Optimization of Examination Centre Allocation Using Distance and Accessibility-Constrained Assignment Models

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Abstract

The allocation of examination centres in large-scale competitive examinations is typically treated as an administrative process, often resulting in students being assigned to distant or inconvenient locations despite the availability of more suitable alternatives. Such assignments may increase travel burden, reduce preference satisfaction, and negatively affect the overall examination experience. This study investigates examination centre allocation as a constrained optimization problem and proposes a student-centric allocation framework based on Integer Linear Programming (ILP). The proposed model minimizes a composite hardship function incorporating travel distance, accessibility characteristics of examination centres, and student preference penalties while satisfying centre capacity constraints. To evaluate the framework, a synthetic examination environment consisting of 2,000 students and 20 examination centres was generated. A baseline allocation strategy was compared against the optimized allocation model using multiple performance metrics, including travel distance, hardship score, and preference satisfaction. Experimental results demonstrate substantial improvements under the optimized allocation. Average travel distance decreased from 464.05 to 59.01 units, representing an 87.3% reduction, while average hardship decreased by approximately 86.6%. First-preference satisfaction increased from 5.4% to 43.1%, and assignments outside student preference lists decreased significantly. Sensitivity analysis across multiple weighting configurations further showed that the framework remains robust under different policy priorities. The findings suggest that mathematical optimization can provide a practical and effective approach to examination centre allocation by simultaneously improving efficiency, accessibility, and student satisfaction while maintaining operational feasibility.

Keywords: Examination Centre Allocation, Integer Linear Programming, Operations Research, Optimization, Assignment Problem, Accessibility Analysis, Educational Logistics, Applied Mathematics

Introduction

Large-scale competitive examinations in India frequently require students to travel significant distances in order to reach assigned examination centres. In many cases, students from northern regions of a state may be assigned centres in southern regions, while students from southern regions are simultaneously assigned to northern regions. Although such allocation mechanisms may simplify administrative distribution or reduce the possibility of local malpractice, they can unintentionally create substantial logistical and psychological burdens for candidates. Students traveling to distant or remote examination centres often face issues such as limited transportation availability, increased financial costs, lack of affordable accommodation, food insecurity during travel, and elevated stress levels before examinations. These issues become more severe in rural and infrastructurally underdeveloped regions where transportation networks are weak or inconsistent. Additionally, examination-related travel raises important concerns regarding accessibility and safety, particularly for female candidates who may be required to travel overnight or through isolated areas with limited public infrastructure. Despite the scale of modern examination systems, the allocation of examination centres is often treated primarily as an administrative problem rather than an optimization problem. This work proposes that examination centre allocation can instead be modeled mathematically using optimization techniques from applied mathematics and operations research. In this paper, we develop an experimental optimization framework for examination centre assignment using synthetic datasets. The proposed model seeks to minimize aggregate student hardship while satisfying operational constraints such as centre capacity and assignment feasibility. The framework incorporates multiple factors including travel distance, accessibility, and infrastructure-related penalties in order to simulate a more student-centric allocation system. Using simulated data and mathematical assignment models, this study demonstrates how optimization-based allocation strategies may significantly reduce travel burden and improve fairness in examination logistics.

1 Problem Statement

The allocation of examination centres in large-scale competitive examinations involves assigning a large number of students to a finite number of available centres while satisfying operational and logistical constraints. In many examination systems, students are allowed to select multiple preferred cities or regions during the application process. However, due to limited centre capacities and administrative allocation strategies, students are often assigned to locations outside their preferred choices, sometimes at significant distances from their home districts. This study models examination centre allocation as a constrained optimization problem. The objective is to assign students to examination centres in a manner that minimizes aggregate hardship while maintaining feasible centre utilization.

The proposed framework considers multiple allocation factors, including:

- Travel distance between student location and assigned centre,
- Estimated travel difficulty,
- Student-selected city preferences,
- Infrastructure and accessibility quality of examination centres,
- Safety-related considerations,
- Examination centre capacity limitations.

