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Linear Programming for Free Nutritious Meal Programs: A Review of Menu Planning, Distribution, and Procurement Optimization

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ABSTRACT
This study synthesizes the application of linear programming (LP) in free nutritious meal programs, with particular relevance to Indonesia's Free Nutritious Meal (MBG) initiative. Using a structured literature review of peer-reviewed articles published between 2000 and 2026 across major academic databases, 50 highly relevant studies were analyzed. The review examines LP applications across three interconnected operational decision levels: menu and nutrition planning, procurement, and distribution logistics. The findings show that LP effectively improves nutritional adequacy, reduces costs, enhances distribution efficiency, and supports environmentally sustainable operations. However, the literature remains fragmented, as most studies focus on a single decision level rather than integrated optimization. In addition, many models rely on deterministic assumptions and lack evaluation of long-term program outcomes such as health, equity, and sustainability. The review identifies key research gaps, including the need for integrated optimization frameworks, incorporation of operational uncertainty through stochastic or robust approaches, and stronger empirical validation in large-scale contexts. This study contributes by highlighting pathways for developing comprehensive decision-support systems capable of coordinating multiple operational components, thereby improving the feasibility and effectiveness of nationwide meal programs such as MBG.

Keywords : Linear programming; school meal programs; food distribution; optimization; mbg; nutrition planning

Introduction

The application of linear programming has proven to be highly valuable in the implementation of free nutritious meal programs, particularly when program managers must simultaneously address multiple, often conflicting objectives. These include ensuring nutritional adequacy, minimizing costs, maintaining menu acceptability, achieving timely distribution, and operating within the constraints of kitchen capacity and transportation fleets (Colombo et al., 2020; Van Dooren, 2018; Elinder et al., 2020; Colombo et al., 2019). Within the broader literature, linear programming has been widely applied, ranging from the classical diet problem to school feeding programs, food assistance systems, and humanitarian operations, demonstrating its direct relevance to the Makan Bergizi Gratis (MBG) program (Van Dooren, 2018; Epstein et al., 2004; Peters et al., 2021).

Empirical evidence highlights two primary pathways through which linear programming delivers benefits. First, it improves meal composition by selecting optimal combinations of ingredients or recipes that meet nutritional targets at minimum cost or with minimal deviation from existing dietary patterns (Verly-Jr et al., 2019; Vieux et al., 2019; Mondal et al., 2026; Miow et al., 2025). Second, integer and mixed-integer linear programming models enhance distribution operations by optimizing facility location, school allocation, vehicle routing, visit sequencing, and delivery scheduling under constraints such as time windows, capacity, and equity considerations (Aydemir-Karadag & Akdere, 2021; Nair et al., 2017; Martínez-Sykora et al., 2023; Cosmi et al., 2024).

Despite these advances, the existing literature remains fragmented. Most studies address nutritional optimization, logistics, or procurement independently, with limited attention to the interactions among these operational decision levels. Furthermore, few studies have examined how these optimization components can be integrated to support large-scale national meal programs such as Indonesia's Free Nutritious Meal (MBG) initiative, where regional diversity, operational complexity, and resource constraints present substantial implementation challenges. Consequently, there is a need for a comprehensive synthesis that not only summarizes existing applications of linear programming but also critically evaluates their operational contributions, implementation limitations, and potential for integrated decision-making.

Accordingly, this review is guided by the following research questions:

RQ1. How has linear programming been applied to optimize free nutritious meal programs across menu planning, distribution and logistics, and procurement decisions?

RQ2. What operational benefits, implementation challenges, and optimization trade-offs have been reported in existing studies?

RQ3. What research gaps remain, and what future research directions can support the development of integrated optimization models for Indonesia's Free Nutritious Meal (MBG) program?

To answer these questions, this review synthesizes and critically compares existing linear programming applications across the three operational decision levels. Based on the identified evidence, the review highlights current research gaps and proposes future directions toward integrated optimization frameworks capable of simultaneously supporting menu planning, procurement, and distribution decisions in large-scale free nutritious meal programs.

