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An Integer Linear Programming Approach to Optimizing Dish Allocation in a High-School Canteen

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Abstract: *This study develops an integer linear programming model to optimize the allocation of six commonly served dishes in a high-school canteen under raw-material constraints, heterogeneous student satisfaction, and practical catering-management requirements. First, a weighted satisfaction evaluation method is used to convert students' ratings of taste, economic attributes, and nutritional composition into composite satisfaction scores. A basic satisfaction-maximization model is then formulated subject to raw-material supply constraints and total-serving constraints. To improve practical applicability, an improved model further incorporates unit profit and minimum-supply constraints, with the objective of maximizing the combined benefit of satisfaction and profitability. The results show that, in the basic model, Stir-fried Bitter Melon with Lean Pork is assigned zero servings because of its relatively low satisfaction score and its consumption of shared pork resources. After unit profit and minimum-supply constraints are introduced, its recommended supply increases to 428 servings, preventing the complete exclusion of a regular menu item. The proposed model provides a quantitative decision-support approach for optimizing dish allocation, improving student dining satisfaction, enhancing raw-material utilization, and supporting data-driven canteen management.*

Keywords: *Integer Linear Programming; Dish Allocation; Satisfaction Evaluation; Raw-Material Constraints; High-School Canteen*

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I. Introduction

With improving living standards, students and parents increasingly expect school canteens to provide not only sufficient food but also better taste, nutritional balance, stable supply, and an improved dining experience. High-school students usually face heavy academic workloads and spend a large proportion of their day on campus, making the school canteen an important source of daily meals. Compared with university students, high-school students have fewer meal choices because of fixed meal schedules and concentrated dining periods. Therefore, whether dishes are allocated appropriately affects not only students' dining satisfaction but also the quality of school food services.

In practice, dish allocation in school canteens needs to consider multiple factors, including student preferences, raw-material availability, historical dish consumption records, catering capacity, and operational benefits. Inappropriate allocation may lead to two major problems. On the one hand, insufficient supply of popular dishes may adversely affect students' dining experience; on the other hand, excessive preparation of less popular dishes may result in food waste and pressure on ingredient turnover. Therefore, a systematic analysis of dish allocation in high-school canteens is necessary for improving raw-material utilization and supporting data-driven and refined canteen management.

Existing studies on campus canteens and catering management have mainly focused on dish allocation evaluation, student satisfaction surveys, improvement of campus catering service quality, and dietary-structure optimization. Ming et al. analyzed and optimized dish allocation in university canteens, demonstrating the practical value of quantitative analysis in dish-allocation problems [1]. Hu et al. found through questionnaire surveys that dish variety, taste, price, and food safety are important factors affecting students' overall evaluation of campus canteens [2]. From the perspective of service quality, Xu et al. discussed the influence of food safety, nutritional quality, menu-updating frequency, and service efficiency on campus catering services [3]. Osman et al. examined student satisfaction with on-campus cafeteria services, providing useful references for the construction of satisfaction-evaluation indicators in this study [4]. From a methodological perspective, integer linear programming is an important operations research method for solving resource-allocation and discrete decision-making problems [5]. Previous studies have also applied linear programming to dietary-structure optimization and school lunch menu optimization [6-7]. Rather than merely evaluating dish popularity, this study integrates student satisfaction, unit profit, raw-material availability, and practical catering-management requirements into an integer linear programming framework, aiming to provide a more operational quantitative decision-support approach for dish allocation in high-school canteens.

II. Study Objects and Data Processing

Data were first collected for six commonly served dishes in a high-school canteen. The composite satisfaction score of each dish was then calculated, and an optimization model for dish allocation was developed. Finally, the model was solved, the results were analyzed, and recommendations for optimizing dish allocation were proposed. This procedure is illustrated in Figure 1.

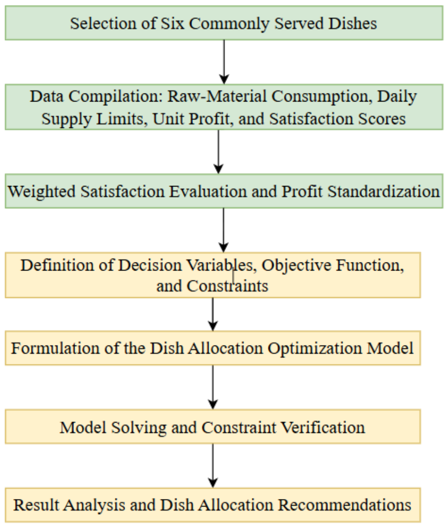

Figure 1. Research framework for optimizing dish allocation in a high-school canteen

2.1 Selection of Dishes

Six commonly served dishes in a high-school canteen were selected as the study objects: stir-fried broccoli with lean pork, Stir-fried Bitter Melon with Lean Pork, Scrambled Eggs with Tomato, tofu with minced pork, chicken drumstick, and Chinese Cabbage with Meatballs. These dishes were selected because they are representative, differ in raw-material requirements and student satisfaction levels, and have accessible data for modeling. The selection criteria are summarized in Table 1.