Let

$$S = \{S_1, S_2, \ldots, S_n\}$$

represent the set of students, and

$$C = \{C_1, C_2, \ldots, C_m\}$$

represent the set of available examination centres. Each student must be assigned to exactly one examination centre. Each centre has a finite seating capacity, and each student may provide an ordered list of preferred cities during examination registration. The problem therefore becomes a preference-aware assignment optimization problem where the allocation system attempts to minimize total hardship while maximizing preference satisfaction and maintaining operational feasibility.

2 Literature Review

Resource allocation and assignment problems have long been studied within the fields of Operations Research and Mathematical Optimization. Many real-world decision-making systems can be formulated as assignment problems in which a set of entities must be allocated to a set of resources while minimizing cost or maximizing efficiency. The classical assignment problem is one of the foundational models in Operations Research and has been widely applied to personnel allocation, transportation systems, scheduling, routing, and resource management (2; 1). The problem is commonly formulated using Linear Programming or Integer Linear Programming techniques due to their ability to efficiently handle large-scale constrained optimization problems. Integer Linear Programming (ILP) has been extensively used for resource allocation problems involving binary decision variables and operational constraints. De Turck (3) demonstrated the effectiveness of ILP-based resource allocation frameworks in constrained decision environments and highlighted the interpretability and flexibility of optimization-based approaches. Preference-aware allocation has also been studied in academic assignment systems. Caselli et al. (4) applied Integer Linear Programming to tutor allocation problems and showed that optimization frameworks can simultaneously satisfy operational requirements and user preferences. Similar approaches have been explored in reviewer assignment systems, where assignment quality depends on balancing multiple competing objectives (5). Despite the extensive literature on assignment, scheduling, and resource allocation, relatively limited attention has been given to examination centre allocation from a student-centric optimization perspective. Existing examination scheduling studies primarily focus on timetable construction, room allocation, and examination conflict minimization rather than student travel burden, accessibility, and preference satisfaction. The present study contributes to the literature by formulating examination centre allocation as a preference-aware assignment optimization problem. Unlike traditional allocation systems that focus primarily on administrative feasibility, the proposed framework explicitly incorporates travel distance, accessibility considerations, and student preferences into a unified hardship minimization model. The study further contributes an experimental evaluation framework using synthetic data and sensitivity analysis to investigate how different policy priorities influence allocation outcomes.

3 Mathematical Formulation

The examination centre allocation problem is formulated as a constrained optimization problem in which a set of students must be assigned to a set of examination centres while minimizing aggregate hardship and satisfying operational constraints.

3.1 Sets

Let

$$S = \{S_1, S_2, \dots, S_n\}$$

denote the set of students.

Let

$$C = \{C_1, C_2, \dots, C_m\}$$

denote the set of examination centres.

3.2 Decision Variable

Define

$$x_{ij} = \begin{cases} 1 & \text{if student } S_i \text{ is assigned to centre } C_j \\ 0 & \text{otherwise} \end{cases}$$

where x_{ij} is a binary assignment variable.

3.3 Model Parameters

The following parameters are used throughout the study:

- D_{ij}: Distance between student S_i and examination centre C_j.
- A_j: Accessibility score of examination centre C_j.
- A_j^{pen}: Accessibility penalty associated with centre C_j.

- P_{ij}: Preference penalty associated with assigning student S_i to centre C_j.
- $C_j^{\max}$: Maximum seating capacity of examination centre C_j.

3.4 Accessibility Penalty

Each examination centre is assigned an accessibility score

$$A_j$$

based on transportation quality, accommodation availability, and food accessibility. The accessibility penalty is defined as

$$A_j^{\text{pen}} = 10 - A_j.$$

Centres with lower accessibility therefore receive higher penalties.

