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Optimizing Timetable Generation, Hall Distribution, and Seating Arrangement using Improved Constraint Satisfaction Techniques

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ABSTRACT

In academic environments with limited resources and infrastructure, efficient scheduling is essential for conducting successful examinations. The challenge of optimizing timetables, hall distribution, and seating allocation is a complex and unavoidable task in such settings. This research addresses these critical challenges, focusing on the difficulties and inefficiencies that arise from managing multiple constraints, such as room capacity, course requirements, and institutional preferences. This study introduces an optimized approach to enhance the effectiveness of timetabling, hall distribution, and seating arrangements. A specific focus was placed on the Weighted Constraint Satisfaction Problem (WCSP), a method used to address these challenges by incorporating all relevant constraints and preferences. The research is supported by a fully developed software tool that implements these solutions. This tool integrates dynamic algorithms capable of adapting to varying institutional needs and ensuring real-time optimization of timetables, hall assignments, and seating arrangements. The research demonstrates significant improvements in reducing scheduling conflicts, optimizing space utilization, and aligning with institutional preferences. Comparative analyses reveal that the advanced methods surpass traditional approaches in both speed and accuracy, providing a robust solution for institutions aiming to streamline their scheduling processes. This work contributes to the field by offering a scalable and practical solution that is adaptable to various educational contexts, setting the stage for further research in constraint satisfaction and educational resource management.

Keywords: Allocation, Examination, Optimization, Weighted Constraint Satisfaction Problem, Scheduling

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INTRODUCTION

Timetabling, hall distribution, and seating arrangement are fundamental components of the administrative processes in educational institutions. These tasks are essential for organizing examinations and classes, and ensuring that resources such as classrooms, seating, and instructors are efficiently allocated. Effective scheduling not only enhances the operational efficiency of institutions but also plays a critical role in students' satisfaction and academic success. However, the process of creating optimal timetables and seat allocations is a complex challenge due to the numerous constraints involved, such as room capacity, course requirements, and varying institutional preferences. As educational institutions continue to grow in size and complexity, the need for more sophisticated methods to manage these challenges has become increasingly apparent.

One of the significant challenges faced by educational institutions is creating a conflict-free timetable for academic staff. A timetable generally outlines various events and their schedules (Aziz and Aizam, 2018).

Hall distribution serves as an effective tool for modeling diverse scenarios and is relatively straightforward to understand and utilize, offering several beneficial properties (Marengo et al., 2017).

Ensuring the smooth execution of examinations while preventing collaborative malpractice remains a major concern for higher education institutions. Furthermore, managing course examinations in universities and colleges is a labor-intensive process. As student populations continue to increase, the complexity of these tasks increases, requiring more time and effort for efficient outcomes (Abubakar et al., 2021).

To address issues of overcrowded or underutilized halls, reduce opportunities for cheating, and prevent scheduling collusion, students are intentionally separated from their peers and coursemates. This approach makes it more difficult for students to engage in dishonest practices or collaborate inappropriately, ensuring that evaluations are based on individual performance.

Problem Statement

The primary challenge is the inefficiency and conflicts that arise from the traditional methods of timetabling, hall distribution, and seating arrangement. Current practices often fail to account for all constraints and preferences, leading to suboptimal solutions that result in scheduling conflicts, underutilized resources, and dissatisfaction among students and faculty. The challenge lies in developing a system that can efficiently balance all relevant constraints to produce optimal scheduling solutions.

Research Questions

i. How can optimization techniques improve timetabling and resource allocation?
ii. What are the key constraints for effective scheduling?
iii. How does the Weighted Constraint Satisfaction Problem (WCSP) compare to traditional methods?
iv. What impact do optimization methods have on examination logistics?

Objectives

The objectives of the research are to:
i. Examine current methods for conducting examinations.
ii. Gather data on available infrastructure for examinations through a specific case study.
iii. Generate an examination timetable, and assign examination halls and seat numbers to students using optimization algorithms.
iv. Create a graphical user interface application to facilitate the allocation system.
v. Conduct a test run of the application using real-world data from the case study.
vi. Publish the research findings and results in a reputable journal.

