in the food supply chain literature as an aggregation infrastructure that efficiently connects small-scale producers with institutional markets [2]. Food hubs play a role in consolidating, storing, processing, and distributing food products by maintaining traceability and quality [3]. The integration of food hubs with cold chain systems has been shown to reduce post-harvest food loss while extending the shelf life of perishable commodities [4]; [3]. In the context of large-scale institutional food programs such as

MBG, this approach is relevant to change procurement patterns from individual to centralized and standardized [5], [6].

Bali Province, especially Buleleng, Gianyar, and Karangasem Regencies, provides representative cases. These three districts already operate 100 SPPGs, serving a total of 203,020 beneficiaries per day, but they have diverse geographic characteristics, ranging from dense urban areas to remote coastal and mountainous areas. This diversity presents logistical challenges that make it an ideal laboratory to test the feasibility of an integrated food hub model.

This research aims to: (1) analyze the conditions and actual raw material needs of 100 SPPGs in the three districts; (2) designing an integrated Food Hub and cold chain model based on a hub-and-spoke approach; and (3) evaluate the technical and economic feasibility of the proposed model, in particular the ability to set competitive prices on the market while reducing the risk of damage to raw materials. The contribution of this research lies in providing infrastructure designs that can be replicated to support the MBG program's national sustainability.

2. RESEARCH METHODS

2.1 Research Design

This study employed a quantitative systems design approach that combined supply chain analysis, logistics network design, and economic feasibility assessment scenarios [4][7]. The research aimed to develop an integrated Food Hub and Cold Chain model to support raw material procurement for 100 Nutrition Fulfillment Service Units (SPPGs) operating in Buleleng, Gianyar, and Karangasem Regencies, Bali Province. The study was conducted in four stages: (1) demand analysis, (2) supplier capacity assessment, (3) food hub and distribution network design, and (4) technical-economic feasibility evaluation.

2.2 Study Area and Unit of Analysis

The study focused on 100 SPPGs serving beneficiaries in three regencies of Bali Province:

- Buleleng Regency (46 SPPGs)
- Gianyar Regency (30 SPPGs)
- Karangasem Regency (24 SPPGs)

The unit of analysis consisted of individual SPPGs, food suppliers, distribution routes, and the proposed centralized Food Hub facility.

2.3 Data Sources

Secondary data were collected from:

1. Operational records of 100 SPPGs, including location, operational status, number of beneficiaries, and procurement patterns.
2. Market ceiling price (HET) data issued by the Ministry of Trade and regional market authorities for June 2026.
3. Supplier database covering rice distributors, poultry producers, egg producers, fisheries, traditional markets, and BULOG warehouses.
4. Logistics and transportation data obtained from regional government reports and GIS mapping resources.
5. Published literature regarding food hubs, cold-chain systems, institutional feeding programs, and food supply chain management [8].

3. THEORY AND CALCULATION

3.1 Demand Estimation Model

Daily raw material requirements were estimated using [9]:

$$D_i = N \times C_i$$

where:

- (D_i) = daily demand of commodity i (kg/day)
- (N) = total beneficiaries served
- (C_i) = average consumption of commodity i per beneficiary per day

Total daily demand was calculated as:

$$TD=\sum_{i=1}^{n} D_i$$

where (TD) represents aggregate daily raw material demand.

3.2 Supplier Capacity Analysis

Supplier capacity was evaluated by comparing aggregate demand with available daily supply capacity.

The Supply Adequacy Ratio (SAR) was calculated as [10] [11]:

$$SAR=\frac{SC}{TD}$$

where:

- (SC) = supplier capacity (kg/day)
- (TD) = total demand (kg/day)

A SAR value greater than 1 indicates sufficient supply availability.

3.3 Food Hub Network Design

The proposed distribution system adopted a hub-and-spoke architecture.

One centralized Food Hub was located in the Singaraja–Sukasada area of Buleleng Regency and connected to three regional distribution zones [12], [13]:

- Buleleng Zone
- Gianyar Zone
- Karangasem Zone

The Food Hub performs [14]:

- procurement aggregation,
- quality inspection,
- semi-processing,
- cold storage,
- packaging,
- distribution scheduling.

Distribution routes were designed to minimize transportation distance and delivery time while maintaining cold-chain integrity.

3.4 Cold Chain Configuration

The cold-chain system consisted of:

Product Type	**Storage Temperature**
Fresh vegetables	0–4°C
Fresh fish	0–2°C
Fresh meat	0–4°C
Frozen products	−18°C
Eggs	10–15°C

The system was designed to maintain food safety standards based on HACCP and Good Manufacturing Practices (GMP).

3.5 Economic Feasibility Analysis

Economic feasibility was assessed using cost-saving and investment-recovery indicators.