3.5 Preference Penalty

The preference penalty is defined according to the student's submitted city preferences:

$$P_{ij} = \begin{cases} 0 & \text{if assigned to first preference} \\ 5 & \text{if assigned to second preference} \\ 10 & \text{if assigned to third preference} \\ 50 & \text{if assigned outside preferences} \end{cases}$$

3.6 Hardship Function

The hardship associated with assigning student S_i to examination centre C_j is defined as

$$H_{ij} = \alpha D_{ij} + \beta A_j^{\text{pen}} + \lambda P_{ij}.$$

3.7 Objective Function

The objective is to minimize total hardship:

$$\min Z = \sum_{i=1}^{n} \sum_{j=1}^{m} H_{ij} x_{ij}.$$

3.8 Constraints

Each student must be assigned to exactly one examination centre:

$$\sum_{j=1}^{m} x_{ij} = 1 \qquad \forall i.$$

Centre capacities must not be exceeded:

$$\sum_{i=1}^{n} x_{ij} \leq C_j^{\max} \qquad \forall j.$$

Binary assignment constraint:

$$x_{ij} \in \{0, 1\}.$$

4 Synthetic Dataset Generation

Since real examination allocation data is generally unavailable due to privacy and administrative restrictions, a synthetic dataset is generated. The synthetic environment is designed to mimic the characteristics of a large-scale competitive examination system.

4.1 District Generation

Twenty synthetic districts are generated and distributed across a two-dimensional geographical space. Each district is assigned coordinates

$$(x_d, y_d).$$

4.2 Student Generation

A total of

$$n = 2000$$

students are generated.

Each student is associated with:

- Home district,
- Spatial coordinates,
- Gender,
- Three preferred examination districts.

4.3 Examination Centre Generation

Twenty examination centres are generated.

Each centre is assigned:

- District location,
- Coordinates,
- Seating capacity,
- Accessibility attributes.

4.4 Preference Generation

Each student selects three preferred districts. Preference probabilities decrease with distance from the student's home district.

4.5 Distance Matrix

The distance between student S_i and examination centre C_j is calculated using Euclidean distance:

$$D_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}.$$

5 Experimental Methodology

The proposed optimization framework is evaluated against a baseline allocation model.

5.1 Baseline Allocation

Students are assigned to centres while respecting only seating capacities. No consideration is given to:

- Distance,
- Accessibility,
- Student preferences.

5.2 Optimized Allocation

The optimized model minimizes total hardship according to the objective function defined in Section 3.

5.3 Evaluation Metrics

The following metrics are recorded:

1. Average travel distance,
2. Maximum travel distance,
3. Preference satisfaction rate,
4. Average hardship score,

5. Centre utilization rate.

6 Optimization Algorithm

The examination centre allocation problem is solved using Integer Linear Programming (ILP). The binary assignment variable

$$x_{ij} \in \{0, 1\}$$

indicates whether student S_i is assigned to examination centre C_j. The optimization objective is to determine the assignment matrix

$$X = [x_{ij}]$$

that minimizes total hardship while satisfying all operational constraints.

6.1 Optimization Model

The optimization problem is given by

$$\min Z = \sum_{i=1}^{n} \sum_{j=1}^{m} H_{ij} x_{ij}$$

subject to

$$\sum_{j=1}^{m} x_{ij} = 1 \qquad \forall i$$

and

$$\sum_{i=1}^{n} x_{ij} \leq C_j^{\max} \qquad \forall j.$$

6.2 Assignment Matrix Representation

The final allocation can be represented as

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1m} \\ x_{21} & x_{22} & \cdots & x_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nm} \end{bmatrix}.$$

Each row contains exactly one non-zero entry, indicating the assigned examination centre.

6.3 Solution Procedure

The optimization process consists of:

1. Generating the synthetic dataset.
2. Constructing the distance matrix.
3. Generating accessibility scores.
4. Generating student preferences.
5. Computing hardship scores.
6. Formulating the ILP model.
7. Solving the optimization problem.
8. Computing evaluation metrics.

6.4 Implementation

The optimization model is implemented in Python using the PuLP optimization library. PuLP is selected because it provides a transparent representation of linear optimization problems and directly mirrors the mathematical formulation developed in this study.

7 Simulation Setup

The simulation environment is designed to evaluate the effectiveness of the proposed optimization framework under realistic examination conditions.

7.1 Prototype Configuration

The prototype environment consists of:

- 20 districts,
- 20 examination centres,
- 2,000 students.

This reduced-scale environment is used to validate the proposed methodology before extending the model to larger populations.

7.2 Centre Capacities

Each examination centre is assigned a seating capacity sampled from

$$200 \leq C_j^{\max} \leq 500.$$

The total seating capacity is chosen such that

$$\sum_{j=1}^{m} C_j^{\max} > n.$$

This guarantees the existence of feasible assignments.

