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A New Integer Model for Selecting Students at Higher Education Institutions: Preparatory Classes of Engineers as Case Study

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Abstract: This study addresses the challenge of selecting outstanding students at higher education institutions under multiple constraints. We propose a novel integer programming solution to manage this process, formulating it as a constrained assignment problem with a maximization objective function. This function prioritizes the fair selection of students while respecting criteria such as academic qualifications, required skills, and student preferences. The goal is to develop a decision support system that efficiently selects qualified students at higher education institutions within a reasonable time. The model was tested using real data from Moroccan preparatory classes, achieving important assignment rates across all student categories. Results demonstrate significance in execution time, fulfillment of student choices, and prioritization of outstanding students. This approach offers a flexible, efficient solution for managing academic merit-based selections, optimizing resource utilization, and enhancing fairness in the selection process.

Keywords: student selection; integer programming; constrained assignment problem; operational research; decision-making tools

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1. Introduction

In the last few years, the use of operational research techniques [1] and artificial intelligence algorithms [2] to make instructional decisions has become an essential tool to manage delicate tasks encountered in our institutions and companies [2,3]. In fact, selecting qualified students for academic programs can be a complex process for higher education institutions. Human resources administrators and IT managers often encounter challenges in managing these tasks, potentially leading to inefficiencies or errors in the selection process [4]. For instance, one common challenge arises when selecting the best students for academic institutions with regulated access. This process is often fraught with difficulties, particularly in determining the appropriate criteria for selection [5] and choosing the right tools to assess students based on these criteria [6,7]. These mistakes are not only pervasive but also exceptionally challenging to resolve accurately. The complexity of these tasks and the large amount of data make the problem nearly impossible to solve using traditional processing methods as they demand a significant amount of resources and time [8]. Consequently, managers and administrators use tools to deal with this issues and focus on some data analytics methods and data mining techniques to predict student performance at university, thereby supporting data-driven decision-making in the admissions process [7]. Also, instead of using manual selection activities for selecting high-achieving students, which cost a huge amount of time and resources, they use some decision support system based on the Analytic Hierarchy Process (AHP) to determine the weight of criteria and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) for the final selection of students [6].

The majority of existing tools primarily focus on conventional statistical methods and predictive techniques rather than efficient mathematical techniques and optimization methods [9]. These advanced methods can effectively model and address issues related to the student selection process as operational research problems, using constrained integer programming techniques [10,11]. However, many similar problems are formulated and solved using operational research techniques, for example, the challenge of assigning students to project topics using integer linear programming tools is addressed, with preferences, side constraints, and fairness considered while maximizing satisfaction [12]. In the same context, a challenge of high failure rates in online higher education is addressed by investigating the use of genetic programming for predicting final grades early in the course [13]. In another context, the problem of managing booking stays at summer resorts affiliated to a foundation has been formulated as a constrained assignment problem, wherein the resources are represented using algebraic sets, the booking rules and criteria are formulated as equations connecting between the algebraic sets, and the decision is reached based on the values taken by the decision variables [14]. An exact algorithm for a class of block relocation problem is proposed [15]; this algorithm aims at solving iteratively a corresponding integer programming problem to generate lower and upper bounds of the block relocation problem. Also, during managing hospital resources, A Mixed Integer Linear Program Formulation (MILP) is proposed to improve the quality of hospitals and the assessment of their capacities [16]. In another work, a new sustainability-focused mixed-integer nonlinear programming (MINLP) model to tackle the challenge of hazardous waste location-routing is proposed [17]. This model considers facility placement, waste transportation routes, and waste residue to optimize a sustainable hazardous waste collection system.

This paper addresses the problem of selecting students who will be admitted to specific programs at higher education institutions. This task is difficult to solve manually and it becomes more complicated and relatively impossible to solve manually when the number of candidates is huge. The problem has been encountered by the board of several higher education institutions while selecting students on the basis of their preferences and competences. The aim of this work is to create a system that facilitates the execution of the student selection task and manages all the operations related to the selection process while yielding guaranteed, transparent, and consistent results within a reasonable time. This objective will be achieved by generating a mathematical formulation that reflects and formulates resources, capacities, and access rules found in most higher education institutions, thus automating the student selection process. This problem is formulated as a linear assignments problem, under constraints ensuring preference, students skills, access rules, and selection criteria that vary across different programs at higher education institutions.

The constraints assignment problem is a famous class of integer programming [18] that models major decision-making problems related to industries [19] and resources management [20,21]. In fact, an efficient integer formulation for a case study in university timetabling is proposed [3]. This model provides a mathematical formulation for timetabling rules and requirements used in the majority of universities and schools. In the same context, the authors proposed two algorithms used to obtain a solution for the transit equilibrium assignment problem that aims at predicting, in a transit network, the distribution of passenger flow [22]. As for the assignment problem, a mixed integer programming formulation is proposed to assign seats to members of parliament [23]. A formulation of the task assignment problem using fractional 0-1 programming is presented in [24]. The latter consists of a weighted objective function that maximizes and a set of constraints that ensures a fair distribution and takes into account preferences and competencies/skills.

The decision-making aspect of the student selection problem at academic institutions makes it flexible enough to be modeled using integer programming. In order to find the optimal assignment of students to available seats in a higher education institution considering both student preferences and competences/skills, the proposed model abides by several criteria related to school report cards, academic achievements, interests, and career aspirations of each student. This problem is formulated as a linear constrained assignment problem [14,20], with an objective function to be maximized, and under constraints ensuring preferences, competences, priority to first choices if possible, access rules of each higher education institution, and that consider all selection criteria defined in each program at the higher education institutions. There are many open-source software [25,26] and commercial solvers [27,28] that can be used to solve linear assignment problems, with some able to handle a large number of constraints within a reasonable time.

This article is organized as follows: The second section delves into the problem statement, providing a comprehensive overview of the criteria and regulations employed in the selection of outstanding students at higher education institutions. The third section articulates the mathematical formulation of the student selection problem, detailing the set of variables, constraints, and the objective function that constitute the model. In the fourth section, a detailed case study is presented, utilizing real data from Moroccan Preparatory classes of Engineers to demonstrate the model's practical application and effectiveness. The article concludes with a thorough discussion of key findings, offering a general conclusion, and exploring potential avenues for future research and enhancements in the student selection process.