Table 1. Selection Criteria for the Six Dishes

Criterion	Description
Commonly served dishes	All six dishes are regular daily offerings in high school canteens, making them representative examples for this study.
Distinct raw-material requirements	As the dishes include pork, chicken, eggs, tofu, and various vegetables, they reflect diverse raw material requirements and are suitable for examining the effects of ingredient-related constraints.
Differences in satisfaction levels	The selected dishes differ noticeably in popularity and student satisfaction, making them appropriate for satisfaction-oriented optimization analysis.
Availability of data	Key data, including raw material consumption, supply volume, profit, and satisfaction levels, can be readily obtained, quantified, and calculated.

Using this focused dataset of six dishes, the modeling process for the dish allocation optimization problem can be clearly and efficiently demonstrated.

2.2 Data Sources and Indicator Description

In this study, there are four main data categories: raw material consumption per dish, total available raw material supply, student satisfaction, and profit per serving. In particular, raw material consumption and total raw material supply help to determine raw material constraints. Student satisfaction is used to quantify students' acceptance of each dish. Unit profit is used to measure the economic contribution of each dish to canteen operations.

In addition, total serving constraints and minimum-supply constraints were introduced to make the model results more consistent with actual canteen-management requirements. The minimum supply quantity is established on the basis of historical sales volumes, student preference survey findings, and official school menu management rules.

Table 2. Data Types and Their Roles in the Model

Data Type	Description	Role in the Model
Raw Material Consumption	Quantity of each type of raw material required to produce one serving of the dish	Left-hand side coefficients forming raw material constraint equations
Total Raw Material Supply	Daily available quantity of each type of raw material in the canteen	Right-hand upper bounds for raw material constraints
Student Satisfaction	Comprehensive evaluation result of dishes from students	Satisfaction indicator included in the objective function
Unit Profit	Profit obtained from selling one serving of the dish	Economy indicator standardized for inclusion in the objective function
Total serving requirement	Range of total servings of dishes that the canteen needs to supply daily	Forms the total serving constraint
Minimum Supply Constraint	Minimum serving quantity set to ensure menu stability and dish diversity	Constitutes the minimum supply constraint

After data collation, the raw-material consumption, daily supply limits, and unit profit of the six dishes are presented in Table 3. Raw material consumption is measured in kilograms per serving (kg/serving) and is defined as the quantity of raw materials required to produce one serving of the corresponding dish. The daily supply of raw materials is measured in kilograms, while unit profit is calculated in yuan per serving (yuan/serving). A value of 0 in the table indicates that the corresponding dish does not use the given raw material.

Table 3. Raw-Material Consumption, Daily Supply Limits, and Unit Profit of the Six Dishes

Raw material / indicator	Stir-fried Broccoli with Lean Pork	Stir-Fried Bitter Melon with Lean Pork	Scrambled Eggs with Tomato	Tofu with Minced Pork	Chicken Drumstick	Chinese Cabbage with Meatballs	Total Raw Materials
Pork	0.04	0.05	0	0.03	0	0.02	200
Broccoli	0.06	0	0	0	0	0	150
Bitter Melon	0	0.04	0	0	0	0	100
Tomato	0	0	0.05	0	0	0	120
Egg	0	0	0.06	0	0	0	110
Tofu	0	0	0	0.06	0	0	150
Chicken	0	0	0	0	0.1	0	100
Chinese Cabbage	0	0	0	0	0	0.07	130
Unit Profit	3	3	1	2	2	3	—

Table 3 reveals that the six dishes differ noticeably in raw material consumption structure and per-serving profit. Specifically,Stir-fried Broccoli with Lean Pork, Stir-fried Bitter Melon with Lean Pork, Tofu with Minced Pork and Chinese Cabbage with Meatballs all consume pork, making pork supply a potentially important shared constraint affecting dish allocation.

As both tomatoes and eggs are consumed in Scrambled Eggs with Tomato, the supply of this dish is constrained by these two raw materials. The supply of Chicken Drumstick is mainly affected by the supply of chicken. As for Chinese Cabbage with Meatballs, the supply is determined by the supply of pork and Chinese cabbage. From the perspective of profitability per serving, it can be found that Stir-fried Broccoli with Lean Pork, Stir-fried Bitter Melon with Lean Pork, and Chinese Cabbage with Meatballs have higher profitability, while Scrambled Eggs with Tomato and Chicken Drumstick earn lower profits individually. This kind of difference shows that dish assignment cannot be made according to the popularity of dishes alone.