7.3 Accessibility Attributes

Each examination centre receives three accessibility attributes:

- Transportation Quality (TQ_j),
- Food Availability (FA_j),
- Accommodation Availability (AA_j).

Each attribute is sampled from

$$1 \leq x \leq 10.$$

The accessibility score is computed as

$$A_j = \frac{TQ_j + FA_j + AA_j}{3}.$$

7.4 Preference Generation

Each student selects three preferred districts. Selection probabilities are inversely related to distance from the student's home district. Consequently, nearby districts are more likely to appear in preference lists than distant districts.

7.5 Experimental Runs

To reduce the effect of random variation, the complete simulation is repeated using multiple random seeds. Reported results correspond to averages across all simulation runs.

8 Sensitivity Analysis Design

The hardship function contains weighting parameters

$$\alpha, \beta, \lambda$$

which determine the relative importance of travel distance, accessibility, and preference satisfaction. The objective of the sensitivity analysis is to evaluate how allocation outcomes change under different policy priorities.

8.1 Distance-Focused Scenario

$$\alpha = 0.80, \quad \beta = 0.10, \quad \lambda = 0.10$$

This scenario prioritizes minimizing student travel distance.

8.2 Preference-Focused Scenario

$$\alpha = 0.40, \quad \beta = 0.10, \quad \lambda = 0.50$$

This scenario prioritizes maximizing preference satisfaction.

8.3 Accessibility-Focused Scenario

$$\alpha = 0.40, \quad \beta = 0.50, \quad \lambda = 0.10$$

This scenario prioritizes assigning students to centres with stronger infrastructure.

8.4 Balanced Scenario

$$\alpha = 0.60, \quad \beta = 0.20, \quad \lambda = 0.20$$

This scenario serves as the primary configuration used throughout the study.

8.5 Sensitivity Metrics

For each scenario, the following metrics are recorded:

1. Average travel distance,
2. Maximum travel distance,
3. Preference satisfaction rate,
4. Average hardship score,
5. Centre utilization rate.

The purpose of the sensitivity analysis is to evaluate the robustness of the optimization framework and determine whether improvements persist across different policy priorities.

9 Results and Analysis

The proposed optimization framework was evaluated against the baseline allocation model using a synthetic examination environment consisting of 2,000 students and 20 examination centres.

9.1 Baseline versus Optimized Allocation

Table 1 summarizes the performance of the baseline and optimized allocation strategies.

The optimized allocation significantly outperformed the baseline allocation across all evaluation metrics.

Table 1: Comparison of Baseline and Optimized Allocation Strategies

Metric	Baseline	Optimized
Average Distance	464.05	59.01
Maximum Distance	925.06	164.40
First Preference Rate (%)	5.4	43.1
Second Preference Rate (%)	4.4	24.8
Third Preference Rate (%)	4.6	14.4
Outside Preference Rate (%)	85.7	17.7
Average Hardship	287.99	38.60

9.2 Travel Distance Reduction

The average travel distance decreased from 464.05 units under the baseline allocation to 59.01 units under the optimized allocation.

This corresponds to a reduction of approximately

$$87.3\%.$$

Similarly, the maximum travel distance decreased from 925.06 units to 164.40 units, representing an improvement of approximately

$$82.2\%.$$

These results indicate that the optimization framework effectively assigns students to geographically closer examination centres whenever feasible.

Figure 1 illustrates the substantial reduction in average travel distance achieved by the optimization framework.