2. Problem Statement

The problem of student selection in the university context is a complex matter that encompasses multiple issues. It manifests as the need to choose, from a group of prospective students, those who will be admitted to specific academic programs. This selection process can often be unclear, misunderstood, or controversial, leading to anxiety among the candidates. In addition, the selection criteria may vary depending on the programs and institutions, which presents challenges of equity and consistency. The emotional impact on unsuccessful students, as well as concerns about diversity and equity, are also aspects of the problem. Furthermore, high demand for certain programs can lead to challenging decisions for selection committees.

Balancing the objective assessment of student skills and abilities while considering diversity and subjective factors is a crucial challenge to address in solving this issue. Moreover, it is crucial to provide students with comprehensive information about the various available specialized fields and to empower them to make their own choices based on their academic achievements, interests, and career aspirations.

The existing selection systems in the education field have various shortcomings that require special attention. One of the major problems is the lack of transparency that often surrounds these processes. The selection criteria and procedures are not always clearly communicated to candidates, potentially leading to confusion and raising questions about the process's fairness. In addition, some selection systems are subject to unintentional bias. For example, when the criteria primarily focus on academic achievements, it can provide an advantage to candidates who have had access to more extensive educational resources, thus creating inequalities. In highly competitive programs, excessive demand can also present significant challenges. The emotional impact on unsuccessful candidates is often overlooked but significant. Emotional stress can be high, especially for those who have invested a lot of time and effort in their application. Another common flaw is the complexity of the selection procedures; long and tedious processes can discourage candidates and hinder the diversity of participation.

3. Objective and Methodology

3.1. Main Objective of Our Work

In this work, we aim to improve selection processes by making them more transparent, fair, and responsive to the changing needs of both candidates and educational programs, and to revise the selection criteria to ensure fairer and more efficient selection systems. At this level, we focus on creating an intelligent system of student selection in higher education institutions under the constraints of skills and preferences. The system will enable the automatic and reliable execution of the student selection process, taking into account multiple selection criteria defined by the institution's administration. The system will effectively address the challenges posed by high demand in competitive programs and the selection of specialized fields during orientation. Furthermore, the system includes several subjective criteria related to students' discipline, academic performance, interests, and career aspirations. The automated aspect of the new selection system ensures transparency, addressing a major issue in selection systems, while also providing reliability, speed in the selection process, and flexibility of the selection criteria, which will be adapted and defined for each institution.

3.2. Methodology

Before delving into the mathematical formulation of the student selection problem, it is essential to first provide a comprehensive description of the environment in which students are situated. This involves a global understanding of the organizational structure of higher education institutions, as these structures play a pivotal role in determining how students are managed, selected, and categorized. Then, a clear exposition of the selection rules and criteria used by these institutions is necessary, as they form the bedrock upon which the entire problem is constructed. Furthermore, it is important to carefully consider the modeling tools that will be employed in developing the mathematical formulation of the problem. These tools must be tailored to accurately represent the complexities of the selection process, ensuring that the model provides a robust framework for analyzing and solving the problem at hand.

3.2.1. Organizational Structure of Higher Education Institutions

Higher education institutions, in which academic programs are centered, play a key role. Each institution can specialize in a particular academic field, such as science, the arts, or business. Departments, meanwhile, operate within institutions and focus on even more specific academic areas. They are responsible for teaching, research, and development of in-depth study programs. Teachers and researchers are the driving force of these departments, delivering courses and actively contributing to academic research. Students, the cornerstone of each higher education institution, are divided into various streams of study and academic levels, all striving to achieve their educational goals. The administration of the institution includes administrative services that manage aspects such as enrollment, selection of students admitted to each stream and academic level, accounting, and human resources. In parallel, student support services offer valuable support, including counseling and career guidance services.

Regarding the process of selecting students for specialty streams, the academic units involved may vary depending on the organizational structure of the higher education institution. However, the main academic units that can play a key role in this process are as follows:

- Higher education institution: This entity is generally responsible for the management of academic programs and specialty streams. It often develops selection criteria specific to their programs and reviews applications.
- Departments: Academic departments within institutions may be responsible for defining more specific selection criteria related to their specific areas. They may also be involved in the assessment of candidates.
- Selection Committees: Some institutions set up selection committees composed of teaching staff members and experts in the field. These committees evaluate applications and recommend candidates for admission to specialty streams.
- Admission Services: In many institutions, a centralized admissions service processes student applications and coordinates the selection process.
- Academic Advisors: Academic advisors can play an advisory role to students, helping them choose the appropriate specialty streams based on their academic and career goals.
- The Governance Bodies of the institution: In some cases, the governance bodies of the institution, such as boards of directors or management committees, may define general policies concerning selection criteria and specialty streams.

These academic units often collaborate to elaborate comprehensive and equitable selection criteria that guide students to appropriate specialty streams that best fit their academic interests and goals.

3.2.2. Rules of Selection

The basic selection rules for the admission of students to specialty streams vary between institutions and are often specific to each academic program. These rules shall be respected during the selection process to ensure competencies, capabilities, and equity of admitted students. These rules are generally related to the capacity of each academic stream, the specialty streams recommended by each candidates if possible, etc. These rules will be described in the following items:

1. Consistency of applications must be respected. Each student must apply to the appropriate streams in a given higher education institution.
2. Selection twice is not permitted. Each student shall be assigned at most to a seat in a chosen academic stream in a given higher education institution. In fact, a student chooses a fixed number of streams belonging to a higher education institution and they are assigned at most to one seat from them.
3. Collisions shall not be permitted. In a given higher education institution and in a particular academic stream, a seat is assigned at most to one student who has already chosen this stream.
4. The maximum number of seats in a particular stream belonging to a higher education institution must be respected. In fact, each stream has its own number of seats that defines the capacity of the stream; then, the number of admitted students in each stream must not exceed the number of available seats.
5. The quotas of students having a particular series of bachelor's degree in each stream must be respected. In fact, in a given higher education institution, each available stream opens access to students with several series of bachelor's degrees with different quotas.
6. Priority is given to the first choices if possible. In fact, each student has the right to choose more than one stream in a given higher education institution and is assigned at most to one from these choices.

The following Table 1 summarizes the basic selection rules at higher education institutions:

Table 1. Basic selection rules at higher education institutions.

Basic Selection Rules
• Consistency of applications must be respected. • Selecting a student twice is not permitted. • Collisions shall not be permitted. • Capacity of each stream must be respected. • Maximal number of seats of each stream must be respected. • Quotas of students having different types of high school diploma shall not be violated. • Priority to the first choices if possible must be taken into account.