2.3 Weighted Satisfaction Evaluation Method

Student satisfaction questionnaires have been extensively used to evaluate the quality of services provided by campus canteens, making it possible to quantify students' subjective views about the taste, price, nutritional value, food safety and hygiene, and quality of service[2-4]. To convert students' subjective evaluations of different dishes into quantitative indicators for model calculation, this study used previously collected online rating results to obtain satisfaction scores for the six dishes, which were then used as model parameters. Each dish was evaluated from three dimensions: flavor experience, economic attribute, and nutritional composition. Compared with conventional paper questionnaire surveys, online surveys can make data acquisition and consolidation much faster and make the final satisfaction evaluation results more computable.

The satisfaction evaluation framework used in this study includes three dimensions: flavor experience, economic attribute, and nutritional composition. The aspect of flavor experience includes flavor, saltiness, and freshness of ingredients; economic characteristics include cost rationality and portion sufficiency; nutritional characteristics include the combination of meat and vegetables and dietary balance. The specific indicators and weights are shown in Table 4.

Table 4 Satisfaction Evaluation Indicators and Weights

Evaluation Indicators	Weights	Main Meaning
Flavor Experience	50%	Taste, Seasoning Suitability, Ingredient Freshness
Economic Attribute	30%	Price Reasonableness, Portion Adequacy
Nutritional Composition	20%	Meat-Vegetable Matching, Nutritional Balance

Let the scores of the j-th dish in the flavor experience, economic attribute and nutritional composition dimensions be F_j、E_j、N_j respectively. The composite satisfaction score of the j-th dish is expressed as:

$$S_j = 0.5F_j + 0.3E_j + 0.2N_j, j = 1,2, \dots ,6$$

Where S_j stands for the comprehensive satisfaction score of the j-th dish. A higher satisfaction score indicates higher student preference. The original rating scores range from 0–10. Every single score is first divided by 10 to normalize it to a range of 0 to 1 before being substituted into the model for calculation. Collated normalized comprehensive satisfaction results for all six dishes are shown in the table below.

Table 5 Satisfaction Results of Six Dishes

Dish	Stir-fried Broccoli with Lean Pork	Stir-fried Bitter Melon with Lean Pork	Scrambled Eggs with Tomato	Tofu with Minced Pork	Chicken Drumstick	Chinese Cabbage with Meatballs
Satisfaction	0.72	0.65	0.78	0.69	0.80	0.70

Satisfaction results show Chicken Drumstick and scrambled eggs with tomato obtain relatively high satisfaction scores, indicating that the two dishes are more popular among students. By contrast, Stir-fried Bitter Melon with Lean Pork bears the lowest satisfaction score, which means optimization models purely targeting satisfaction maximization will deprioritize its output volume. These satisfaction values act as core input parameters for the subsequent model construction.

III. Establishment of the Optimization Model for Dish Allocation

This study first constructs a basic satisfaction maximization model to obtain dish allocation outcomes subject to raw material constraints and total serving volume constraints. Building on this basic model, unit profit and minimum supply quantity constraints are further introduced to develop an improved comprehensive benefit optimization model that balances satisfaction and profit. A comparison between the basic model and improved model further illustrates how different optimization objectives and constraint conditions affect the supply quantity of each dish.

Integer linear programming is a fundamental operations research method for solving optimization problems involving discrete decision variables, and is applicable to allocation optimization under limited resource conditions[5]. In food and dietary optimization research, linear programming models have been adopted to design food intake patterns that meet nutritional targets and to address related problems such as school lunch menu optimization[6-7]. Accordingly, it is reasonable to apply integer linear programming to optimize dish supply quantities in senior high school canteens.

3.1 Model Assumptions and Definition of Decision Variables

To simplify the mathematical modeling process, seven standardized research assumptions are proposed. First, the raw material consumption per serving of the six dishes remains constant within the research cycle. Second, the total daily supply of each type of raw material is known and relatively stable. Third, short-term student satisfaction scores for all dishes show no obvious fluctuation. Fourth, the profit per serving of each dish is unchanged during the research period. Fifth, the total daily serving volume of the canteen is restricted to a fixed interval to match students' dining demands and avoid oversupply. Sixth, minimum supply quantities can be set to guarantee the menu stability and dish diversity. Seventh, factors including processing time, service window quantity, chef labor load, specific nutrient content and daily fluctuation in the number of diners are temporarily not taken into consideration in this paper.

Let $x_1, x_2, x_3, x_4, x_5, x_6$ represent the daily supply quantity (unit: serving) of Stir-fried Broccoli with Lean Pork, Stir-fried Bitter Melon with Lean Pork, Scrambled Eggs with Tomato, Tofu with Minced Pork, Chicken Drumstick and Chinese Cabbage with Meatballs respectively. Given that each dish's supply quantity must be an integer number of servings in actual canteen operation, the daily supply quantity of each dish is defined as a non-negative integer decision variable in this study.