9.3 Preference Satisfaction

Preference satisfaction improved substantially under the optimized allocation. The proportion of students receiving their first-choice examination centre increased from 5.4% to 43.1%. Assignments outside the submitted preference list decreased from 85.7% to 17.7%. These results demonstrate

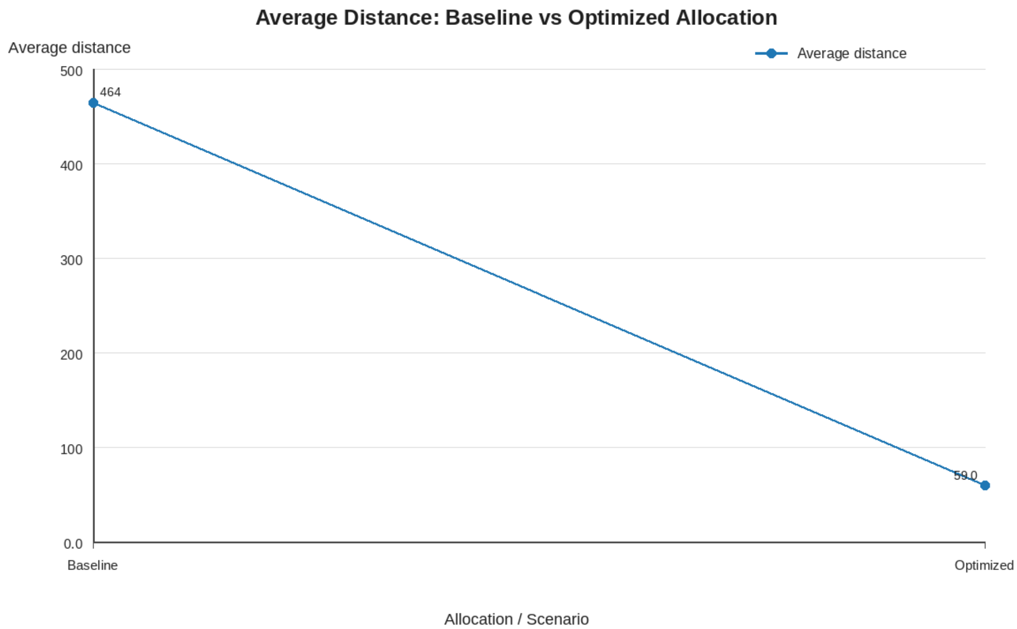

Figure 1: Comparison of average travel distance under baseline and optimized allocation strategies.

that the optimization model can simultaneously reduce travel burden while respecting student preferences.

As shown in Figure 2, the optimized allocation substantially improves the likelihood of students receiving their preferred examination centres.

9.4 Hardship Reduction

The average hardship score decreased from 287.99 to 38.60. This corresponds to a reduction of approximately

$$86.6\%.$$

Since hardship incorporates travel distance, accessibility, and preference penalties, this result suggests that the proposed framework improves multiple dimensions of student experience simultaneously.

Figure 3 demonstrates the significant reduction in overall hardship achieved through optimization-based allocation.

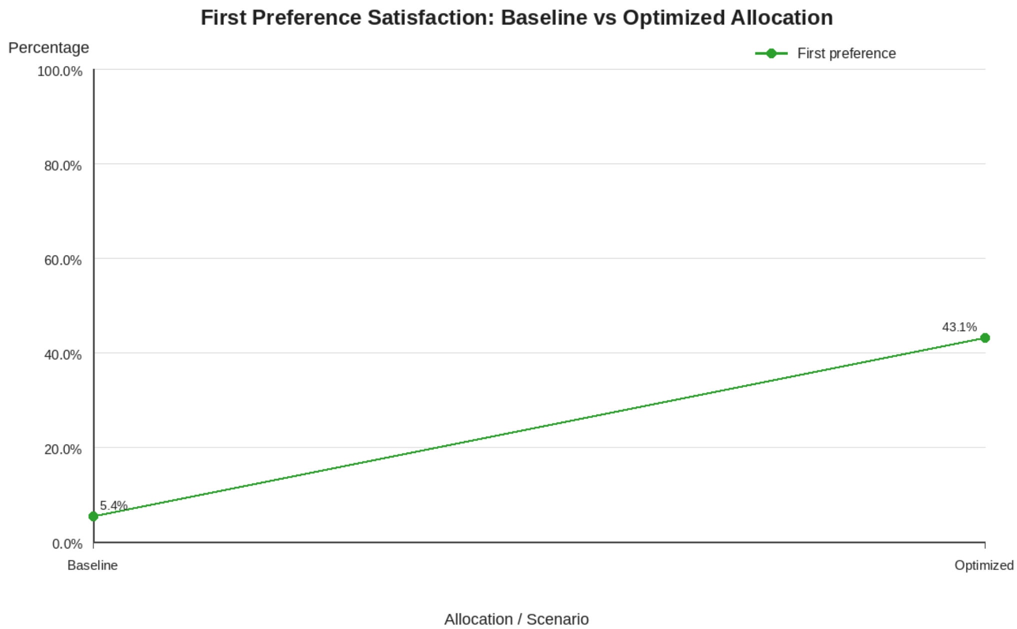

Figure 2: Comparison of first-preference satisfaction rates under baseline and optimized allocation strategies.