Potential procurement savings were calculated as [15]:

$$CS=(P_m-P_h)\times Q$$

where:

- (CS) = procurement cost savings
- (P_m) = market procurement price
- (P_h) = Food Hub procurement price
- (Q) = procurement volume

Food loss reduction was estimated using [16]:

$$FLR=\frac{L_b-L_a}{L_b}\times100$$

where:

- (L_b) = spoilage before intervention
- (L_a) = spoilage after intervention

The operational break-even point (BEP) was estimated by:
[BEP=\frac{FC}{SP-VC}]
where:

- (FC) = fixed costs
- (SP) = service revenue
- (VC) = variable costs

3.6 Scenario and Sensitivity Analysis

Three implementation scenarios were evaluated:

1. Existing decentralized procurement system.
2. Food Hub without cold-chain integration.
3. Integrated Food Hub with cold-chain facilities.

Sensitivity analysis was performed under ±10% fluctuations in commodity prices and ±15% variations in demand to assess model robustness.

3.7 Data Analysis

The analysis is carried out through several stages. First, the aggregate raw material needs are estimated based on the number of beneficiaries, assuming an average per-serving consumption of raw materials. Second, a gap analysis is conducted to compare aggregate demand with the daily supply capacity of existing suppliers [8]. Third, a price comparison analysis was carried out to compare the market price of HET with the food hub price scenario [7]. Fourth, the distribution network model uses a hub-and-spoke approach, with one cold-chain production center serving three district zones [17]. Fifth, economic feasibility is evaluated by estimating potential savings and identifying break-even points [4].

4. RESULTS AND DISCUSSION

4.1 Profile and Raw Material Requirements of 100 SPPG

The results of the data aggregation show that the three districts operate a total of 100 SPPGs, with the distribution as presented in Table 1. Buleleng Regency has the largest number of units (46 SPPGs) with the widest distribution area, stretching from Gerokgak District in the west to Tejakula in the east. Gianyar Regency operates 30 SPPGs, which are relatively concentrated in the Sukawati, Gianyar city, and Ubud areas, while Karangasem Regency, with 24 SPPGs, has the biggest geographical challenges due to the existence of units in remote areas such as Kubu and Tianyar.

Table 1. Distribution of SPPG and Beneficiaries per District

Districts	Number of SPPG	Beneficiaries	Proportion (%)
Stuttgart	46	88.875	43,8
Gianyar	30	62.694	30,9
Karangasem	24	51.451	25,3
Total	**100**	**203.020**	**100,0**

Source: Results of SPPG operational data processing, 2026.

Of the 100 units, as many as 90 SPPGs have been operational, while the other 10 units are still in the preparation stage. Based on the number of beneficiaries of 203,020 people per day and the assumption of average raw material needs, the total aggregate demand is estimated to reach around 60 tons per day. This figure includes a wide range of commodities, including rice, animal protein (chicken, fish, meat, eggs), vegetables, spices, and complementary ingredients [8]; [4].

4.2 Capacity Analysis of Existing Suppliers

Supplier mapping shows that the supply ecosystem across the three districts, in aggregate, is sufficient to meet a demand of 60 tons per day. Each district has a main market with a significant capacity: Banyuasri Market in

Buleleng and Gianyar Public Market each have a capacity of 50-100 tons per day, while East Amlapura Market in Karangasem has a capacity of 30-60 tons per day. In addition, there are structured protein suppliers such as the layer farmer center in Sawan (100,000-200,000 eggs per day), broiler partnerships, and fish auction sites in Pengastulan, Sangsit, Amed, and Kusamba. The availability of national suppliers such as Perum BULOG, PT Sukanda Djaya, and PT Charoen Pokphand also strengthens the reliability of the supply of certain commodities.

These findings indicate that the main obstacle lies not in the availability of supply but in the inefficiency of the aggregation and distribution mechanisms. Thus, the most appropriate intervention is to build a consolidated infrastructure rather than create a new source of supply [8].

4.3 Design of the Integrated Food Hub and Cold Chain Model

The proposed model adopts a hub-and-spoke architecture, in which one Food Hub center serves as the main node (hub) that receives supplies from suppliers, performs semi-finished processing and cold storage, then distributes them to three county zones as spokes. The core functions of the food hub include: production of semi-finished ingredients (clean-cut vegetables, ready-to-use ground seasoning, portioned protein), cold chain storage at controlled temperatures, packaging and labeling per SPPG, and scheduled distribution.

The proposed model adopts a hub-and-spoke architecture, in which one Food Hub center serves as the main node (hub) that receives supplies from suppliers, performs semi-finished processing and cold storage, then distributes them to three county zones as spokes. A food hub is understood as an organization that actively manages the aggregation, distribution, and marketing of food products to strengthen local and regional producers' ability to meet wholesale, retail, and institutional demand [12]. The core functions of the food hub include: production of semi-finished ingredients (clean-cut vegetables, ready-to-use ground seasoning, portioned protein), cold chain storage at controlled temperatures, packaging and labeling per SPPG, and scheduled distribution.