The task of selecting a limited number of students from a very large number of candidates—taking under consideration competences and preferences of each student, selection criteria, and all these rules—is a complicated process that requires a great deal of time and a large number of employees to prepare the lists of students assigned. Hence, automating this task means that we reduce time and employees, which are usually a burden on the management department.

3.2.3. Methodology Adopted

To effectively address the complexities of the student selection problem, integer programming techniques are particularly well-suited due to their ability to model the discrete and binary nature of selection decisions, such as determining whether a student is admitted or rejected [29,30]. These techniques can efficiently manage a variety of complex and interdependent constraints, including capacity limits, eligibility requirements, and institutional policies, while optimizing multiple objectives like maximizing student satisfaction, academic quality, and diversity. Additionally, these techniques offer scalability, making them suitable for application across a range of educational institutions, and provide the flexibility to adapt to different selection scenarios. Furthermore, the decisional nature of the student selection problem makes it flexible enough to be modeled using integer programming techniques.

4. The Mathematical Model of Student Selection Problem

In order to formulate the student selection problem at a given higher education institution, we use constrained integer programming techniques. More precisely, we formulate this problem as a constrained assignment problem with binary variables and under constraints ensuring satisfaction of selection rules and criteria imposed by the managing department of the higher education institution.

4.1. General Features of the Model

The formulation of the student selection problem as a constrained assignment problem is characterized by six main parameters that are considered as basic structural elements for our model. These sets of parameters are defined as follows:

- The student who has the right to apply for a seat in an academic stream to pursue their studies. The set of all these students is denoted by S, e.g., $S = \{student\#1, student\#2, \ldots, student\#|S|\}$.
- The seat to which an admitted student is assigned to pursue their studies. The set of all available seats is denoted A, e.g., $A = \{seat\#1, seat\#2, \ldots, seat\#|A|\}$.
- The academic stream in which a student will pursue their studies. The set of all available streams in the higher education institution is denoted by B, e.g., $B = \{stream\#1, stream\#2, \ldots, stream\#|B|\}$.
- The type of Baccalaureate tokens from which each student graduates; the set of all these baccalaureate types is denoted by T, e.g., $T = \{type\#1, type\#2, \ldots, type\#|T|\}$.
- The quota of students having a particular type of baccalaureate in a specific stream. The set of all possible quotas in the different streams is denoted by Q, e.g., $Q = \{quota\#1, quota\#2, \ldots, quota\#|Q|\}$.
- The number of seats available in an academic stream that represent the capacity of stream. The set of all these numbers is denoted by N, e.g., $N = \{nbr_c / c \in C\}$.

Besides, in this paper, we use a set of binary variables usually adopted by researchers to describe and make links between different sets that define the basic structure of our integer programming formulation. These variables are denoted by $x_{s,a}$, where $s \in S$ and $a \in A$. The variable $x_{s,a}$ takes the value 1, when the student s is assigned to the seat $a \in A$, and it takes zero otherwise.

4.2. Special Features of the Model

The general sets and variables described above are relatively insufficient to meticulously describe and detail existing links in a flexible way. In addition, they do not allow for proper formulation of different constraints that concretize the rules applied by the process of student selection. Moreover, the large number of elements in each general set will increase the complexity of the model. Therefore, to solve this problem, we designate other subsets of the original sets that will help us reduce the complexity of the model. These subsets will also make the formulation of constraints easier than the original sets.

- $A_b = \{a \in A : a =$ seat available in the stream $b \in B\}$.
- $S_b = \{s \in S : s =$ student applying for the stream $b \in B$ to pursue their studies$\}$.
- $S_t = \{s \in S : s =$ student having the series $t \in T$ of the baccalaureate$\}$.

- $S_{b,t} = S_b \cap S_t$.
- $B_s = \{b \in B : b =$ a stream chosen by the student $s \in S\}$.
- $B_t = \{b \in B : b =$ a stream open for students having the baccalaureate series $t \in T\}$.
- $T_b^{sat} = \{t \in T : t =$ a baccalaureate series required to apply for the stream $b \in B\}$ whose quota of seats devoted to students with this type of baccalaureate is exhausted.
- $\overline{T_b^{sat}} = \{t \in T : t =$ a baccalaureate series required to applying for the stream$b \in B\}$ whose quota of seats devoted to students with this type of baccalaureate is not exhausted.
- $T_b = T_b^{sat} \cup \overline{T_b^{sat}} = \{t \in T : t =$ a baccalaureate series required to apply for the stream $b \in B\}$.
- $N_b = \{n_b / b \in B : n_b$ is the number of available seats in the academic stream $b\}$
- $Q_{b,t} = \{q \in Q : q =$ the quota of seats devoted to bachelors having the series $t \in T$ of baccalaureate in the academic stream $b \in B\}$.
- $PA = \{(s, b) \in S \times B : (s, b) =$ a priori assignment in which the student $s \in S$ is assigned to the academic stream $b \in B\}$.

4.3. Objective Function

As we said earlier, the student selection problem is defined as the process of selecting students satisfying rules and conditions, and having certain criteria distinguish them from other students. In our case, we distinguish between students using a weight coefficient $w_{s,b}$ that will identify each student and that will depend directly on the academic performance, interests, career aspirations, and the stream chosen b of the each student s. Given that the selection rules and criteria differ from one higher education institution to another, the detail of the calculation method of these weight coefficients is given in the case study in Section 4.5, in which we specify the higher education institution, its organizational structure, and all other characteristics that allow us to define the appropriate calculation method of weight coefficients. In general, the objective function of our model is given by the following equation:

$$\forall b \in B : \quad Maximize \left\{ \sum_{s \in S_b} \sum_{a \in A_b} w_{s,b} x_{s,a} \right\}. \tag{1}$$

where

- B: the set of all available streams belonging to the higher education institution;
- S_b: the set of student applying for the stream b;
- A_b: the set of available seats in the stream b.

This function intends to select students having maximal weight coefficient among all other students. The weight coefficient is calculated so that each student has their own weight coefficient that shall be distinct from all other students' weight coefficients.

4.4. Constraints of the Model

In general, constraints reflect rules and requirements respected by the problem studied. In this section, we present the mathematical formulation of constraints. We subdivide these constraints into four main sets, each consisting of a number of equations.