METHODOLOGY

This study employs a structured literature review methodology to synthesize existing applications of linear programming (LP) in free nutritious meal programs and related food distribution systems. Relevant literature was collected from major scholarly databases, including Semantic Scholar, Scopus, Web of Science, PubMed, and Google Scholar, using combinations of keywords such as linear programming, mixed-integer linear programming, school meal programs, food distribution, routing, scheduling, procurement, and nutrition optimization.

The search was limited to peer-reviewed journal articles published between 2000 and 2026. Following the removal of duplicates, titles and abstracts were screened based on predefined inclusion and exclusion criteria. Studies were included if they explicitly applied LP-based optimization methods to menu planning, food distribution, procurement, scheduling, or other operational decision-making problems. Conference papers, editorials, theses, book chapters, and studies not related to operational optimization were excluded.

The literature search and study selection process is illustrated in Figure 1. Following the initial database search, retrieved records were filtered based on relevance, publication type, and predefined inclusion criteria. The screening process yielded 50 highly relevant studies for in-depth analysis. Each article was systematically examined to extract key information, including optimization objectives, decision variables, mathematical formulations, constraints, application domains, reported outcomes, and identified research gaps. A narrative-comparative synthesis was subsequently conducted to evaluate existing approaches across menu planning, logistics, and procurement, while identifying opportunities for developing integrated optimization frameworks applicable to Indonesia’s Free Nutritious Meal (MBG) program.

The analysis was organized according to the research questions and focused on three aspects: (i) the application of linear programming across different operational decision levels, (ii) reported operational benefits, implementation challenges, and optimization trade-offs, and (iii) research gaps and future opportunities for integrated optimization in large-scale meal programs.

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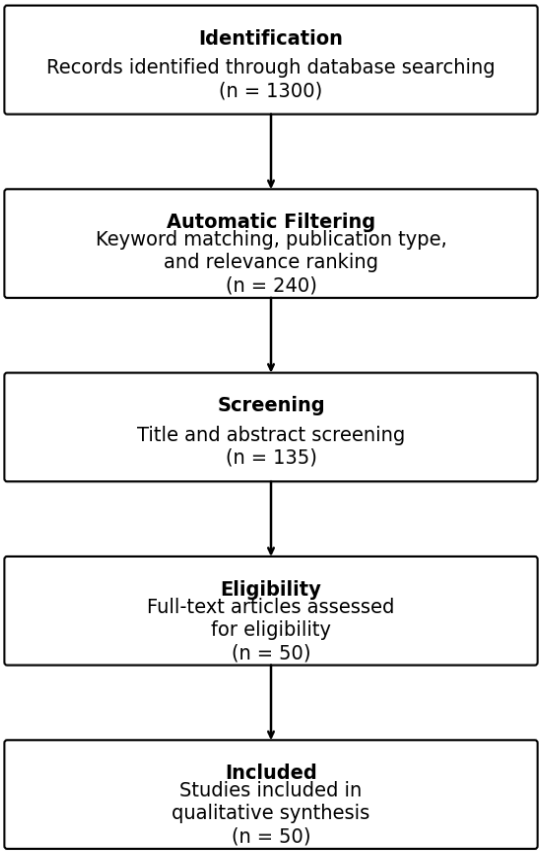

Figure 1 Literature Search and Study Selection Process

Before discussing each research question individually, Figure 2 presents the conceptual framework synthesized from the reviewed literature. The framework illustrates how linear programming applications span three interconnected operational decision levels—menu planning, procurement, and distribution—and how their integration contributes to improved operational performance while simultaneously revealing current research gaps and future research directions.

RESULTS AND DISCUSSION

Figure 2 provides an overview of the conceptual relationships identified in this review. The framework serves as a guide for organizing the subsequent discussion according to the three research questions.