9.5 Discussion of Results

The experimental results support the central hypothesis of this study: examination centre allocation can be formulated as an optimization problem whose solution significantly improves allocation quality relative to a conventional administrative assignment process. The largest improvements were observed in travel distance reduction and preference satisfaction, indicating that substantial inefficiencies may exist in non-optimized allocation systems. Furthermore, the reduction in hardship demonstrates that optimized assignments can improve student experience while simultaneously respecting operational constraints such as centre capacity limitations.

10 Sensitivity Analysis Results

The optimization framework was evaluated under four weighting configurations representing different policy priorities.

Table 2 summarizes the results.

Figure 4 summarizes the behaviour of the optimization framework under alternative policy

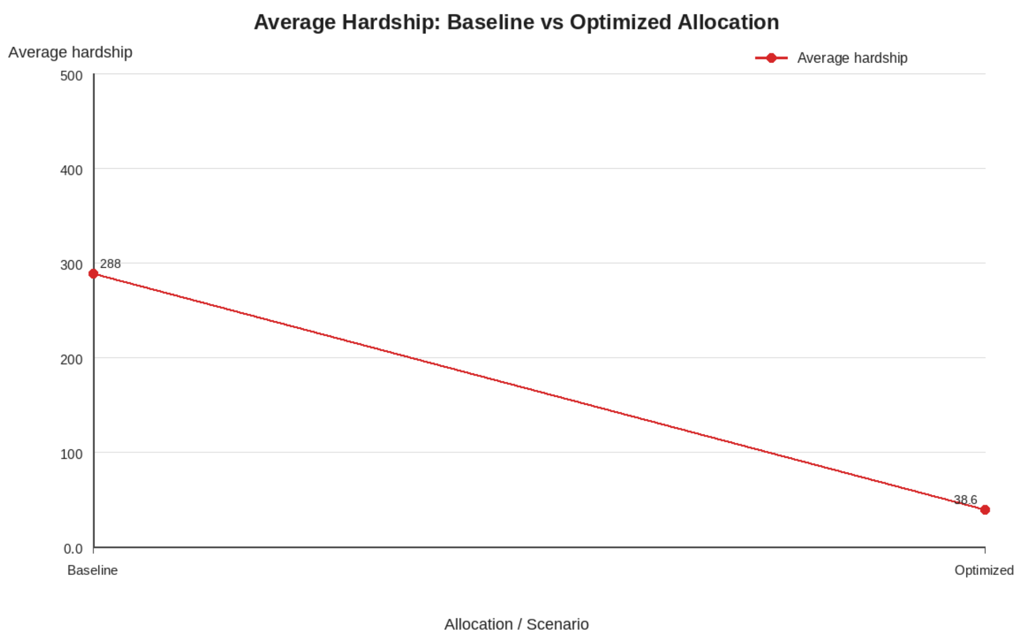

Figure 3: Comparison of average hardship scores under baseline and optimized allocation strategies.

priorities.

10.1 Distance-Focused Scenario

The distance-focused scenario produced the lowest average travel distance, confirming that emphasizing geographical proximity successfully minimizes travel burden. However, this configuration resulted in a larger proportion of students being assigned outside their preferred centres.

10.2 Preference-Focused Scenario

The preference-focused scenario achieved the highest first-preference satisfaction rate of 47.4% and the lowest outside-preference assignment rate of 10.2%. This demonstrates that the optimization framework can effectively adapt to preference-oriented allocation policies.