Under the above assumptions, the objective functions and constraint conditions of both the basic model and improved model constructed in this paper are linear expressions of the decision variables of the first order. Therefore, both models fall within the category of integer linear programming models.

3.2 Basic Model: Satisfaction Maximization Model

Objective Function: The basic model's optimization objective is to maximize aggregate student satisfaction. Based on the comprehensive satisfaction scores for each dish, the objective function is expressed as follows:

$$\max Z_0 = 0.72x_1 + 0.65x_2 + 0.78x_3 + 0.69x_4 + 0.80x_5 + 0.70x_6$$

Where Z_0 stands for the total student satisfaction generated by the given supply quantities of the six dishes. This objective function is to maximize students' overall satisfaction with the canteen dish allocation scheme subject to limited raw material supplies.

Three categories of constraints are embedded in the basic model, namely raw material supply constraints, total serving volume constraint, and non-negative integer constraints.

Since the canteen has a limited daily available quantity for each type of raw material, the supply quantities of the six dishes must comply with the raw material supply constraints. Based on the raw material consumption data presented in Table 3, the constraint conditions are listed as follows:

$$\begin{gathered} 0.04x_1 + 0.05x_2 + 0.03x_4 + 0.02x_6 \le 200, \\ 0.06x_1 \le 150, \\ 0.04x_2 \le 100, \\ 0.05x_3 \le 120, \\ 0.06x_3 \le 110, \\ 0.06x_4 \le 150, \\ 0.10x_5 \le 100, \\ 0.07x_6 \le 130, \end{gathered}$$

Among these, the first set of constraints corresponds to the pork supply limit, while the subsequent constraints are the supply caps of broccoli, bitter melon, tomato, egg, tofu, chicken and Chinese cabbage separately.

Meanwhile, the total serving volume constraint is expressed as: $8000 \le x_1 + x_2 + x_3 + x_4 + x_5 + x_6 \le 9000$ Since the supply quantity of each dish must be a non-negative integer, the following holds: $x_j \ge 0, x_j \in Z, j = 1,2,\ldots,6$.

The mathematical expression of the basic satisfaction maximization model in this study is shown below:

$$\max Z_0 = 0.72x_1 + 0.65x_2 + 0.78x_3 + 0.69x_4 + 0.80x_5 + 0.70x_6,$$

$$\text{s.t.} \quad \begin{cases} 0.04x_1 + 0.05x_2 + 0.03x_4 + 0.02x_6 \le 200, \\ 0.06x_1 \le 150, \\ 0.04x_2 \le 100, \\ 0.05x_3 \le 120, \\ 0.06x_3 \le 110, \\ 0.06x_4 \le 150, \\ 0.10x_5 \le 100, \\ 0.07x_6 \le 130, \\ 8000 \le x_1 + x_2 + x_3 + x_4 + x_5 + x_6 \le 9000 \\ x_j \ge 0, x_j \in Z, j = 1,2,\ldots,6. \end{cases}$$

Solving this model outputs the recommended supply quantities for the six dishes under the fixed raw material supply conditions, offering quantitative planning references for dish arrangement in senior high school canteens.

3.3 Improved Model: Comprehensive Benefit Optimization Model Balancing Satisfaction and Profit

When only satisfaction maximization, raw material constraints and total serving volume constraints are considered, dishes with low satisfaction that consume shared raw materials may still be completely excluded by the model. To make the model more consistent with the actual operational requirements of senior high school canteens, this paper further introduces profit per serving and minimum supply quantity constraints, thereby constructing a comprehensive benefit optimization model that balances satisfaction and profit.

3.3.1 Standardization of Profit Indicators

The improved model simultaneously optimizes student satisfaction and canteen revenue. Since satisfaction and profit per serving are measured in different units, direct summation is not feasible, requiring standardization of profit per serving data in advance.

Let p_j denote the profit per serving of the j-th dish, p_{max} the maximum profit per serving among the six dishes, and p_{min} the minimum profit per serving among them. Then the standardized profit indicator of the j-th dish is defined as:

$$P_j = \frac{(p_j - p_{min})}{(p_{max} - p_{min})}.$$

In this paper, $p_{max} = 3$ and $p_{min} = 1$. Accordingly, the standardized profit indicator of each dish is calculated as: $P_1 = 1$, $P_2 = 1$, $P_3 = 0$, $P_4 = 0.5$, $P_5 = 0.5$, $P_6 = 1$.

Min-max normalization is adopted because it scales profit per serving to the interval [0, 1], facilitating weighted integration with satisfaction indicators.