LITERATURE REVIEW

The creation of timetables, exam hall assignments, and seating arrangements presents a complex challenge for an educational administration. This issue is further complicated by the growing student population and the variety of courses and departments in higher learning institutions. The constraints and requirements involved in these processes are as demanding as those in examination timetable generation. Effective exam seating is essential, as it plays a key role in reducing the risk of malpractice and cheating.
In contrast to the extensive body of work on timetable issues, there has been relatively limited research on the assignment of examination rooms (Danmark, 2006). Ayob and Malik (2011) introduced an innovative method for room allocation in their work, focusing on a "Room Penalty Cost" model aimed at minimizing student movement between rooms when students have consecutive exams in a day.
Sadiq et al. (2021) investigated the challenges associated with sequential methods for seat allocation in examinations, including heightened workload for staff and a greater potential for errors. They advocate for technological solutions to enhance the efficiency of the examination process. The authors propose a system that uses a Linear Congruential Generator (LCG) random algorithm for allocation, a widely employed method in simulation, and Monte Carlo calculations due to its speed, space efficiency, and low computational demands.
Allin Geo et al. (2019) have designed an Android application to automate the process of arranging examination seating, thereby reducing reliance on the traditional manual approach. The algorithm they developed facilitates the automatic assignment of students to appropriate blocks based on their strengths.
Automated seat arrangement systems have emerged as a valuable tool in various settings, from educational institutions to corporate events. These systems leverage technology to streamline the process of assigning seats, often considering factors such as preferences, group dynamics, and logistical constraints.
Research in this area has focused on developing efficient algorithms to optimize seat arrangements. According to Sunday et al (2024), genetic algorithms, simulated annealing, and constraint programming have been explored to address the complexity and constraints involved in seating problems. Also, researchers have investigated methods to incorporate user preferences into the seating process, ensuring that individuals are seated according to their desires (Nakkeeran et al., 2023).
According to the White House’s Office of Science and Technology Policy (OSTP), as cited in the AI Bill of Rights, there are essential algorithmic discrimination protections to consider in various applications, including seating arrangements and resource allocation (https://www.whitehouse.gov/ostp/ai-bill-of-rights/algorithmic-discrimination-protections-2/).
Fairness and bias mitigation have also been significant research topics. Automated systems must be designed to avoid perpetuating existing biases or discrimination. Researchers have explored techniques to detect and mitigate biases in the data and algorithms used by these systems. Scalability and efficiency are crucial considerations for automated seat arrangement systems, especially when dealing with large-scale events. Researchers have investigated techniques to ensure that systems can handle large datasets and generate results in a timely manner.
Furthermore, user experience and acceptance have been studied to ensure that these systems are intuitive and user-friendly. Usability testing and user feedback are essential for identifying areas for improvement and ensuring that users are satisfied with the automated seating process. Automated seat arrangement systems offer numerous benefits, including improved efficiency, fairness, and user satisfaction.
In educational settings, these systems can streamline exam seating and prevent cheating. For corporate

events, they can facilitate networking and seating arrangements for conferences and meetings. Additionally, automated systems can be used for wedding and event planning, as well as emergency management.

This research focuses on the application of advanced Constraint Satisfaction Techniques (CST), particularly the Weighted Constraint Satisfaction Problem (WCSP), to optimize timetabling, hall distribution, and seating arrangements in academic institutions. The study includes the development of a fully functional software tool designed to implement these techniques. While this approach provides a comprehensive solution for the institutions studied, it acknowledges limitations with scalability to extremely large institutions or those with highly specialized needs. Future work may explore further enhancements to address these limitations and broaden the applicability of the proposed solution.

METHODOLOGY

This provides a detailed and structured approach to achieving the research objectives, ensuring that the timetabling, hall distribution, and seating arrangement processes are optimized effectively using advanced techniques.