4.4.1. Uniqueness Constraints

- This set of constraints ensures that, in a higher education institution, each student shall be assigned at most to one seat in a stream of their choices. This constraint is given by the following equation:

$$\forall s \in S,\ \forall b \in B_s : \sum_{a \in A_b} x_{s,a} \leq 1. \tag{2}$$

where

 - S: the set of all students;
 - B_s: the set of streams chosen by the student s.
- This set of constraints ensures that, in each stream b, a seat is assigned to one and only one student who has applied for the stream b. This rule is formulated by the following equation:

$$\forall b \in B,\ \forall a \in A_b : \sum_{s \in S_b} x_{s,a} \leq 1. \tag{3}$$

4.4.2. Capacity Constraints

- In a specified stream, the number of admitted students is limited. So, the number of assigned students to a stream shall not exceed the number of available seats in this stream.

$$\forall b \in B : \sum_{s \in S_b} \sum_{a \in A_b} x_{s,a} \leq n_b. \tag{4}$$

 where
 - n_b: the number of available seats in the stream b.
- For each stream $b \in B$, the number of students having a particular series of baccalaureate and assigned to seats in the stream b shall not exceed the quota of seats devoted to students having this series of baccalaureate in the stream b, described as follows:

$$\forall b \in B,\ \forall t \in T_b : \sum_{s \in S_{b,t}} \sum_{a \in A_b} x_{s,a} \leq q_{b,t}. \tag{5}$$

 where
 - T_b: the set of all baccalaureate series required to applying for the stream b;
 - $S_{b,t}$: the set of students applying for the stream $b \in B$ and having the series t of baccalaureate;
 - $q_{b,t}$: the quota of seats devoted to bachelors having the baccalaureate series t in the stream b.
- In several cases, some students hold some types of baccalaureates in some streams that cannot exceed their quotas of seats, which can generate some unoccupied seats in such streams. In order to maximize the use of the academic resources, we redistribute these unoccupied seats among the other students holding other types of baccalaureate whose quotas of seats are exhausted. This property can be added by replacing the constraints (5) with the following constraints (6):

$$\forall b \in B,\ \forall t \in T_b : \sum_{s \in S_{b,t}} \sum_{a \in A_b} x_{s,a} \leq q_{b,t} + p_{b,t}. \tag{6}$$

 where $p_{b,t}$ is calculated using the following method:
 - For $b \in B$ and $t \in \overline{T_b^{sat}}$, we calculate the number of unoccupied seats in the stream b devoted to students holding the baccalaureate type t:

$$r_{b,t} = q_{b,t} - \left|S_{b,t}\right|$$

 - Then, we calculate the total number of unoccupied seats in the stream b:

$$r_b = \sum_{t \in \overline{T_b^{sat}}} r_{b,t}$$

 - Therefore, we redistribute this number of unoccupied seats among students holding the type of baccalaureate $t \in T_b^{sat}$ using the following equation:

$$h_{b,t} = \left[\frac{r_b}{\left|T_b^{sat}\right|} \right]$$

where $[x]$ refers to the integer part of x.

– The integer division generates a reminder denoted rem_b, which is also redistributed among students holding the baccalaureate type $t \in T_b^{sat}$ using the following equation:

$$p_{b,t} = \begin{cases} h_{b,t} + 1 & t_i \in \{t_i \in T_b^{sat} : i = 1, \ldots, rem_b\} \\ h_{b,t} & t_i \in \{t_i \in T_b^{sat} : i = rem_b + 1, \ldots, |T_b^{sat}|\} \end{cases}$$

4.4.3. Consecutiveness Constraints

- Consecutiveness of student choices: For every student, priority to first choices must be considered. In fact, each student wishes satisfy their first choice before the second, etc. This rule can be formulated by the following equation:

$$\forall s \in S,\ \forall b_i \in B_s (i = 1, \ldots, |B_s| - 1) : \sum_{a \in A_{b_{i+1}}} x_{s,a} \leq \sum_{a \in A_{b_i}} x_{s,a} \quad (7)$$

- Consecutiveness of competent students: This set of constraints ensures that priority is given to competent students. In this sense, students who have the higher weight coefficient will be assigned to a seat from their chosen streams. The following constraint formulates this rule:

$$\forall s, r \in S,\ \forall b \in B_s \cap B_r (w_{s,b} < w_{r,b}) : \sum_{a \in A_b} x_{s,a} \leq \sum_{a \in A_b} x_{r,a} + \sum_{b' \in B_s \cap B_r \setminus \{b\}} \sum_{a \in A_{b'}} x_{r,a} \quad (8)$$

where

– $w_{s,b}$: the weight coefficient of the student s.

In this equation, the term $\sum_{b' \in B_s \cap B_r \setminus \{b\}} \sum_{a \in A_{b'}} x_{r,a}$ takes two possible values: It takes the 1 value if the student r is assigned to one of the streams b and b'—in this case, the student s can be assigned to a seat in the stream b; otherwise, it takes the 0 value if the student r is not assigned to any stream—in this case, and given that $w_{s,b} < w_{r,b}$, the student r should not assigned to any stream.

4.4.4. Pre-Assignment Constraints

- This set of constraints ensures that certain students will be assigned to a seat in a stream of their choices and could be used either for the pre-allocation of students or for better handling and reducing complexity and computational difficulties. These constraints are formulated by the following equation:

$$\forall (s, b) \in PA : \sum_{a \in A_b} x_{s,a} = 1. \quad (9)$$

where

– PA: the set of a priori assignments to the list of students $s \in S_b$.

4.5. Determination of Weight Coefficients

The weight coefficients are generally established by the board of each institution, as every institution has its own criteria and parameters for evaluating student competencies. These criteria are linked to the specific fields of study and the prerequisites required for entry into a given program. The weight coefficients are calculated based on these criteria and parameters, which are defined to avoid special cases where students have identical coefficients within the same stream, a situation that could cause the problem to become degenerate. Our proposed method for calculating these weight coefficients is based on detailed criteria and considers several parameters related to each student's academic curriculum and chosen stream. This approach enhances the traditional method of calculating weight coefficients, providing a definitive confirmation of student assignments while avoiding degeneracy.

5. Real Case Study

In order to demonstrate the efficacy and effectiveness of our proposed model to solve the student selection problem in higher education institutions, the Moroccan preparatory classes are considered as a real case study.