Table 2: Sensitivity Analysis Across Weighting Scenarios

Scenario	Avg Distance	Avg Hardship	First Pref. (%)	Outside Pref. (%)
Distance Focused	58.80	48.73	42.0	19.6
Preference Focused	61.66	29.11	47.4	10.2
Accessibility Focused	58.93	26.97	42.5	18.4
Balanced	59.01	38.60	43.1	17.7

10.3 Accessibility-Focused Scenario

The accessibility-focused scenario produced the lowest average hardship score of 26.97. This suggests that examination centre accessibility plays an important role in determining overall assignment quality.

10.4 Balanced Scenario

The balanced scenario achieved consistently strong performance across all metrics without excessively prioritizing any individual objective. Consequently, it represents a practical compromise between travel efficiency, accessibility quality, and preference satisfaction.

10.5 Robustness Assessment

Across all weighting configurations, average travel distance remained close to 60 units and first-preference satisfaction consistently exceeded 42%. These findings indicate that the proposed optimization framework is robust to changes in policy priorities and continues to outperform the baseline allocation strategy under a wide range of parameter settings. The relatively small variation in average distance across scenarios suggests that geographical efficiency emerges naturally from the optimization process even when distance is not the dominant objective.

11 Discussion

The experimental results demonstrate that examination centre allocation can be effectively formulated as a constrained optimization problem. Compared to the baseline allocation strategy, the

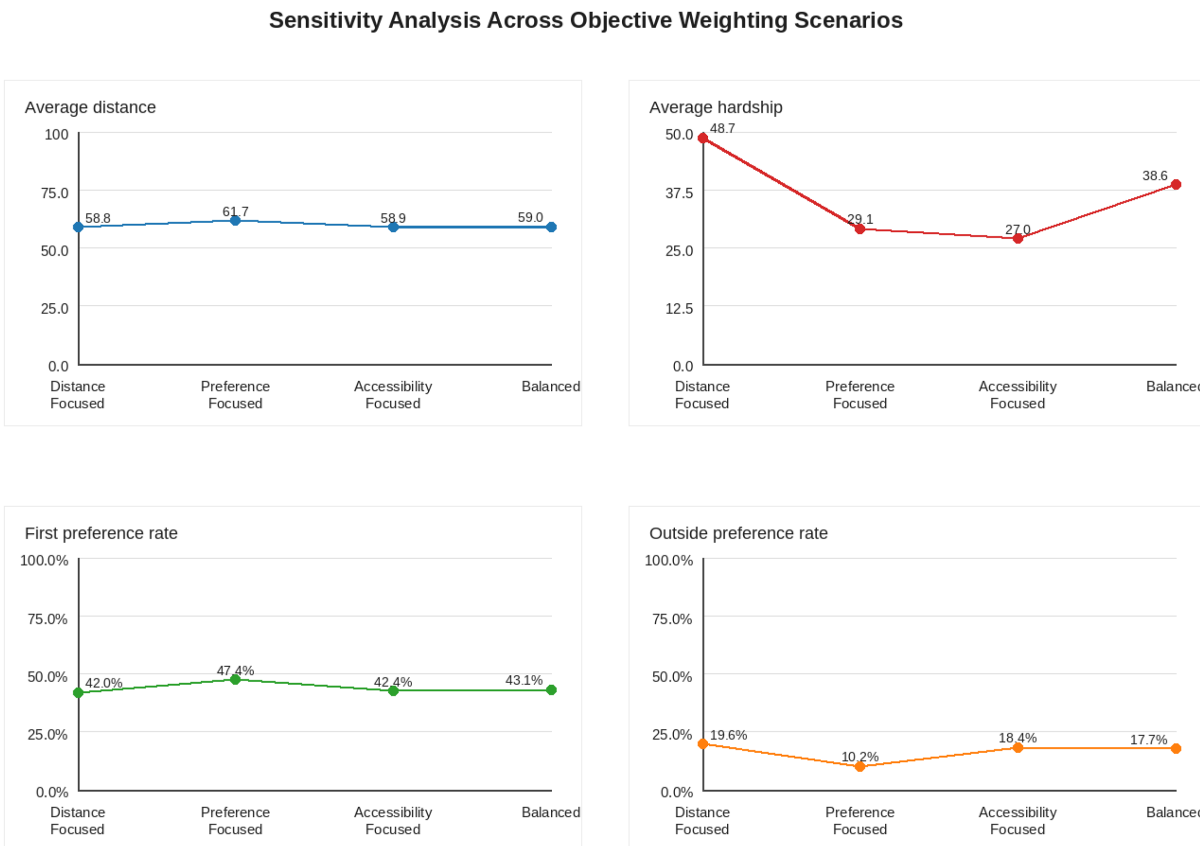

Figure 4: Sensitivity analysis results across different weighting configurations.