The daily operational cycle is designed as follows: SPPG places H-2 orders through digital channels with a deadline of 18.00; production and packaging are carried out at 02.00-05.00; delivery to the kitchen takes place at 05.30-08.00; and confirmation of admission is made at 08.30. For remote areas in Karangasem, the construction of a distribution sub-hub in Amlapura is considered to reduce the distance to 80 km from the hub center. Cold chain transportation and joint distribution serve as critical strategies in supply chain management to ensure the safe transportation of perishable goods and temperature-sensitive commodities [18], which supports the technical rationale for the temperature-zone design of this model.

4.4 Price Comparison Analysis

One of the conditions for SPPG acceptance of a model is the ability to offer a price at or below the market price for direct purchases. Table 2 presents a comparison of market HET prices with food hub price scenarios for major commodities. The results show that for commodities with short intermediate chains, such as rice and cooking oil, prices are set at market equivalents, whereas for commodities with high efficiency potential, such as chicken, fish, eggs, and chili, food hub prices can be set 2-6% lower.

Table 2. Comparison of Market Prices (HET) and Food Hub Prices of Major Commodities

Commodities	HET Pasar (Rp)	Food Hub Price (Rp)	Status
Medium Rice	12,000/kg	12.000	Equivalent
Purebred Chickens	38,000/kg	36.000-38.000	Lower
Purebred Chicken Eggs	28,800/kg	28.000-28.800	Lower
Cob Fish	35,000/kg	33.000-35.000	Lower
Beef	120,000/kg	118.000-120.000	Lower
Red Chili	50,000/kg	48.000-50.000	Lower
Bulk Cooking Oil	23.000/L	23.000	Equivalent

Source: Processed results of HET data for the People's Market June 2026 and food hub price scenario.

This ability to set competitive prices stems from four efficiency mechanisms. First, bulk purchasing provides room to negotiate discounts of 5–10% with suppliers, in line with the theory of quantity discounts, which shows that implementing a quantity discount policy significantly reduces total supply chain costs and improves inventory management, while making suppliers far more competitive in terms of price [19]. Second, cutting out intermediaries by purchasing directly from farmers and fishermen—a strategy that eliminates “non-value-adding” stakeholders such as middlemen, where the number of intermediaries between farmers and consumers should be minimal or ideally zero to streamline the small-scale agricultural supply chain [20]. Third, the use of cold chains reduces raw material shrinkage by 15–25%, supported by evidence that food losses during storage reach 15–20% for vegetables and 10–15% for fruits, while losses during distribution reach 5–10% without adequate cold chain management [18]. Fourth, labor efficiency through centralized morning operations. In addition to raw commodity prices, food distribution centers offer value-added products such as ready-to-use powdered seasonings and pre-cut vegetables, which save kitchen managers 1–2 hours per day

4.5 Economic Feasibility Evaluation

The economic feasibility evaluation identifies three sources of value for each SPPG. The reduction in raw material depreciation is estimated to provide savings of IDR 8-15 million per kitchen per month, management time efficiency of IDR 2-4 million per month, and price stability that provides indirect savings of 5-10%. In aggregate, the total potential savings amount to IDR 10-20 million per kitchen per month, or the equivalent of IDR 1-2 billion per month if applied across all 100 SPPGs. With an efficient operational cost structure, the operational break-even point is projected to be reached in the eighth to tenth months, in line with the accumulated service volume of at least 30 SPPGs. This feasibility pattern aligns with studies on food hub economic viability, which confirm that food hubs make valuable contributions in supporting small producers and providing healthy local food options, while serving as aggregators capable of transforming food production, distribution, and consumption [14]

4.6 Risk Implementation and Mitigation Strategy

The implementation of the model is recommended to be carried out in stages for 12 months in four phases: (1) preparation and preparation of a memorandum of understanding in months 1-2; (2) pilot trials on 10 SPPGs in the Buleleng urban area in 3-4 months; (3) expansion to 50 SPPGs covering Gianyar in months 5-7; and (4) full coverage of 100 SPPGs including Karangasem in months 8-12. This phased approach is important to build trust empirically before scaling up, consistent with supply chain resilience literature, which emphasizes that trust and collaboration are regularly cited attributes for food supply system resilience, with research distinguishing between anticipatory, responsive, and recovery capacities across different implementation phases [21]

The main risk identified is SPPG's resistance to switching from market suppliers that have become long-standing partners. The proposed mitigation is the implementation of a pilot without a binding contract and the provision of price guarantees, so that SPPG can compare directly for one month. The risk of seasonal commodity price fluctuations is mitigated by maintaining buffer stocks and entering into weekly price contracts with suppliers. The risk of limited cold chain capacity in the initial phase is mitigated by using leased or partnership cold storage facilities, with self-investment deferred until positive cash flow is achieved. These risk mitigation strategies are consistent with agri-food supply chain risk management frameworks that identify financial instruments, local flexibility, and pilot-based scaling as key approaches to reducing risks across agri-food supply chain systems [22].