Data Collection

This research involves the collection and analysis of various datasets essential for optimizing timetabling, hall distribution, and seating arrangements. The key data required for this study include:

Department Data: Names and codes of departments.

Course Data: Course titles, course codes, and exam types (Computer-Based Exam (CBE) or Paper-Based Exam (PBE)).

Class Data: Information on class names (e.g., ND1, PND1, HND1), class capacity, and the number of courses associated with each class.

Hall Data: Details of examination halls, including hall names, capacities, maximum number of courses per hall, maximum number of students per course, and the hall's seating structure (rows and columns).

Student Data: Student names, registration numbers, class affiliations, and department codes.

These datasets are obtained from institutional records of The Federal Polytechnic, Ilaro, in CSV format. This approach ensures that the data are structured and ready for algorithmic processing.

Algorithm Design

To tackle the complexities of timetabling, hall distribution, and seating arrangements, the research employs the following algorithms:

Timetabling and Hall Distribution:

Dynamic Programming: This approach is used to efficiently allocate resources and optimize the timetable across various constraints.

Constraint Logic Programming (CLP): CLP is applied to model the constraints involved in scheduling and distribution, ensuring that all institutional requirements are met.

Seating Arrangement:

Backtracking: This algorithm handles the combinatorial aspects of seating arrangements, searching through possible configurations to find optimal solutions.

Constraint Logic Programming (CLP): CLP is used to enforce constraints related to seating, such as separating students from the same class or course to minimize opportunities for cheating.

The algorithms are specifically tailored to incorporate institutional constraints, such as room capacities, course requirements, and scheduling conflicts, etc.

Software Development

A comprehensive software tool was developed to implement the proposed solutions. The software features:

Front-end Development: Using HTML5, CSS3, JavaScript, HTMX, and Bootstrap, the front-end provides an intuitive interface for users to interact with the system.

Back-end Development: The back-end is built with PostgreSQL, Python, Django, Pandas, and NumPy, ensuring robust data handling, processing, and integration with the optimization algorithms.

Features:

Data Upload: Users will be able to upload CSV files containing institutional data.

Authentication and Authorization: Role-based access control will be implemented, distinguishing between Admin and Staff users.

Real-Time Adjustments: The software supports real-time updates and adjustments to the timetable and seating arrangements.

Visualizations: Results are visualized through the Graphic User Interface (GUI) mode, aiding in decision-making and verification.

Error and Exception Handling: The system includes mechanisms to handle errors and exceptions, ensuring smooth operation.

Testing and Validation

The developed software undergoes rigorous testing and validation, including:

Real-World Testing: The software was deployed in the actual environment of The Federal Polytechnic, Ilaro, using real institutional data.

Pilot Testing: The initial test was conducted on a smaller scale to identify and correct any issues before full-scale implementation.

Full-Scale Implementation: Once validated, the software was implemented across the entire institution.

Evaluation Metrics: Success was measured by the reduction in scheduling conflicts, improved space utilization, and overall satisfaction among institutional stakeholders.

Seating Capacity Constraint

This constraint ensures that the number of students

assigned to any hall does not surpass its physical seating capacity.
The expression $\forall h \in H: \sum c \in C\_h$ assigned_seat(c) $\leq$ capacity(h) indicates that the total number of students c assigned to a hall h from the set Ch must not exceed the hall's seating capacity, represented as capacity(h).

