# Optimizing University Dining Hall Profitability During Inflation: A Case Study of UW-Madison

Qisheng Su

University of Wisconsin Madison, 702 W Johnson St, Suite 1101, Madison, 53715, Wisconsin

qsu28@wisc.edu

**Abstract.** Facing rising operational costs and the need to balance student satisfaction, university dining halls are under the challenge of optimizing their meal plans. Existing approaches commonly rely on fixed meal plans with limited choices and suppliers, leading to potential student dissatisfaction. However, such methods often suffer from the trade-off between supply and demand, potentially exacerbating conflicts and diminishing student satisfaction. This paper proposes an innovative approach that leverages an optimization model to adjust portion sizes and caloric compositions dynamically. The methodology involves mathematical modeling, allowing for precise adjustments in portion sizes and food composition. This dynamic approach offers the potential to improve both cost-effectiveness and student satisfaction. Validation of the model's performance demonstrates its ability to resolve institutional contradictions and enhance overall satisfaction, offering substantial potential value for university dining operations. Future improvements to the model could explore incorporating real-time market data, improving sensitivity analysis, and considering external factors such as student feedback and competitor pricing, further refining its ability to navigate economic uncertainty and optimize dining hall profitability.

**Keywords:** University Dining Optimization, Linear Programming, Mixed-Integer Linear Program

## 1 Introduction

This project studies how the university dining hall can maximize profit by balancing the trade-off between students' dissatisfaction and increasing operation costs. In recent years, as Mathewson notes [1], college dining costs have risen 47 percent in the past year, while overall food costs have risen 26 percent nationwide over the same period. This results in today's undergraduate students who purchase a dining plan at a college dining hall typically spending much more on food than Americans who cook and eat at home. Meanwhile, the rising labor and food costs have been threatening the profitability of the university dining hall [2]. Specifically, inflation rises so fast that the dining hall is stuck with a fixed meal plan revenue for an entire year, so cutting costs is the only way to reduce total loss. The dining hall can provide smaller portions and less


F. Cao et al. (eds.), *Proceedings of the 2023 5th International Conference on Economic Management and Cultural Industry (ICEMCI 2023)*, Advances in Economics, Business and Management Research 276,
https://doi.org/10.2991/978-94-6463-368-9_54

meat to achieve this goal. However, the dining hall shall give food to a particular nutrition standard [3] by optimizing what food is provided and how much food is provided to satisfy the dining requirements while effectively cutting the cost.

These raw material food cost data will be estimated from grocery prices on the U.S. BUREAU OF LABOR STATISTICS website [4]. In this case, the baseline operating cost of dining will be collected from UW 2021-2022 budget pages 9 and 10 [5], where the University Dining, as an auxiliary unit of UW Madison, generated 99.5 million dollars in total income and 93.3 million dollars in total expenditure. Moreover, the non-dinning revenue is estimated from the number of students living in residence halls [6] and the average rate of 7500 dollars per person per year [7], and we assume university housing achieves break-even on revenue and expenditure on non-dinning business. We also assume all students living in residence halls choose the mid-tier dining plan of 4350 dollars per person per year, which includes 14 meals per week. Then, we assume nonresident dining to be 12 dollars per meal on average [8].

Next, we assume no matter how many nonresident visits, the dining hall always prepares 18 meals per resident student per week, and there are four weeks a month, eight months per academic year. Another assumption is that only raw material prices in the academic year under consideration action differ from the previous academic year, and the number of resident visits to the dining hall remains the same as the baseline year and is unaffected by what the dining hall does. If necessary, the dining hall can adjust the caloric composition of served foods and the portion size, independently impacting the cost. Under this scenario, per a 5% reduction in the portion size, the food cost is reduced by 0.5% because students crowd, and the speed of food distribution is slowed, effectively lowering the total quantity of food provided; we assume the current caloric composition of raw materials is 50% carb, 20% vege, and 30% meat (percentages add up to one). To estimate the number of nonresident visits, we assume increasing(decreasing) per 1% of meat gains(loses) 40 non-meal plan visits per month. Decreasing(increasing) per 1% of carb gains(loses) 10 monthly non-meal plan visits. There are currently 1,500 non-meal plan visits per month. In any two consecutive months (sliding window), carbo/vege/meat composition can't be lower than 20%/10%/10% so the dining hall can meet nutrition standards. We assume nonresident visits are a perturbation on the meal-plan visits and thus only contribute to the revenue, not the cost.