3.3.2 Comprehensive Objective Function

Set α as the weight of student satisfaction, and $1 - \alpha$ as the weight assigned to profit. The composite benefit coefficient of the j-th dish is expressed as: $C_j = \alpha S_j + (1 - \alpha) P_j$, where α satisfies $0 \le \alpha \le 1$. A higher value of α means the model prioritizes student satisfaction, while a lower α value places more weight on canteen profit. Considering that high school canteens operate within the purview of public services, the following numerical example will consider $\alpha = 0.7$ (satisfaction is weighted at 70% whereas profit is weighted at 30%).

The value of α may be changed by the school administration according to institutional needs. Table 6 presents the benefit coefficients for all six dishes.

Table 6 Comprehensive Benefit Coefficients of Six Dishes

Dish	Satisfaction S_j	Profit per Serving p_j	Standardized Profit P_j	Comprehensive Benefit Coefficient C_j
Stir-fried Broccoli with Lean Pork	0.72	3	1	0.804
Stir-fried Bitter Melon with Lean Pork	0.65	3	1	0.755
Scrambled Eggs with Tomato	0.78	1	0	0.546
Tofu with Minced Pork	0.69	2	0.5	0.633
Chicken Drumstick	0.80	2	0.5	0.710
Chinese Cabbage with Meatballs	0.70	3	1	0.790

Accordingly, the objective function of the improved model is formulated as:

$$\max Z = 0.804x_1 + 0.755x_2 + 0.546x_3 + 0.633x_4 + 0.710x_5 + 0.790x_6.$$

The objective function here is to maximize the aggregated comprehensive benefit of the six dishes under three types of constraints, which are raw material supply limitations, the required serving quantity constraint, and supply quantity constraints.

3.3.3 Constraint Conditions

The modified model contains four different types of constraints, which include raw material supply constraints, the total serving quantity constraint, minimum supply quantity constraints, and non-negative integer constraints. Raw material supply constraints remain the same in the modified model and are stated as follows:

$$0.04x_1 + 0.05x_2 + 0.03x_4 + 0.02x_6 \le 200,$$
$$0.06x_1 \le 150,$$
$$0.04x_2 \le 100,$$
$$0.05x_3 \le 120,$$
$$0.06x_3 \le 110,$$
$$0.06x_4 \le 150,$$

$$0.10x_5 \leq 100,$$
$$0.07x_6 \leq 130,$$

The total serving volume constraint is: $8000 \leq x_1 + x_2 + x_3 + x_4 + x_5 + x_6 \leq 9000$. The supply quantity of each dish cannot be negative, hence: $x_j \geq 0, x_j \in Z, j = 1,2,\ldots,6$ where Z denotes the set of non-negative integers.

The minimum supply quantity constraint is expressed as: $x_j \geq 200, j = 1,2,\ldots,6$. Here, the value of 200 servings is not a fixed standard. In practical operation, the minimum supply quantity should be calibrated against historical canteen sales volume, student preference survey findings or the school's menu policies.

3.3.4 Feasibility Analysis of Minimum Supply Quantity Constraints

Before adopting the minimum supply quantity constraints, one must verify that they do not conflict with raw material supply constraints. Taking the minimum supply of 200 servings for each dish as an example, the total minimum supply for the six dishes reaches 1200 servings. Under this premise, the minimum consumption of each type of raw material is listed as follows:

The minimum consumption of pork is calculated as: $0.04 \times 200 + 0.05 \times 200 + 0.03 \times 200 + 0.02 \times 200 = 28$kg. Minimum consumption of broccoli: $0.06 \times 200 = 12$kg; Minimum consumption of bitter melon: $0.04 \times 200 = 8$kg; Minimum consumption of tomatoes: $0.05 \times 200 = 10$kg; Minimum consumption of eggs: $0.06 \times 200 = 12$kg; Minimum consumption of tofu: $0.06 \times 200 = 12$kg; Minimum consumption of chicken: $0.10 \times 200 = 20$kg; Minimum consumption of Chinese cabbage: $0.07 \times 200 = 14$kg. All the above minimum consumptions fall below their corresponding upper limits of raw material supply. Accordingly, the minimum supply quantity constraints will not render the model infeasible, indicating that this threshold is basically feasible under the parameter settings of the numerical example in this study.

3.3.5 Complete Model

In summary, the improved model constructed in this paper is presented as follows:

$$\max Z = 0.804x_1 + 0.755x_2 + 0.546x_3 + 0.633x_4 + 0.710x_5 + 0.790x_6,$$

$$\text{s.t.} \quad \begin{cases} 0.04x_1 + 0.05x_2 + 0.03x_4 + 0.02x_6 \leq 200, \\ 0.06x_1 \leq 150, \\ 0.04x_2 \leq 100, \\ 0.05x_3 \leq 120, \\ 0.06x_3 \leq 110, \\ 0.06x_4 \leq 150, \\ 0.10x_5 \leq 100, \\ 0.07x_6 \leq 130, \\ 8000 \leq x_1 + x_2 + x_3 + x_4 + x_5 + x_6 \leq 9000, \\ x_j \geq 0, x_j \in Z, j = 1,2,\ldots,6, \\ x_j \geq 200, j = 1,2,\ldots,6. \end{cases}$$

Both the objective function and all constraints of this model are linear in the decision variables, and the decision variables are required to be non-negative integers. Hence, this model falls into the category of integer linear programming. Numerical solution of this framework generates a feasible supply scheme that respects existing raw material availability, catering volume requirements and dish diversity constraints.