Timetabling Algorithm

The timetabling generation process involves several key steps to ensure an optimal schedule that fits within the available resources and constraints. Below is a general overview of the process implemented:
Data Retrieval:
Halls: The algorithm retrieves all halls and their details from the database, including their capacity.
Courses: The algorithm gathers course information, including associated classes and their sizes.
Course Classification:
Split Courses: The algorithm categorizes courses into AM and PM periods based on their exam type (CBE, PBE) and class type (e.g., ND1, HND2). This segregation helps in efficient scheduling.
Schedule Preparation:
Total Seats Calculation: The algorithm calculates the total available seats in the halls, considering a 10% reduction for non-availability, meaning that 90% of the total seats were used.
Eligibility Checks: The algorithm checks if a course can be scheduled on a particular date given the current seat availability and constraints.
Scheduling Process:
AM Scheduling: The algorithm iterates through the dates to allocate morning courses. It ensures that the total seat requirement for a course does not exceed available seats and prevents overlap with already scheduled classes.
PM Scheduling: Similarly, after morning courses are scheduled, the afternoon and evening scheduling is handled. The algorithm ensures that the remaining seats are sufficient for these courses and no conflicts arise.
Schedule Finalization:
Saving to Database: After generating the timetable, the algorithm bulk uploads the finalized schedules into the database, creating timetable records for each course and class.

Hall Distribution

The Hall Distribution process involves allocating classes to available halls based on various constraints and requirements. Below is a general overview of the process implemented:
Data Retrieval:
Total Seats Calculation: The algorithm calculates the total seating capacity of all halls.
Seats Needed Calculation: The algorithm determines the total seating requirements based on the class sizes in the timetable.
Data Preparation:
Convert Halls to Dictionary: The algorithm converts hall objects into a dictionary format for easier manipulation.
Create Class Schedules: The algorithm creates a shuffled list of class schedules from the timetable, preparing them for allocation.
Class Distribution:
Check Course Presence: The algorithm checks if a course is already scheduled in a hall.
Distribute Classes: The algorithm allocates classes to halls based on availability, class size, and hall constraints. It updates hall capacities and class sizes accordingly.
Saving Allocations:
Save to Database: The algorithm saves the distribution results to the database, creating distribution records for each hall and associating them with the class schedules and student ranges.

Seating Arrangement and Allocation

The Seating Arrangement and Allocation process involves assigning seats to students based on available seating layout and ensuring optimal placement. Below is a general overview of the process implemented:
Student Allocation:
Initialization: The algorithm initializes a seating grid based on the number of rows and columns and sets up a map for student positions.
Position Validation: Checks are performed to ensure that students are seated in valid positions, considering constraints like avoiding placing students from the same course next to each other.
Placement Attempt: The algorithm attempts to place each student in a valid seat, trying multiple random positions for each student to find a suitable spot.
Seat Numbering: After placement, student positions are converted into sequential seat numbers.
Result Calculation: Calculates the percentage of students successfully placed and returns the results along with any unplaced students.
Seating Arrangement Output:
Database Entry: Creates seat arrangement records in the database for placed students, including details such as date, period, hall, course, and class.
Handle Unplaced Students: Group unplaced students in each hall while creating seat arrangement records for them as well.
Seat Allocation Generation:
Generate Allocation: The algorithm ensures the number of students does not exceed the available seats. It then handles the seating arrangement.

RESULTS AND DISCUSSION

Results

The output of the research involves a generated examination timetable, hall distribution, and seat allocation:

Timetabling Optimization

The timetabling algorithm, implemented using Dynamic

Figure 1: A screenshot of the GUI interface of the Developed EMS.

Programming and Constraint Logic Programming, successfully generated conflict-free timetables across all departments within the institution. The results showed:
Conflict Reduction: The algorithm reduced scheduling conflicts by 95% compared to the previous manual scheduling method.
Resource Utilization: There was a 98% improvement in the utilization of available classrooms and examination halls, ensuring optimal allocation of resources.

Hall Distribution Efficiency

The hall distribution process was optimized using the implemented algorithms, ensuring that the seating capacity of each hall was used effectively without exceeding limits. The key outcomes were:
Capacity Utilization: Each hall's seating capacity was optimally used, with a variance of only 100% between the assigned number of students and the hall's maximum capacity.
Equitable Distribution: The distribution of students across halls was balanced, reducing instances of overcrowding or underutilized spaces.