## 2 Mathematical Model

The mathematical model formulated for this project seeks to maximize the profitability of the university dining hall while considering the trade-off between students' satisfaction and operational costs. The key variables, constraints, and objective function are detailed below:

**Decision Variables**

Let $s_i$ denote the portion size reduction factor in month $i$ (1), $c_{f,i}$ represent the caloric composition of component $f$ in month $i$ (2), and $N_i$ indicate the number of non-resident visits in month $i$ (3).

**Constraints**

The optimization problem is subject to several constraints:

$$\text{Caloric Composition Constraints:} \quad \sum_f c_{f,i} = 1, \quad \forall i \in \text{Months}(4),$$

$$\text{Portion Size Constraints:} \quad c_{f,i-1} + c_{f,i} \geq 0.1 \times 2, \quad \forall f,\ i \in \text{Months}(5),$$

$$\text{Non-Resident Visitor Constraints:} \quad N_i = \left(\frac{c_{\text{meat},i-1} - 0.3}{0.01} \times 40\right) - \left(\frac{c_{\text{carb},i-1} - 0.5}{0.01} \times 10\right)$$

$$- 2 \cdot s_{i-1} \cdot N_1 + N_1, \quad \forall i \in \text{Months}(6).$$

Note: the i in months cannot be 0 and the i in portion size constraints should be greater than or equal to 2.

**Objective Function**

The objective is to maximize the total revenue while minimizing costs:

$$\text{Maximize:} \quad \text{Revenue} = 8 \times 10^3 \times (18 \times \sum_f p_{f,1} \cdot c_{f,1} - \sum_f \sum_i p_{f,i} \cdot c_{f,i})$$

$$+ 8 \times 10^3 \times \sum_i \left((1 - s_i) \cdot \sum_f p_{f,i} \cdot c_{f,i}\right) + 8 \times 10^3 \times 4350 + \sum_i N_i \cdot 12.$$

(7)

**Fig. 1.** Major components of mixed integer linear program to maximize the school dining hall profit

The optimization problem can be succinctly expressed as follows:

Maximize: Revenue

Subject to: Caloric Composition Constraints, Portion Size Constraints, Non-Resident Visitor Constraints.

In summary, this optimization problem, formulated as a Mixed-Integer Linear Programming (MILP) problem, addresses the critical challenge of maximizing the profitability of the university dining hall. This challenge is achieved while meticulously considering the delicate balance between student satisfaction and operational costs. Our mathematical model is driven by key decision variables:

- $s_i$, representing the portion size reduction factor in month $i$ (1).
- $c_{f,i}$, denoting the caloric composition of component $f$ in month $i$ (2).
- $N_i$, indicating the number of non-resident visits in month $i$ (3).

**Fig. 2.** Generalized standard form of this linear optimization program

These variables are intricately guided by a set of specific constraints. First, the caloric composition must sum up to 100%for each month (4). Second, changes in component proportions should not deviate by less than 10% between consecutive months (5). Third, the number of non-resident visits ($Ni$Ni) is intricately determined by alterations in meat and carb compositions, with the inclusion of the portion size factor (6) (Fig.1).

Our objective function is designed to maximize total revenue while minimizing costs (7) (Fig.1). It combines various elements, including adjustments to caloric composition, reductions in portion sizes, constant contributions, and non-resident visit revenue. In essence, our model is a complex optimization challenge that seeks to find the optimal combination of portion sizes, food compositions, and non-resident visits to maximize profitability. This framework in general form adeptly captures the intricate trade-offs among these factors (Fig.2).

Through this comprehensive mathematical model, this study provides valuable solutions to adapt to various inflation scenarios, enabling university dining halls to make informed decisions that consider both student satisfaction and financial sustainability.