RQ1: Applications of Linear Programming Across Operational Decision Levels

As illustrated in Figure 2, existing LP applications can be organized into three operational decision levels that collectively support integrated decision-making for free nutritious meal programs. To address RQ1, the reviewed studies were classified according to the operational decision level at which linear programming was applied. The analysis reveals that existing applications can be grouped into three interconnected domains: menu and nutrition planning, distribution and logistics, and procurement and contracting. Rather than functioning as isolated optimization problems, these domains collectively support the operational performance of large-scale free nutritious meal programs such as Indonesia's Free Nutritious Meal (MBG) initiative.

Foundational studies demonstrate that linear programming extends beyond menu optimization by integrating nutritional requirements with supply chain decisions, facility location planning, vehicle routing, and delivery scheduling (Colombo et al., 2020; Peters et al., 2021; Aydemir-Karadag & Akdere, 2021). Table 1 summarizes the primary objectives, decision variables, key constraints, reported outcomes, and implementation challenges associated with each operational decision level.

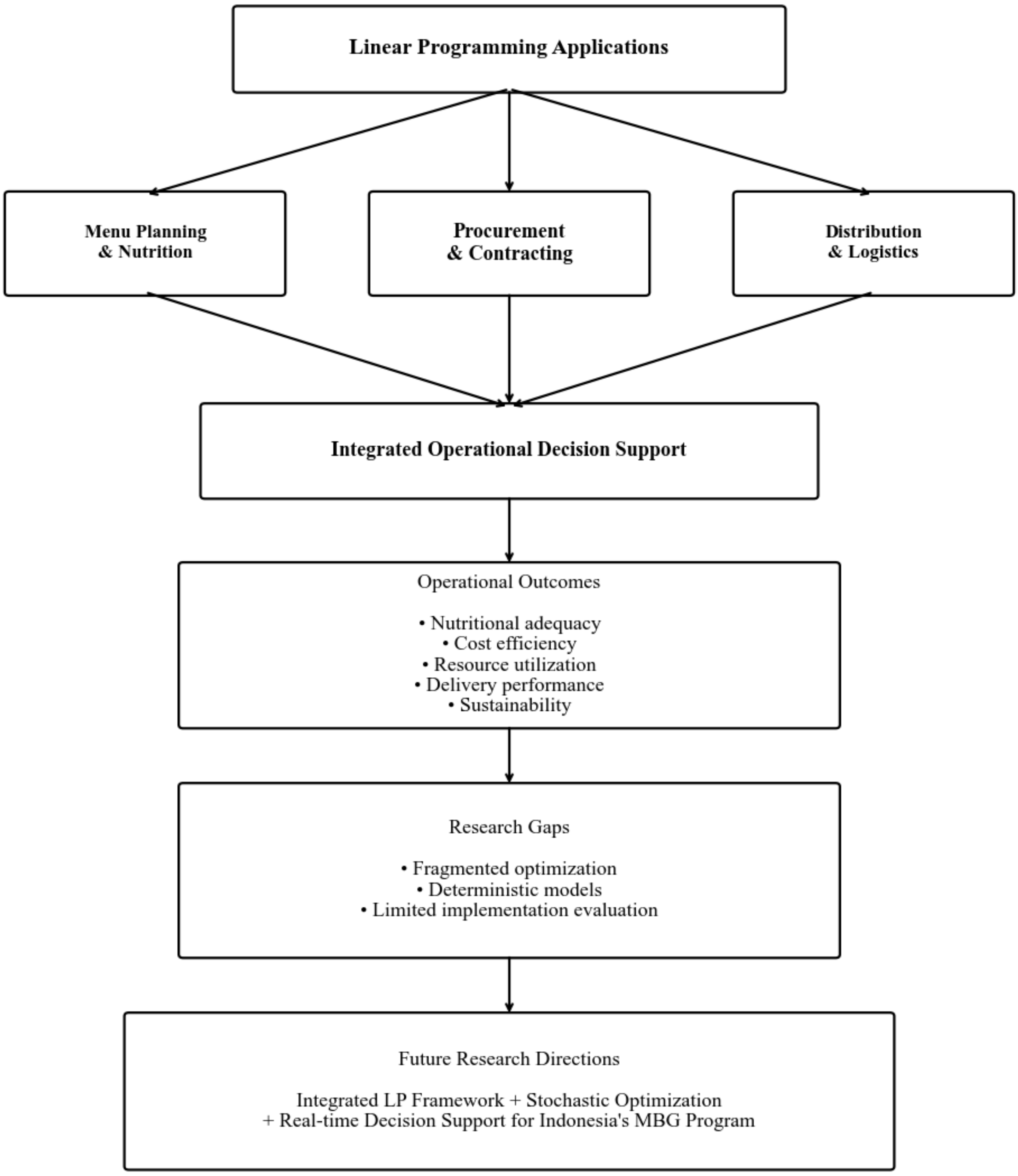

Figure 2 Conceptual Framework of Linear Programming Applications for Free Nutritious Meal Programs

Tabel 1 Comparison across decision levels

Dimension	Menu and Nutrition Planning	Distribution and Logistics	Procurement and Contracting	Citations
Primary Objective	Satisfy nutritional requirements while minimizing costs.	Ensure timely delivery and minimize travel distance.	Improve procurement efficiency, service coverage, and transparency.	Prajapati et al., 2025; Nair et al., 2017; Epstein et al., 2004
Decision Variables	Portion sizes, recipe selection, and menu frequency.	Facility location, vehicle routing, and delivery sequence.	Service contract assignment and allocation.	Colombo et al., 2020; Aydemir-Karadag & Akdere, 2021; Epstein et al., 2004

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Dimension	Menu and Nutrition Planning	Distribution and Logistics	Procurement and Contracting	Citations
Key Constraints	Nutritional requirements, budget limitations, and menu acceptability.	Vehicle capacity, delivery time windows, and food perishability.	NP-hard optimization complexity and social benefit considerations.	Colombo et al., 2020; Aydemir-Karadag & Akdere, 2021; Epstein et al., 2004
Reported Outcomes	Reduced costs and carbon emissions while maintaining nutritional quality.	Improved resource utilization and distribution efficiency.	Enhanced service quality and broader service coverage.	Colombo et al., 2020; Nair et al., 2017; Epstein et al., 2004