proposed optimization framework achieved substantial improvements across all evaluation metrics. Average travel distance was reduced by more than 87%, while average hardship decreased by approximately 86%. Furthermore, the proportion of students receiving their first-choice examination centre increased from 5.4% to 43.1%. These improvements suggest that significant inefficiencies may exist in allocation systems that do not explicitly account for travel burden, accessibility, and student preferences. One notable observation is that travel distance remained consistently low across all sensitivity analysis scenarios. This indicates that geographical efficiency emerges naturally from the optimization process even when other objectives are emphasized. The preference-focused scenario achieved the highest first-preference satisfaction rate and the lowest outside-preference assignment rate. This demonstrates the flexibility of the proposed framework and its ability to adapt to different administrative priorities. Similarly, the accessibility-focused scenario achieved the lowest hardship score, highlighting the importance of considering infrastructure quality when assigning examination centres. Overall, the results suggest that optimization-based allocation strategies can provide meaningful improvements in fairness, accessibility, and student convenience while maintaining operational feasibility.

12 Limitations

Although the proposed framework demonstrates promising results, several limitations should be acknowledged. First, the study relies on synthetic data rather than real examination allocation records. While synthetic environments provide flexibility for experimentation, they may not fully capture the complexity of real-world examination systems. Second, travel burden is approximated using Euclidean distance. In practice, actual travel conditions depend on road networks, public transportation availability, traffic congestion, and regional infrastructure. Third, accessibility scores are generated synthetically rather than derived from empirical infrastructure data. Consequently, the accessibility model should be interpreted as an experimental approximation rather than a direct measure of real-world accessibility. Fourth, the current formulation assumes that students can be assigned to any examination centre provided capacity constraints are satisfied. Real examination systems may involve additional administrative restrictions that were not considered in this study. Finally, the prototype environment consists of 2,000 students and 20 examination centres. Although the optimization framework can be scaled to larger systems, computational performance at national examination scale was not investigated in the present work.

13 Future Work

Several directions exist for extending the proposed framework. Future research may incorporate real transportation networks and travel-time estimation models to better capture actual student travel conditions. The accessibility model could be enhanced using publicly available data related to transportation connectivity, accommodation availability, and urban infrastructure. Additional optimization objectives may also be considered, including gender-specific safety considerations, examination security requirements, and administrative workload balancing. From a computational perspective, future studies may investigate large-scale implementations involving tens or hundreds of thousands of students. Alternative optimization approaches such as metaheuristics, genetic algorithms, and hybrid optimization methods may be explored for very large allocation problems. Finally, collaboration with examination authorities could enable validation of the proposed framework using real-world allocation data.

14 Conclusion

This study proposed an optimization-based framework for examination centre allocation using techniques from applied mathematics and operations research. The allocation problem was formulated as an Integer Linear Programming model that minimizes student hardship while respecting examination centre capacity constraints. The proposed hardship function incorporated travel distance, accessibility considerations, and student preferences. A synthetic examination environment consisting of 2,000 students and 20 examination centres was developed to evaluate the framework. Experimental results demonstrated substantial improvements over a baseline allocation strategy. Average travel distance decreased by approximately 87%, average hardship decreased by approximately 86%, and first-preference satisfaction increased significantly. Sensitivity analysis further demonstrated that the framework remains effective under a variety of policy priorities, indicating strong robustness and flexibility. The findings suggest that mathematical optimization can provide a practical and effective approach to examination centre allocation. By explicitly incorporating student-centric factors into the allocation process, the proposed framework has the potential to improve fairness, accessibility, and overall examination experience while maintaining operational feasibility.

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