5.1. Presentation of the Moroccan Preparatory Classes

The Moroccan preparatory classes are a set of higher education institutions affiliated with the Moroccan Ministry of Education. They constitute a two-year post-baccalaureate cycle. In order to provide a favorable socio-educational environment and to strengthen equity between students, the system of boarding school is generalized to all centers of the preparatory classes. There are 29 public preparatory centers affiliated with the Ministry of Education, each having its own academic streams and capacity. The main mission of the administration council of the preparatory classes is to select between the huge number of candidate students, where outstanding students having higher competence and criteria have the best chance to access preparatory classes.

Preparatory classes are selective higher education courses that admit students with high academic standards. They are generally accommodated in colleges. Preparatory classes aim at raising success rates in the entrance contests of the high institutes of business and engineering. The main mission of the preparatory classes system is to participate in the training of a national elite that is qualified to lead the country's scientific and technological development. Over a two-year period of schooling, the preparatory classes provide training at a level equivalent to the graduate programs of higher education. Students acquire a solid general knowledge, allowing them to achieve the following:

- Appropriate a work methodology based on organization, investigation, personal initiative, and perseverance.
- Develop autonomy and skills for thinking and reasoning as well as communication.
- Adapt to different problem situations.
- Gradually familiarize themselves with situations requiring sustained effort that may arise during their subsequent training and during execution of their professions.

The preparatory classes are divided into two main poles: a scientific and technological pole and an economic and commercial pole. The science and technology preparatory classes are categorized in three streams whereas the second pole (Economics and Commercial) offers two streams, as shown in the following Table 2.

Table 2. Main poles of the preparatory classes.

Poles	Stream	Abbreviation
Scientific and Technological	Mathematics, Physics, and Engineering science	MPSI
	Physics, Chemistry, and Engineering science	PCSI
	Technology and Industrial Sciences	TSI
Economic and Commercial	Economics and Trade, Scientific option	ECS
	Economy and Trade, Technological option	ECT

5.2. Ways of Access to Preparatory Classes

This is based on the student's nationality and the institution from which the student received their Baccalaureate certificate. Access to preparatory classes is organized in three ways:

- For holders of a Moroccan baccalaureate, access to preparatory classes is regulated by a ministerial letter. It specifies the procedures and steps to be followed for the application as well as all the selection and registration procedures.
- For students of Moroccan nationality and holding a foreign baccalaureate, application files are assessed at the central service level by a special committee. About twenty places, all courses combined, are reserved each year for this category of candidates.
- For students of foreign nationality with a foreign baccalaureate, the Moroccan Agency for International Cooperation (AMCI) centralizes application files. It also manages the quota reserved for this category of candidates. Around one hundred places are reserved for these candidates across the study streams.

In this work, we will focus just on the first way because the second and the third ways are easy to manage. In fact, the number of places and candidatures is relatively small. However, the first way to access preparatory classes is so hard and impossible to manage manually. In the following section, we will explain in more detail the complexity of this problem by presenting statistics relative to the task of selecting students to be part of the preparatory classes using the first method.

5.3. Statement of the Student Selection Problem at Preparatory Classes

The student selection problem at preparatory classes is defined as the process of selecting admitted students for preparatory classes to pursue their undergraduate studies in a specific stream. The organizational structure of preparatory classes in Morocco imposes some conditions and criteria that must be applied during the selection process. In other words, the problem is defined under several rules and requirements that must be present in admitted students. These rules allow selecting qualified students based on the history of their school performance, like the total mark of the baccalaureate, the number of years repeated by a student during the baccalaureate time frame, etc.

The student selection process is an annual task. Every year after the baccalaureate exams, the management department of preparatory classes begins by announcing the application time limit for baccalaureate students. The latter apply to a seat in their favorite stream. By placing appointments on the website portal, each student fills a form of requirement fields containing main information and criteria needed to distinguish between the competence levels of students. These criteria are mainly based on the student's school history—their competences and capabilities. So, our work mainly aims at designing a decision-making system that is capable of managing different tasks related to the selection process in an intelligent way and within a reasonable amount of time.

Since 2014, the number of requests for access to the preparatory classes has been growing, as shown in Table 3 and Figure 1, and the selection problem has become more and more difficult to solve. In fact, the number of candidates for preparatory classes is enormous in comparison to the number of places available; in addition, the selection of admitted students is performed under several constraints, which increases the complexity of the student selection problem as a combinatorial optimization problem.

Table 3. Description of the number of requested and assigned students during the latest years.

Streams	MPSI		PCSI		TSI		ECS		ECT		Total Number of Students	
Year	**Requests**	**Assigned**	**Requests**	**Assigned**	**Requests**	**Assigned**	**Requests**	**Assigned**	**Requests**	**Assigned**	**Requests**	**Assigned**
2014	26,356	1775	30,409	743	2096	484	19,736	70	20,066	789	98,663	3861
2015	25,515	1779	29,677	709	2147	520	22,544	62	21,051	978	100,934	4048
2016	31,060	1804	31,937	723	2556	551	23,513	68	24,177	937	113,243	4083
2017	22,323	1822	25,966	729	1887	557	20,306	62	18,306	1017	88,788	4187
2018	28,200	1858	26,933	682	1833	549	26,041	350	3812	713	86,819	4152
2019	33,366	1914	32,243	693	1922	600	30,892	383	4691	793	103,114	4383
2020	31,646	1899	31,518	693	2363	594	24,892	405	5276	743	95,695	4334

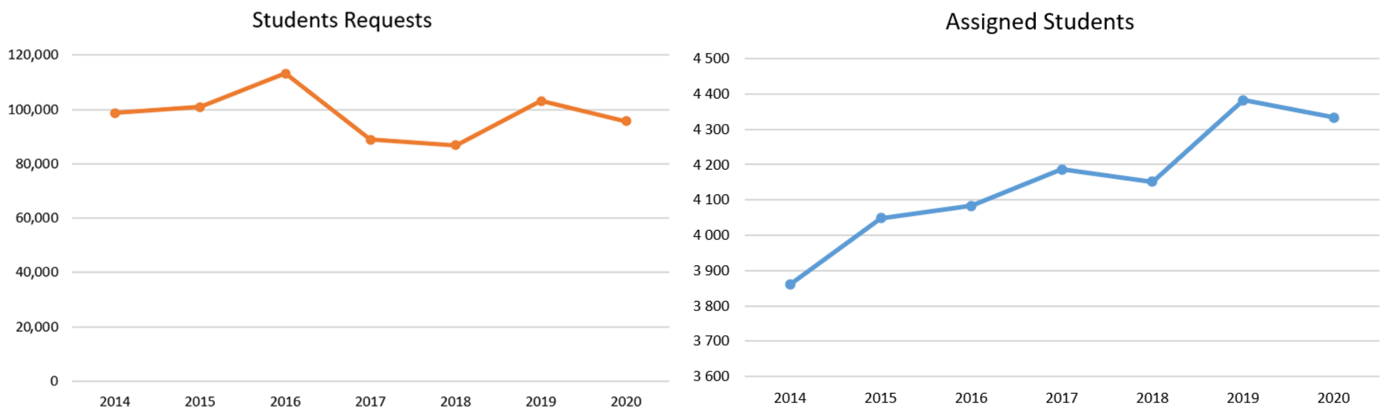


Figure 1. Description of the evolution of the number of requested and assigned students during the latest years.