Major Challenges	Menus that deviate substantially from established dietary preferences may reduce user acceptance.	Dependence on accurate field data and effective stakeholder coordination.	High computational complexity in solving large-scale scenario-based optimization problems.	Colombo et al., 2019; Serang et al., 2026; Epstein et al., 2004

An important finding emerging from Table 1 is that menu planning, procurement, and logistics represent highly interconnected decision levels rather than independent optimization problems. Menu planning determines nutritional composition and ingredient demand, procurement governs supplier selection and resource allocation, while logistics ensures timely delivery under capacity and routing constraints. Consequently, decisions made at one level directly influence the feasibility and performance of the others. Despite these operational interdependencies, most reviewed studies optimize only a single decision level, limiting the practical applicability of existing LP models for nationwide meal programs such as Indonesia's MBG initiative. This finding highlights the need for integrated optimization frameworks capable of simultaneously coordinating multiple operational decisions.

At the menu and scheduling level, models have evolved from simple ingredient selection to realistic multi-day meal planning. Integer and binary constraints enable control over menu repetition, dietary diversity, and dish compatibility, making solutions more practical compared to continuous linear models (Benvenuti & De Santis, 2020; Lip et al., 2025; Gerdessen & Berg, 2023). These models also allow rapid adaptation to disruptions by generating alternative menus. The key features and operational outcomes of these approaches are summarized in Table 2.

Tabel 2 Key features and outcomes of linear programming in menu scheduling

Feature	Result
Decision unit	Daily/weekly dishes (Benvenuti & De Santis, 2020)
Variation constraints	Limits on menu repetition (Benvenuti & De Santis, 2020)
Acceptability	Minimal deviation from baseline diets (Colombo et al., 2020)
Practicality	Integer solutions are more realistic than continuous linear programming models (Lip et al., 2025; Hui et al., 2021)
Sudden disruptions	Rapid generation of alternative menus (Gerdessen & Berg, 2023)

Collectively, these findings indicate that LP-based menu scheduling has evolved beyond simple cost minimization toward practical operational decision support. Recent studies increasingly incorporate menu diversity, acceptability, scheduling flexibility, and disruption management, reflecting a growing emphasis on implementation feasibility rather than purely mathematical optimality.