## 3 Experiment

The Julia code uses JuMP, Clp, and LinearAlgebra libraries to maximize a university dining hall's profits while maintaining student satisfaction by adjusting food prices for inflation and optimizing food quantities and compositions. It focuses on meat, carbs, and vegetables, aiming to maximize revenue from meal plans and non-resident visitors. Here's a condensed summary:

The code establishes an optimization model using JuMP to enhance a university dining hall's profitability while ensuring student satisfaction. It adapts food prices for inflation and considers portion sizes and meal composition. The goal is to maximize revenue from meal plans and non-resident visitors. The code defines data, variables, constraints, and an objective function in distinct sections. It uses an optimization solver to provide results, including caloric composition, portion size reductions, non-resident visitor numbers, and total revenue.

The optimization problem determines monthly caloric composition (carb, meat, vegetable), portion size reduction, and non-resident visitor numbers, aiming to maximize total revenue while considering constraints on meal composition, visitor numbers, and portion size reduction. The process involves six major steps:

1. Optimization Tool and Model Creation: Specify the Clp optimization tool and create the model 'm' using JuMP.
2. Data Setup: Define month types and adjust food prices based on certain factors.
3. Variables and Constraints: Define decision variables for caloric composition ('c'), portion size reduction ('s'), and non-resident visitor numbers ('N'). Add constraints to ensure composition adds up to 1, maintain composition continuity between months, and calculate visitor numbers based on meal composition.
4. Objective Function: Maximize total revenue by considering revenue from meal plans, non-resident dining, and ingredient costs based on meal composition.
5. Solve the Optimization Problem: Use the 'optimize!' function to find optimal values for decision variables that maximize the objective function.
6. Extract and Print Results: After solving the problem, display caloric composition, non-resident visitor numbers, portion size reduction, total revenue, and detailed cost and composition breakdown for each month.

This code provides a versatile tool for dining hall management, allowing users to adjust data, constraints, and the objective function to adapt to changing market scenarios for informed decision-making. To be specific, the intended users of these codes, such as a school cafeteria manager or a manager at a food service company, can reuse them by following these steps: First, they can modify the model's parameters and data for specific situations and needs, such as adjusting month ranges, updating food types, or re-estimating food prices. This way, they can customize the model for a specific restaurant or cafeteria environment. Secondly, users can run the model repeatedly to obtain optimization results according to economic conditions or market changes. They can easily modify the objective function to focus on key performance indicators, such as profit maximization or cost minimization. In addition, users can embed this code into a real-time decision support system to make real-time decisions in their day-to-day operations. This allows them to make timely adjustments and decisions based on the latest data and intelligence. Finally, users can perform scenario analysis to assess business performance under different scenarios, such as considering inflation, food price fluctuations, or changes in different customer needs. This helps them develop strategies to deal with uncertainty and ensure that restaurants remain competitive in various market conditions.

Together, these codes and outputs (see appendix) provide restaurant managers with a flexible and sustainable tool to continuously optimize restaurant operations, balancing economic benefits and customer satisfaction while responding to changing market conditions and economic challenges. Users can reuse this code for continuous business improvement and decision support, depending on the context and needs.

## 4 Results and Discussion

The optimization process iteratively maximizes revenue while adhering to constraints, resulting in the following key findings:

1. Caloric Composition (Matrix Form):

- Component 1 (Carb) varies with peaks in months 1 and 4.
- Component 2 (Meat) fluctuates, with highs in months 3 and 5.
- Component 3 (Vegetable) varies, peaking in months 3 and 5.

2. Non-Resident Visitor Numbers:

- Monthly non-resident visitors range from 1,500 to a peak of 4,000 in months 4 to 7.

3. Shrinkage in Portion Served:

- No portion shrinkage (all values are zero).

4. Objective Value:

- Total revenue from optimization is approximately $35.32 million.

5. Detailed Breakdown:

- Baseline Cost: 39.5 million of dollars.
- Baseline Food Cost: Initial composition-based cost for the first month.
- Meal Plan Total Revenue: 4,350 dollars per undergraduate for 8,000 students.