5.4. Organizational Structure of the Preparatory Classes

The accommodation of the preparatory classes is performed by some national institutions of public education; an institution that hosts preparatory classes is called an accommodation facility/center. Each accommodation school hosts students of specified regions. In each province, an educational directorate is responsible for organizing and supervising students enrolled in secondary schools that are subordinate to this educational directorate. For example, the center MOHAMMED V BENI MELLAL accommodates students of secondary schools from three regional directorates: BENI MELLAL, AZILAL, and FEQIH BEN SALEH. The number of students accommodated by each accommodating school is limited according to the capacity of the center. Each center contains a number of educational streams, and to each educational streams is assigned a specified number of students regarding the number of available seats in this stream. The following Table 4 describes the data of four centers during 3 years.

Table 4. Description of data of centers during the year 2023.

Center	Available Streams	Requests Number
High school Moulay Idriss (Fez)	MPSI	4532
	PCSI	6725
	ECT	799
High school Mohmmed V (Casablanca)	MPSI	7503
	PCSI	7974
High school Moulay Ismael (Meknes)	ECS	5290
	ECT	812
Technical high school (Mohammedia)	MPSI	7271
	TSI	728

Candidacy conditions to access preparatory classes are defined as the following: a student should be in the final year of the baccalaureate phase in a Moroccan public or private institution accredited by the Moroccan state, and the student age should not exceed 21 years on 31 December of the current year.

Note that each student is characterized by the following:

- The number of repeated years in the baccalaureate phase;
- Age, specialty, and the total mark of the student;
- A mark awarded by the class council;
- A qualifying average of subjects, calculated in terms of the educational streams chosen.

Given that the number of seats in each educational stream available in an accommodation center is very limited, and the number of candidate students in each educational stream is very large, the task of selecting qualified students becomes very complicated. In the following section, we designate the rules to be followed during the selection process.

5.5. Data Description

In this experimental part, we test our model using data of four centers of preparatory classes of the academic session of 2023, where each center is characterized by the following:

- Streams available in this center;
- Type of Baccalaureate series required to access each stream;
- Quota of seats devoted to holders of each Baccalaureate series;
- Number of seats available in each stream in this center.

As we stated in the weight coefficients calculation section, each student is characterized by a weight coefficient that identifies them in a unique manner. In this section, we use several parameters in the formulation of the weight coefficient and to describe data. The following Table 5 gives the signification of these parameters:

Table 5. Significations of used parameters.

Designation	Parameter	Signification
Streams	MPSI	Mathematics, Physics, and Engineering Sciences
	PCSI	Physics, Chemistry, and Engineering Sciences
	TSI	Technology and Industrial Sciences
	ECT	Economics and Trade, Technology Option
	ECS	Economics and Trade, Scientific Option
Baccalaureate series	SM	Mathematical Sciences
	SX-SP	Experimental Sciences-Physical Sciences
	SX-SVT	Experimental Sciences-Life and Earth Sciences
	SX-SA	Experimental Sciences-Agricultural Sciences
	SE	Economic Sciences
	STE	Electrical Science and Technology
	STM	Technology and Mechanical Sciences
	SGC	Accounting Management Sciences

The following Table 6 shows the data that characterize each of the centers:

Concerning the students' data, each student is characterized by a weight coefficient. The latter is calculated on the basis of several parameters. The calculation method of this weight coefficient is given by the following equation:

$$\forall s \in S : \ w_{s,b} = N_1 + (N_2 - 10) + \frac{170 * N_3}{20} + \frac{10 * N_4}{20} + N_5 + N_6 \tag{10}$$

where

- $N_1 = \begin{cases} 0, & \text{if the corresponding student has repeated} \\ & \text{the second year of Baccalaureate cycle.} \\ 5, & \text{if the corresponding student has repeated} \\ & \text{the first year of Baccalaureate cycle.} \\ 10, & \text{otherwise.} \end{cases}$
- $N_2 = \dfrac{M_1 + 2 * M_2}{3}$ where
  - M_1 : The passing rate achieved in the first year of the Baccalaureate cycle;
  - M_2 : The passing rate achieved in the second year of the Baccalaureate cycle.
- N_3 : The qualifying average of subjects for each stream. For example, for the stream MPSI, the parameter N_3 is calculated using the equation

$$N_3 = \frac{4M + 3Phy + 0,5LV_2 + 1Fr + 0,5Ar}{9}$$

where M, Phy, Lv_2, Fr, and Ar are the marks attained in the final exam of the second year, namely, in the subjects considered for accessing the MPSI stream:

- M : the math mark;
- Phy : the physics mark;
- Ar : the Arabic mark;
- Fr : the french mark;
- LV_2 : the English mark.

- N_4 : a grade attributable by the class council (rated on 25).
- $N_5 = \frac{|B_s| - ord_b}{|B_s|}$: a grade that takes into account the range of the stream chosen, where $|B_s|$ is the number of possible choices.
- $N_6 = \frac{t_{max} - t_s}{t_{max} - t_{min}}$: a grade that takes into account the exact date of students candidature, where
  - t_{max} : deadline for submission of candidature on the web site;
  - t_{min} : starting date for submission of candidature on the web site;
  - t_s : exact submission date of candidature of student s on the web site.

Behind the formulation of this weight coefficient, an important condition must be satisfied to identify each student in a unique manner. In fact, N_1, N_2, N_3, and N_4 are marks that can be equal for the same students; when this is the case, the marks N_5 and N_6 allow to strictly differentiate among these students.

At this level, these data are sufficient enough to generate all the weight coefficients needed to optimize the objective function.