The reviewed studies indicate a clear evolution of LP-based menu optimization. Early models primarily focused on minimizing costs while satisfying nutritional requirements, whereas more recent formulations incorporate practical considerations such as menu diversity, acceptability, meal repetition, and operational flexibility. This evolution reflects a transition from purely mathematical optimization toward decision-support tools that better accommodate real-world implementation requirements.

Beyond menu planning, logistics-oriented studies employ mixed-integer linear programming (MILP) to optimize routing, school allocation, and delivery scheduling while considering operational constraints such as vehicle capacity, delivery time windows, and food perishability. Although these models consistently improve operational efficiency, most published evidence originates from simulation studies or local case studies rather than nationwide implementations (Aydemir-Karadag & Akdere, 2021; Nair et al., 2017; Cosmi et al., 2024).

Overall, the reviewed literature demonstrates that LP applications have expanded from nutritional optimization toward broader operational decision support encompassing menu planning, logistics, and procurement. However, relatively few studies simultaneously optimize these three decision levels within a unified mathematical framework, indicating an important opportunity for future research.

RQ2: Operational Benefits, Challenges, and Trade-offs

To answer RQ2, the reviewed studies were analyzed with respect to their reported operational benefits, implementation challenges, and optimization trade-offs. Overall, the literature consistently demonstrates that linear programming improves economic efficiency while maintaining nutritional quality and operational feasibility. However, these benefits are frequently accompanied by practical implementation challenges that require additional modeling considerations.

Implementation studies report substantial operational improvements. For example, optimized school meal programs in Sweden reduced greenhouse gas emissions by approximately 40%, decreased operational costs by 11%, and maintained student satisfaction (Colombo et al., 2020). Likewise, multi-objective optimization applied to school meals in Boston improved caloric intake and dietary quality while simultaneously reducing both costs and environmental impacts (Stern et al., 2023). In developing-country contexts, however, achieving complete nutritional adequacy under strict budget constraints often requires either substantial menu modifications or additional financial investment (Ayoob et al., 2024; Mondal et al., 2026; Colombo et al., 2025).

The magnitude of reported benefits varies considerably across studies because optimization performance depends strongly on local implementation conditions, including food prices, dietary habits, procurement systems, and available logistics infrastructure. Consequently, results obtained in developed countries cannot be directly generalized to large-scale implementation in developing countries such as Indonesia without appropriate contextual adaptation.

One of the principal strengths of linear programming is its ability to explicitly quantify trade-offs among competing objectives. Rather than providing a single optimal solution, LP enables decision-makers to evaluate whether nutritional targets can be achieved within existing budget constraints or whether additional procurement resources, alternative ingredients, or modified operational strategies are required. Such transparency makes LP particularly valuable as a policy-support tool for large-scale public nutrition programs.

Despite these advantages, several implementation challenges remain. Conventional LP models often struggle to capture qualitative aspects such as cultural food preferences, menu acceptability, stakeholder coordination, and operational uncertainties. Consequently, numerous studies recommend extending LP models through integer programming, goal programming, preference-based optimization, or hybrid optimization techniques to improve practical applicability (Benvenuti & De Santis, 2020; Van Dooren, 2018; Tranzola Santos et al., 2022).

RQ3: Research Gaps and Future Research Directions

The research gaps identified in this review, as summarized in Figure 2, indicate that future studies should move beyond isolated optimization models toward integrated decision-support frameworks. To address RQ3, the reviewed literature was critically examined to identify remaining research gaps and future opportunities for integrated optimization. The evidence indicates that research on menu optimization is relatively mature, whereas logistics optimization remains moderately developed and largely context dependent. Procurement optimization has received comparatively less attention, particularly within integrated decision-support frameworks.