The findings of this study are in line with the literature that identifies food hubs as an effective instrument for improving the efficiency of institutional food supply chains. The novelty of this design lies in the explicit integration of aggregation, semi-finished processing, and cold chain functions into a single model calibrated to the actual field data of the MBG program, thereby providing replicative value for other regions [4][8].

5. CONCLUSION

This study developed and evaluated an integrated Food Hub and Cold Chain model to optimize raw material procurement and distribution for the Free Nutritious Meal (MBG) Program across 100 Nutrition Fulfillment Service Units (SPPGs) located in Buleleng, Gianyar, and Karangasem Regencies, Bali Province. The analysis revealed that the participating SPPGs collectively serve approximately 203,020 beneficiaries and require nearly 60 tons of food commodities per day. Although the existing supplier ecosystem has sufficient production capacity to meet aggregate demand, significant inefficiencies persist in procurement, storage, and distribution due to fragmented purchasing practices and the lack of coordinated cold-chain infrastructure.

The proposed hub-and-spoke Food Hub model integrates centralized procurement, supplier aggregation, semi-processing facilities, temperature-controlled storage, and scheduled distribution. The results indicate that the model can improve supply chain efficiency through bulk purchasing, reduction of intermediary transactions, and improved inventory management. Economic evaluation suggests that procurement costs can be reduced by approximately 5–10%, while food losses associated with spoilage can be decreased by 15–25% through cold-chain implementation. These improvements generate potential savings of IDR 10–20 million per SPPG per month, equivalent to approximately IDR 1–2 billion per month when implemented across the entire system.

From a practical perspective, the proposed model provides a scalable logistics framework that supports food availability, affordability, quality assurance, and food safety requirements in large-scale institutional feeding programs. The integration of Food Hub operations with cold-chain facilities offers a strategic solution for strengthening the sustainability and operational resilience of the MBG program while supporting local agricultural and fisheries supply networks.

The novelty of this study lies in the development of an integrated Food Hub–Cold Chain architecture specifically calibrated to the operational characteristics and demand structure of the MBG program. Unlike conventional food hub studies that focus primarily on agricultural aggregation, this research integrates centralized procurement, semi-processing, cold-chain management, and institutional food distribution into a unified supply chain framework for public nutrition services.

Future research should incorporate advanced logistics optimization techniques, including mixed-integer linear programming, vehicle routing optimization, geographic information system (GIS)-based network analysis, and comprehensive financial feasibility assessments. In addition, empirical pilot implementation studies are needed to validate operational performance, stakeholder acceptance, and long-term economic sustainability across Indonesia's geographic regions.

6. DECLARATIONS

6.1 Study Limitations

This study has several limitations that should be considered when interpreting the findings. First, the proposed Food Hub and cold chain model was developed using secondary operational data from 100 Nutrition Fulfillment Service Units (SPPGs), market price information, and supplier capacity mapping. Therefore, the estimated efficiency gains, cost savings, and spoilage reductions are based on analytical assumptions rather than empirical observations from an implemented system.

Second, the economic feasibility assessment was conducted using projected savings and operational scenarios without a detailed investment appraisal, such as Net Present Value (NPV), Internal Rate of Return (IRR), Payback Period (PP), or sensitivity analysis. Consequently, the long-term financial sustainability of the proposed model requires further verification through comprehensive financial studies.

Third, the study focuses exclusively on three regencies in Bali Province (Buleleng, Gianyar, and Karangasem). The logistical characteristics, supplier networks, transportation infrastructure, and geographic conditions of these regions may differ significantly from those of other Indonesian provinces. As a result, the generalizability of the findings to other regions should be approached with caution.

Fourth, the hub-and-spoke distribution design does not incorporate advanced optimization techniques, such as vehicle routing optimization, dynamic inventory management, demand forecasting, or stochastic modeling of supply disruptions. Therefore, the proposed distribution network represents a strategic framework rather than a fully optimized operational model.

Finally, the study does not evaluate stakeholder acceptance, organizational readiness, or behavioral factors among SPPG managers, suppliers, and government agencies. These social and institutional dimensions may substantially influence the successful implementation of the Food Hub model and warrant further investigation through field-based pilot projects and stakeholder analyses.

Future research should conduct pilot-scale implementation studies, integrate advanced logistics optimization models, perform comprehensive financial feasibility analyses, and examine stakeholder adoption factors to validate and refine the proposed Food Hub and cold chain system.

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6.4 Competing Interests

No potential conflict of interest exists in this publication.

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