Table 6. Characteristics of the studied data.

Center	Stream	Capacity	Requests Number	Baccalaureate Series	Requests Number	Quotas of Seats	Availability
High school Moulay Idriss (Fez)	MPSI	140	15,281	SM	1328	90%	126
				SX-SP	13953	10%	14
	PCSI	68	6724	SM	1234	40%	27
				SX-PC	5328	40%	27
				SX-SVT and SX-SA	162	20%	14
	ECT	72	799	SE	721	75%	54
				SGC	78	25%	18
High school Mohmmed V (Casablanca)	MPSI	175	7544	SM	5474	90%	157
				SX-PC	2070	10%	18
	PCSI	70	7975	SM	1346	40%	28
				SX-PC	6428	40%	28
				SX-SVT and SX-SA	201	20%	14
High school Moulay Ismael (Meknes)	ECS	72	5137	SM	982	50%	36
				SX-SP	4155	50%	36
	ECT	72	812	SE	728	75%	54
				SGC	84	25%	18
Technical high school (Mohammedia)	MPSI	64	7271	SM	1830	90%	57
				SX-SP	5441	10%	7
	TSI	96	727	STE	486	70%	67
				STM	241	30%	29

6. Results and Discussion

This experimental section aims to demonstrate and prove the effectiveness and capability of our model in addressing conflicts and challenges encountered in managing the student selection process at higher education institutions. The results presented in this paper delve into all aspects pertaining to the satisfaction of student applications vis-à-vis the regulations established by the management department of the preparatory classes. These results stem from a case study conducted using real data from the Moroccan preparatory classes.

6.1. Computational Environment

The resolution algorithm used to obtain the assignment results is coded in Java Jee language under eclipse IDE using the optimization software package IBM ILOG CPLEX Optimization Studio, which provides well-performing tools specialized in solving optimization problems [31]. All tests and computational results reported in this experimental section are performed on a personal laptop with an Intel(R) core(TM) i7-3612 QM 2.60 GHz processor, 16 GB of RAM, and the Windows 11 operating system. These are considered enough for achieving all kinds of tasks to yield the assignment results of students to the available seats in this case study.

6.2. Results Presentation

In this part, we present results of our model on the data of the four preparatory classes centers. These results were evaluated using two pertinent metrics, execution times and assignment rates, presented by the following equation:

$$\tau = \frac{Ass}{Av} \tag{11}$$

where Ass refers to the number of admitted students and Av refers to the number of available seats in the suitable context. These results are presented in the following Table 7:

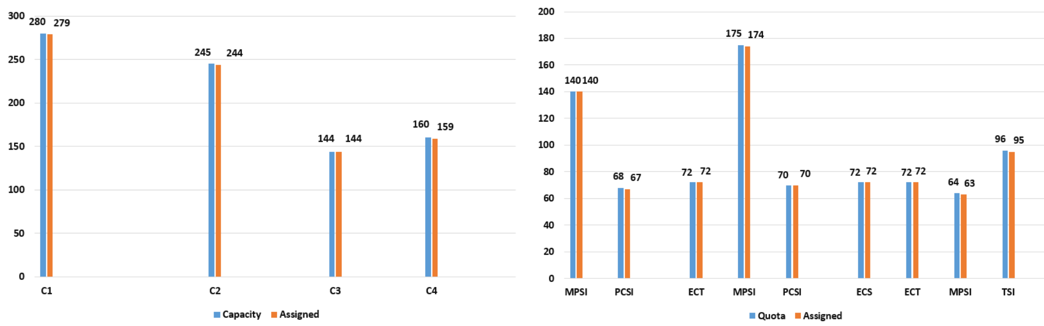
Table 7. Characteristics of the studied data.

Center	Stream	Capacity	Requests Number	Baccalaureate Series	Availability	Assigned Number	Assignment Rate	E-Time (s)
C_1 : High school Moulay Idriss (Fez)	MPSI	140	15,281	SM	126	126	100%	153,561.72
				SX-SP	14	14	100%	
	PCSI	68	6724	SM	27	27	100%	
				SX-PC	27	27	100%	
				SX-SVT and SX-SA	14	13	92.85%	
	ECT	72	799	SE	54	54	100%	
				SGC	18	18	100%	
C_2 : High school Mohmmed V (Casablanca)	MPSI	175	7544	SM	157	157	100%	86,278.98
				SX-PC	18	17	94.44%	
	PCSI	70	7975	SM	28	28	100%	
				SX-PC	28	28	100%	
				SX-SVT and SX-SA	14	14	100%	
C_3 : High school Moulay Ismael (Meknes)	ECS	72	5137	SM	36	36	100%	19,118.04
				SX-SP	36	36	100%	
	ECT	72	812	SE	54	54	100%	
				SGC	18	18	100%	
C_4 : Technical high school (Mohammedia)	MPSI	64	7271	SM	57	57	100%	27,858.45
				SX-SP	7	6	85.71%	
	TSI	96	727	STE	67	67	100%	
				STM	29	28	96.55%	

The following Figures 2 and 3 show the satisfaction rates of each of the constraints of our decision-making solution.