The first and most significant research gap concerns the fragmented nature of existing optimization models. Although menu planning, procurement, and logistics are operationally interdependent, the majority of reviewed studies optimize only one decision level at a time. Consequently, improvements achieved in one operational component may reduce the feasibility or efficiency of another. For example, nutritionally optimal menus may require ingredients that exceed procurement capacity or substantially increase transportation complexity. This fragmentation limits the practical applicability of LP models for nationwide meal programs such as MBG, where multiple operational decisions must be coordinated simultaneously.

Another significant research gap concerns outcome evaluation. Most studies assess operational indicators such as cost, nutritional adequacy, greenhouse gas emissions, routing efficiency, or service coverage. In contrast, there is limited empirical evidence linking optimization models to long-term program outcomes, including student health, educational performance, attendance, nutritional equity, and program sustainability (Stern et al., 2023; Uzhir et al., 2025).

The second research gap relates to the limited consideration of operational uncertainty. Most LP formulations assume deterministic parameters, including food demand, travel times, ingredient availability, procurement costs, and supplier reliability. However, nationwide meal programs operate in highly dynamic environments characterized by seasonal food availability, transportation disruptions, fluctuating demand, and regional differences. Consequently, deterministic optimization models may generate solutions that are difficult to implement under real operating conditions.

The third research gap concerns implementation evaluation. Existing studies primarily assess optimization performance using operational indicators such as cost reduction, nutritional adequacy, routing efficiency, and greenhouse gas emissions. Comparatively little attention has been devoted to evaluating long-term implementation outcomes, including student health, nutritional equity, stakeholder acceptance, educational performance, and institutional sustainability. As a result, the broader societal impacts of LP-based optimization remain insufficiently understood.

Addressing these research gaps requires a transition from isolated optimization models toward integrated decision-support frameworks. Future research should therefore prioritize optimization approaches that simultaneously coordinate menu planning, procurement, production scheduling, inventory management, and distribution while explicitly accounting for operational uncertainty through stochastic or robust optimization techniques. Furthermore, integrating optimization models with real-time operational information and evaluating both operational and societal outcomes would substantially improve their practical relevance for nationwide implementation of Indonesia's MBG program.

CONCLUSION

This review demonstrates that linear programming has evolved from a tool primarily used for nutritional optimization into a broader operational decision-support approach encompassing menu planning, procurement, distribution, and scheduling. Across the reviewed literature, LP applications consistently support three interconnected operational decision levels, confirming that effective implementation of free nutritious meal programs requires coordinated optimization rather than isolated decision-making.

The review further shows that LP provides substantial operational benefits, including improved nutritional adequacy, reduced costs, enhanced distribution efficiency, and lower environmental impacts. Nevertheless, these benefits depend heavily on local implementation conditions, including food availability, procurement capacity, logistics infrastructure, and stakeholder coordination. Consequently, optimization models should be viewed as decision-support tools whose effectiveness is determined not only by mathematical formulation but also by the operational context in which they are implemented.

This review also identifies a substantial research gap in the limited integration of menu planning, procurement, logistics, and scheduling within existing LP formulations. Most published studies optimize these operational functions independently despite their strong interdependencies. Furthermore, deterministic assumptions and the limited evaluation of long-term program outcomes reduce the applicability of current optimization models to large-scale national meal programs such as Indonesia's MBG initiative.

Future research should prioritize integrated optimization frameworks that simultaneously coordinate menu planning, procurement, production scheduling, inventory management, and distribution under operational uncertainty. Incorporating stochastic optimization, robust optimization, real-time operational information, and sustainability indicators will improve the practical relevance of LP models for large-scale implementation. Moreover, future empirical studies should evaluate optimization performance not only through operational metrics but also through long-term outcomes such as nutritional equity, student well-being, program resilience, and institutional sustainability. Ultimately, the value of linear programming for Indonesia's MBG program lies not merely in generating mathematically optimal solutions, but in providing an integrated decision-support framework capable of coordinating nutritional, logistical, procurement, and operational decisions required for the sustainable implementation of a nationwide free nutritious meal program.

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