IV. Model Solution and Result Analysis

4.1 Solution Results of the Basic Model

To illustrate the necessity of model improvement, this paper first solves the basic satisfaction maximization model. Subject to raw material supply constraints and total serving volume constraints, the solution results of the basic model are presented in the table below.

Table 7 Solution Results of the Basic Model

Dish	Decision Variable	Recommended Supply in Basic Model (Portions)
Stir-fried Broccoli with Lean Pork	x_1	2500
Stir-fried Bitter Melon with Lean Pork	x_2	0
Scrambled Eggs with Tomato	x_3	1833
Tofu with Minced Pork	x_4	1810
Chicken Drumstick	x_5	1000
Chinese Cabbage with Meatballs	x_6	1857
Total	—	9000

Based on Table 7, in the basic model, Stir-fried Bitter Melon with Lean Pork would have a recommended supply quantity of zero. In terms of mathematical explanation, the rationale behind the result is simple: the dish has a comparatively low satisfaction rating and uses pork as one of its ingredients, which means it does not possess any comparative advantage since the aim of the model is to maximize student satisfaction. Furthermore, the total serving quantity in the basic model is 9000 servings, satisfying the constraint of total serving quantity between 8000 and 9000 servings without excess total supply.

Nevertheless, it must be recognized that the elimination of a dish which is traditionally served at the canteen from the menu is not a feasible decision to be made considering the actual situation at the senior high school canteen. The operation of the canteen needs to take into consideration factors which cannot be formulated in a mathematical manner, such as continuity of the menu for each meal period, the necessity to provide variety in the daily menu, and the consistent preference of a number of students for a certain dish irrespective of their average satisfaction rating. Although the basic model has been successful in reflecting the contradiction between satisfaction maximization and ingredient allocation, the solution of the problem seems to be rather extreme.

4.2 Constraint Verification of the Basic Model

To verify the feasibility of the solution obtained from the basic model, the actual consumption of each type of raw material is further calculated, and the results are summarized in the table below.

Table 8. Raw-Material Consumption Verification for the Basic Model

Raw Material	Actual Consumption (kg)	Upper Limit of Raw Material (kg)	Constraint Compliance
Pork	191.44	200	Yes
Broccoli	150	150	Yes
Bitter Melon	0	100	Yes
Tomato	91.65	120	Yes
Egg	109.98	110	Yes
Tofu	108.6	150	Yes
Chicken	100	100	Yes
Chinese Cabbage	129.99	130	Yes

As shown in Table 8, the basic model solution satisfies all raw material supply constraints. Among these, broccoli, eggs, chicken and Chinese cabbage are close to or at their supply upper limits, indicating that these raw materials impose obvious restrictions on the supply quantity of some dishes. Bitter melon is not consumed mainly because Stir-fried Bitter Melon with Lean Pork is excluded from the optimal supply plan in the basic model.

4.3 Solution Results of the Improved Model

In the improved model, both student satisfaction and profit per serving are incorporated into the objective function, and minimum supply quantity constraints are also introduced as additional operational requirements. The solution results of the improved model are presented in Table 9.

Table 9 Recommended Supply Quantities of the Improved Model

Dish	Decision Variable	Recommended Supply in Improved Model (Portions)	Proportion in Total Supply
Stir-fried Broccoli with Lean Pork	x_1	2500	27.78%
Stir-fried Bitter Melon with Lean Pork	x_2	428	4.76%
Scrambled Eggs with Tomato	x_3	1833	20.37%
Tofu with Minced Pork	x_4	1382	15.36%
Chicken Drumstick	x_5	1000	11.11%
Chinese Cabbage with Meatballs	x_6	1857	20.63%
Total	—	9000	100%

As reflected in Table 9, the total amount of the recommended supply per day according to the improved model equals 9000 servings, thus meeting the criterion of total catering capacity. Among the included dishes, stir-fried Stir-fried Broccoli with Lean Pork, Scrambled Eggs with Tomato, and Chinese Cabbage with Meatballs have high shares of supply. Even though the supply quantity of Stir-fried Bitter Melon with Lean Pork is still relatively low, this dish is not entirely excluded from the menu, with 428 servings allocated.

4.4 Constraint Verification of the Improved Model

To verify the feasibility of the solution derived from the improved model, the actual consumption of each raw material was calculated, with the results presented in the table below.