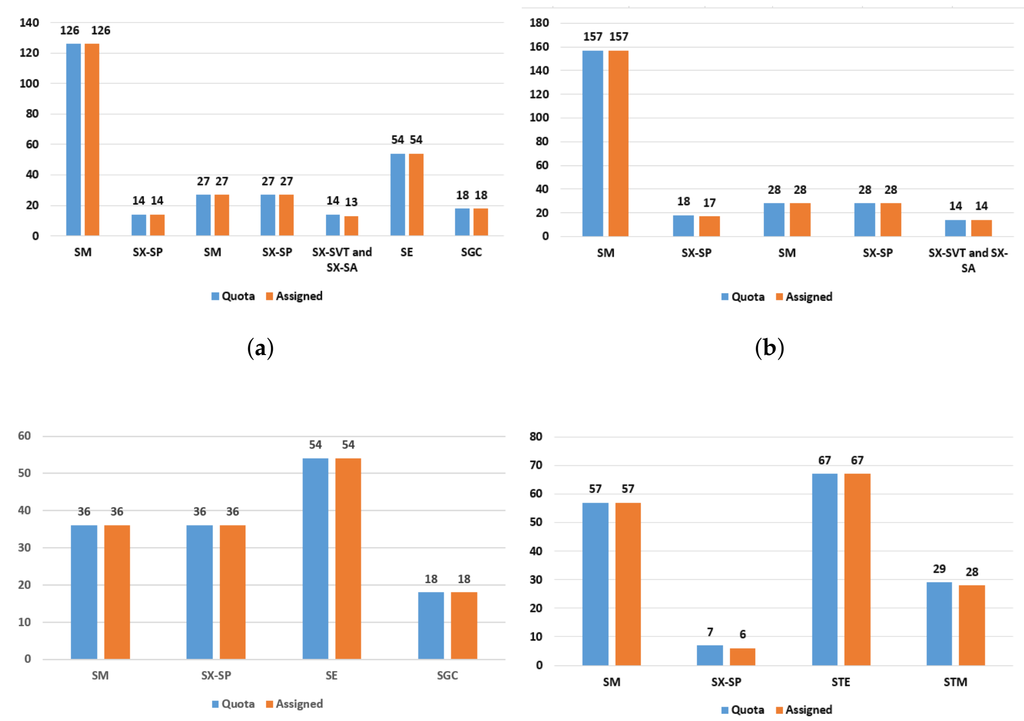
From these results, it can be noted that the test of our model of student selection at academic institutions on the Moroccan preparatory classes data is strongly successful, with an assignment rate of 100% for all streams and for each center (Figure 2), this means that all student assignments to available seats under resource, capacity, quota, and preference constraints have been optimally performed, without any breach of constraints or selection rules (Figures 2 and 3), and they maximize the specified objective function well.

This proves the effectiveness of our model and its adaptability to solving similar student selection problems.



(**a**) (**b**)

Figure 2. Satisfaction of centers' and streams' capacities. (**a**) Satisfaction of the centers' capacities. (**b**) Satisfaction of streams' capacities.



(**c**) (**d**)

Figure 3. Satisfaction of the quota constraints for each center. (**a**) Satisfaction of students' quota in the center C_1. (**b**) Satisfaction of students' quota in the center C_2. (**c**) Satisfaction of students' quota in the center C_3. (**d**) Satisfaction of students' quota in the center C_4

6.3. Comparative Study

To demonstrate the power and efficiency of our model in addressing the student selection challenges encountered in higher education institutions and its ability to replace the existing traditional system, we conducted a comparative analysis between the results obtained by our model and those derived from traditional methods used by the management department of preparatory classes (available at: https://www.cpge.ac.ma/CPGEPages/Cont/Statistiques.aspx (accessed on 19 August 2024)) using the same real-world dataset. This comparison, shown in Table 8, serves as a robust validation of the effectiveness of our approach in improving the selection process. By juxtaposing the results obtained through our model with those obtained through traditional methods, we can discern the advantages and potential enhancements offered by our model. This comparative evaluation not only highlights the performance and accuracy of our model but also underscores its potential to manage the student selection process, paving the way for more simplified and effective practices within higher education institutions.

According to this comparison, the results obtained are exactly the same as those found by the current traditional system in terms of number of admitted students. These results provide strong evidence of the effectiveness of our system and its ability to replace the current system based on traditional office automation techniques, which not only consume a lot of time but also mobilize a large number of human resources. Thus, the results obtained confirm the relevance and efficiency of our system, thus supporting the proposal to replace the existing system, which is the primary goal of this research. This evidence supports the automation of administrative processes, which would streamline operations by reducing the need for extensive human resources and decreasing processing time, while also enhancing the accuracy and transparency of results.

Table 8. Comparison of results between our method and the traditional method.

Center	Stream	Baccalaureate Series	Availability	Our Method	Traditional Method
High school Moulay Idriss (Fez)	MPSI	SM	126	126	126
		SX-SP	14	14	14
	PCSI	SM	27	27	27
		SX-PC	27	27	27
		SX-SVT and SX-SA	14	13	14
	ECT	SE	54	54	54
		SGC	18	18	18
High school Mohmmed V (Casablanca)	MPSI	SM	157	157	157
		SX-PC	18	17	18
	PCSI	SM	28	28	28
		SX-PC	28	28	28
		SX-SVT and SX-SA	14	14	14
High school Moulay Ismael (Meknes)	ECS	SM	36	36	36
		SX-SP	36	36	36
	ECT	SE	54	54	54
		SGC	18	18	18
Technical high school (Mohammedia)	MPSI	SM	57	57	57
		SX-SP	7	6	7
	TSI	STE	67	67	67
		STM	29	28	29

7. Conclusions

In this work, we addressed the challenge of student selection for admission to specific programs at higher education institutions. This task is difficult to solve manually and becomes increasingly complex and nearly impossible when dealing with a large number of candidates. The issue is commonly faced by boards at various higher education institutions when selecting students based on their preferences and skills while managing limited resources. Our goal was to develop a system that simplifies the student selection process; manages all related operations; and provides guaranteed, transparent, and consistent results in a reasonable amount of time.

To achieve this goal, we followed several key steps: First, we established a thorough understanding of the organizational structure of higher education institutions, which dictates how students are managed and selected. We defined the selection rules and criteria that form the basis of the selection process. Next, we adapted and formulated resources and competencies into algebraic sets and parameters, and translated access rules, selection criteria, and objectives into equations to build the mathematical formulation of the problem. We also identified potential risks, including challenges related to integrating new systems, potential resistance from the management department, and ensuring system reliability.

These steps enabled us to develop a mathematical programming model formulated as a linear assignment problem, incorporating constraints related to competencies, preferences, skills, access rules, and selection criteria commonly found in higher education programs.

A real case study was conducted using data from the 2023 session to select students for Moroccan preparatory classes. Our system produced excellent results, achieving a high assignment rate across all streams and centers. This success was due to optimal student placement into available seats while adhering to constraints on resources, capacity, quotas, and preferences. This demonstrated the effectiveness and adaptability of our model, fulfilling our primary objective of replacing the traditional system, which is time-consuming and requires extensive human resources.

However, there are several limitations to this study. The system's performance is highly dependent on the accuracy and completeness of input data, which may not always be guaranteed. Additionally, the model may require further refinement to accommodate diverse institutional requirements and varying constraints not considered in the current implementation. Future research should explore these aspects by expanding the model to handle different types of constraints and preferences, incorporating additional real-world scenarios and testing the system's adaptability across various educational contexts. Moreover, the integration of advanced technologies, such as machine learning and artificial intelligence, could further enhance the system's capabilities and efficiency.

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