- Non-Resident Dining Revenue: 12 dollars per visit.

6. Detailed Caloric Composition and Prices:

- Monthly caloric composition and total cost based on composition and food prices.

The unique feature of this study is the use of a mixed integer linear programming method to solve the profit maximization problem in the catering industry. This linear programming method, which includes integer variables and linear constraints, has been widely used in agricultural operations. For example, Ghezavati et al. [9] modeled the mathematical distribution problem after qualitative separation to maximize dealers' profit by using fresh agricultural products- tomatoes. They designed a quality loss function based on the applicable quality of each customer in the real world, considering the freshness, maturity, and quantified food quality loss, to complete the mixed integer modeling. In contrast, this paper proposes a hybrid integer programming model aiming at the profit maximization of the school canteen. This model can still be effectively solved under the influence of real-time changes such as inflation rate, changes in food prices, and changes in cafeteria passenger flow under the changeable economic situation. In the study of De et al. [10], based on the Norwegian salmon supply chain network, they adopted the mathematical formula of mixed integer linear programming model to solve the problems related to transportation cost and supply chain efficiency. This approach can also be applied to profit optimization in school canteens by turning constraints into students' tastes and needs that must be met. This unique approach considers several critical factors, including the inflationary effect of food prices and the optimization of the quantity and composition of food products, focusing on regulating the supply of essential ingredients such as meat, carbohydrates, and vegetables in the management of canteen operations.

In summary, the optimization model provides insights into balancing profitability and student satisfaction. Caloric composition adjustments are presented, offering a strategy for managing carb, meat, and vegetable proportions over eight months. Users can adapt parameters to align with constraints and optimization objectives, accommodating changing food prices while ensuring nutrition. The model yields an objective value representing optimal revenue under average inflation. Detailed results highlight economic implications, including baseline revenue, food costs, meal plans, and non-resident dining revenue. Comparative analysis reveals model effectiveness, but limitations exist. Assumptions of linear relationships, constant resident visits, and minimal price fluctuations oversimplify reality. Broader considerations include food quality, customer satisfaction, data accuracy, and scalability. Assumption variations should be explored through robustness tests and scenario analyses to address result sensitivities, enhancing decision-making amid economic uncertainty.

## 5 Conclusion

In conclusion, this project has effectively addressed the formidable challenge of optimizing university dining hall profitability while harmonizing student satisfaction and operational efficiency. Through the application of linear optimization in real-world scenarios, it has delivered tangible and practical solutions. The development of a robust mathematical model has enabled us to fine-tune portion sizes, caloric compositions, and non-resident visits to achieve desired financial outcomes across a spectrum of inflation scenarios.

The optimization results have unveiled various scenarios encompassing caloric composition and meal plan pricing strategies, all with the primary objective of revenue maximization. Considering three distinct caloric components with adaptable proportions for each month, we've determined that baseline costs amount to 39.5 million dollars, serving 8,000 undergraduates over 18 meals. The meal plan alone generates an approximate total revenue of 34.8 million dollars, supplemented by an additional 280,800 dollars from non-resident dining. Diverse caloric compositions have been recommended for each month, each associated with corresponding total costs. The overarching goal remains revenue maximization, resulting in a revenue range spanning from approximately 35.3 million to 35.5 million dollars across different scenarios. While the model has yielded invaluable strategic insights and demonstrated adaptability to varying inflation contexts, it's important to acknowledge its inherent limitations, rooted in simplified linear assumptions and potential data errors. To enhance the model's reliability and applicability, sensitivity analyses are crucial to discern how assumptions influence results.

Moving forward, there exists an exciting opportunity to develop a more comprehensive and dynamic model that empowers university dining halls to incorporate real-time market conditions, student feedback, and competitor pricing into their strategies. This adaptive approach is essential for thriving amidst the escalating competition in the catering industry, especially within an ever-fluctuating economic landscape. In essence, this research also serves as a practical and actionable solution to the profitability challenges faced by university dining halls. It lays the groundwork for continued enhancements and the sustainable evolution of this model, ultimately contributing to informed decision-making and operational excellence in the higher education culinary sector.

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