Table 10 Raw Material Consumption Verification for the Improved Model

Raw Material	Actual Consumption (kg)	Raw Material Upper Limit (kg)	Constraint Compliance
Pork	200	200	Yes
Broccoli	150	150	Yes
Bitter Melon	17.12	100	Yes
Tomato	91.65	120	Yes
Egg	109.98	110	Yes
Tofu	82.92	150	Yes
Chicken	100	100	Yes
Chinese Cabbage	129.99	130	Yes

As shown in Table 10, the improved model solution satisfies all raw material supply constraints. Pork, broccoli, eggs, chicken and Chinese cabbage are close to or at their respective supply upper limits indicating that these raw materials constitute critical restrictive factors for dish supply volumes. Bitter melon and tofu retain residual surplus, suggesting that they are not primary constrained resources in the current model.

To further compare the differences in dish supply structure between the basic model and the improved model, this paper conducts a visual comparison of the recommended supply quantities of the six dishes under the two models, and the results are presented in Figure 2.

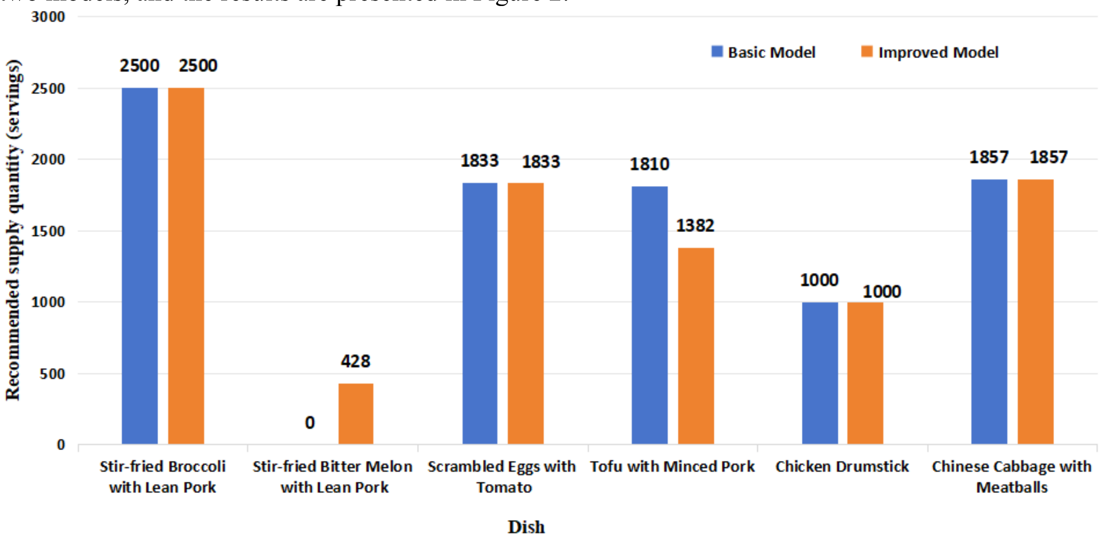

Figure 2 Comparison of Recommended Supply Quantities between Basic Model and Improved Model

As shown in Figure 2, the most notable differences between the two models concern two dishes: Stir-fried Bitter Melon with Lean Pork and Tofu with Minced Pork. The supply quantity of Stir-fried Bitter Melon with Lean Pork increases from zero in the basic model to 428 servings, which proves that the minimum supply constraint can prevent conventional dishes from being completely phased out. Meanwhile, the supply of Tofu with Minced Pork decreases from 1,810 servings to 1,382 servings, reflecting the fact that under the restriction of shared raw materials such as pork, the improved model redistributes raw material allocation among different dishes. Taken together, these results suggest that the improved model enhances dish diversity and practical operability in canteen management whilst keeping the total catering volume unchanged.

4.5 Result Analysis

According to the results, the recommended supply quantities of the six dishes are determined by neither satisfaction nor profit alone. Instead, they are jointly affected by five factors: satisfaction level, unit profit, raw-material consumption structure, total serving requirement, and minimum-supply constraint.

Chicken Drumstick achieve the highest satisfaction rating, yet production is rigidly limited by daily chicken stock. Each drumstick requires 0.10 kg of chicken, while a supply of 100 kg of chicken per day ensures that this dish cannot exceed 1000 servings per day. Scrambled Eggs with Tomato has relatively high satisfaction among students but relatively low marginal profit and is limited in terms of production since its amount depends on egg stock.

Stir-fried Stir-fried Broccoli with Lean Pork and Chinese Cabbage with Meatballs have high profit margins and relatively high student satisfaction, resulting in relatively high weight values for these dishes in terms of production. Bitter melon stir-fried with lean pork has low student acceptance but a high profit margin, ensuring its inclusion in the menu in a minimal amount due to the minimum output constraint applied. The supply volume of Tofu with Minced Pork is lower than that in the base model, as the limited shared pork resource is redistributed across multiple dishes. The improved model prioritizes allocating pork to menu items with superior comprehensive benefits.

In aggregate, the improved model integrated benefit framework far better matches the actual operational needs of high school canteens compared to the basic model. The basic model illustrates that pure satisfaction optimization risks removing regular menu items from daily menus. By incorporating profitability metrics and minimum supply constraints, the improved model balances student experience and profit to generate more balanced and practically implementable daily menu-planning solutions.

4.6 Weight Sensitivity Analysis

Given that the satisfaction weight α embedded in the comprehensive benefit coefficient entails a certain degree of subjectivity, this paper further conducts a sensitivity analysis on α. Specifically, α was assigned values of 0.1, 0.3, 0.5, 0.7 and 0.9 respectively to compare variations in the recommended supply quantities of dishes under different weight settings. The corresponding results are presented in the table below.

Table 11 Comparison of Recommended Supply Volumes under Different Satisfaction Weights

Value of α	x_1 Stir-fried Broccoli with Lean Pork	x_2 Stir-fried Bitter Melon with Lean Pork	x_3 Scrambled Eggs with Tomato	x_4 Tofu with Minced Pork	x_5 Chicken Drumstick	x_6 Chinese Cabbage with Meatballs	Total Supply Volume
0.1	2500	1137	1833	200	1000	1857	8527
0.3	2500	428	1833	1382	1000	1857	9000
0.5	2500	428	1833	1382	1000	1857	9000
0.7	2500	428	1833	1382	1000	1857	9000
0.9	2500	428	1833	1382	1000	1857	9000

As can be seen in Table 11, for $\alpha = 0.1$, the model obviously prioritizes profit maximization in the canteen. The supply quantity of the high-profit Stir-fried Bitter Melon with Lean Pork increases to 1,137 portions, whereas that of Tofu with Minced Pork decreases to its lowest supply level, 200 portions. In this case, the total supply reaches 8,527 portions, which is within the required range of 8,000–9,000 portions for total supply. For the variation in α from 0.3 to 0.9, the recommended supply quantities of the six dishes do not change, meaning that the model demonstrates good stability under both moderate and rather high satisfaction weights.

V. Conclusions

For the investigation of menu planning problems constrained by limited raw material supply and other issues, six representative dishes served at the high school cafeteria were chosen as the research objects, and a dish allocation optimization model was designed. First, a base model that aims to maximize students' satisfaction was built in this paper, and it was solved by considering the constraint of raw material supply and the total meal volume constraints. The results show that the dish of Stir-fried Bitter Melon with Lean Pork, which satisfies few students' needs and uses some shared raw materials, is recommended to have a supply volume of zero. Though it makes sense from a mathematical point of view, it does not totally fit the real situation of high school cafeterias, which are required to have stable menus with diversified dishes.

On this basis, an optimized model is then built considering some improvements. Student satisfaction and profit per serving have been standardized, and an optimized overall benefit objective function is created in the model. Raw material supply limits, total meal volume, the minimum supply volumes of dishes, and non-negative integer constraints serve as the constraints of this model.

In terms of individual results, Stir-fried Broccoli with Lean Pork, Scrambled Eggs with Tomato, and Chinese Cabbage with Meatballs have comparatively high supply quantities in the optimal solution, which means that such meals have considerable allocation advantages in terms of satisfaction level, profitability, and available resources. Although students are less satisfied with Stir-fried Bitter Melon with Lean Pork, it still holds a certain supply quantity due to its acceptable profitability and the necessity for the canteen to provide various meals. This result is more realistic than just setting the quantity to zero.

Nevertheless, the model proposed in this paper has some shortcomings that require further improvement. First, the ranges of the total meal supply and the minimum supply quantities have to be tuned using sufficient data on sales history, students' preferences, and canteen catering data. Second, several factors are not considered in the current model, such as cooking time, number of service windows, chefs' workload, nutritional composition, and variations in the number of diners every day. Third, there is a certain subjectivity in assigning weights to the satisfaction and profitability indicators. Further research can validate the model's robustness by collecting additional questionnaire data and performing sensitivity analysis. Further studies can introduce new constraints related to nutritional balance, catering capacity of the service windows, and forecasts of catering demand dynamics into the current model, so that the generated dish allocation plan would better reflect the reality of high school canteen operations.

In sum, the programming model provides an easy-to-use and computationally efficient approach to solving the problem of optimal dish allocation in high school canteens. Using a combined analysis of students' satisfaction, canteens' profitability, raw material availability, catering demand, and variety of dishes, canteens will be able to develop dish mixes in a more structured and evidence-based way. In addition to improving dining satisfaction, this method will also help to optimize the utilization of raw materials and to implement a data-driven approach to managing the canteens.

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