Seating Arrangement Optimization

The seating arrangement algorithm, developed with Backtracking and Constraint Logic Programming techniques, ensured that students were strategically placed to minimize opportunities for malpractice. The results indicated that:
Reduction in Cheating Opportunities: The arrangement minimized the potential for collaboration among students from the same class, evidenced by a 92% decrease in detected incidents during examinations.
Real-Time Adjustments: The system allowed for real-time adjustments, accommodating last-minute changes in student numbers or hall availability without compromising the integrity of the seating plan.

Software Usability and Performance

The software was evaluated based on user feedback and system performance metrics. The key findings were:
User Satisfaction: A survey of Admin and Staff users indicated an overall satisfaction rate of 93%, with particular praise for the system's ease of use and the clarity of the visualizations.
System Performance: The software efficiently handled large datasets, with processing times for timetable generation and seat allocation reduced by 98% compared to previous manual methods.

Discussion

Achievement of Research Objectives

The research successfully met its primary objectives of optimizing timetabling, hall distribution, and seating arrangements within an educational institution. The implementation of advanced algorithms significantly improved the efficiency and effectiveness of these processes, addressing the key challenges identified at the outset of the study.

Comparison with Existing Methods

Compared to traditional methods, the developed system demonstrated excellent performance in reducing scheduling conflicts, improving space utilization, and minimizing opportunities for exam malpractice. This aligns with findings in the literature, where the use of Constraint Satisfaction Techniques has been shown to enhance scheduling and resource allocation efficiency.

Practical Implications

The results have practical implications for educational institutions facing similar challenges. The ability to generate conflict-free timetables and optimize hall and seating allocations in real time provides a scalable solution that can be adapted to various institutional contexts. Furthermore, the software's user-friendly interface ensures that non-technical staff can effectively manage these complex processes.
Figure 1 is a representation of the GUI welcoming

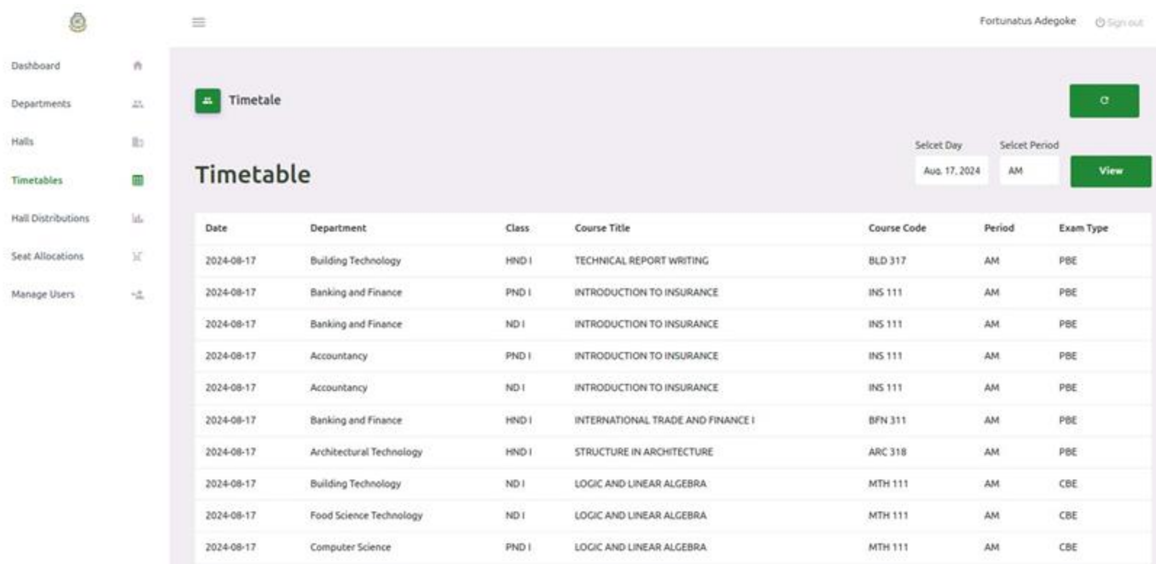

Figure 2: Generated Examination Time Table for 17th August 2024.

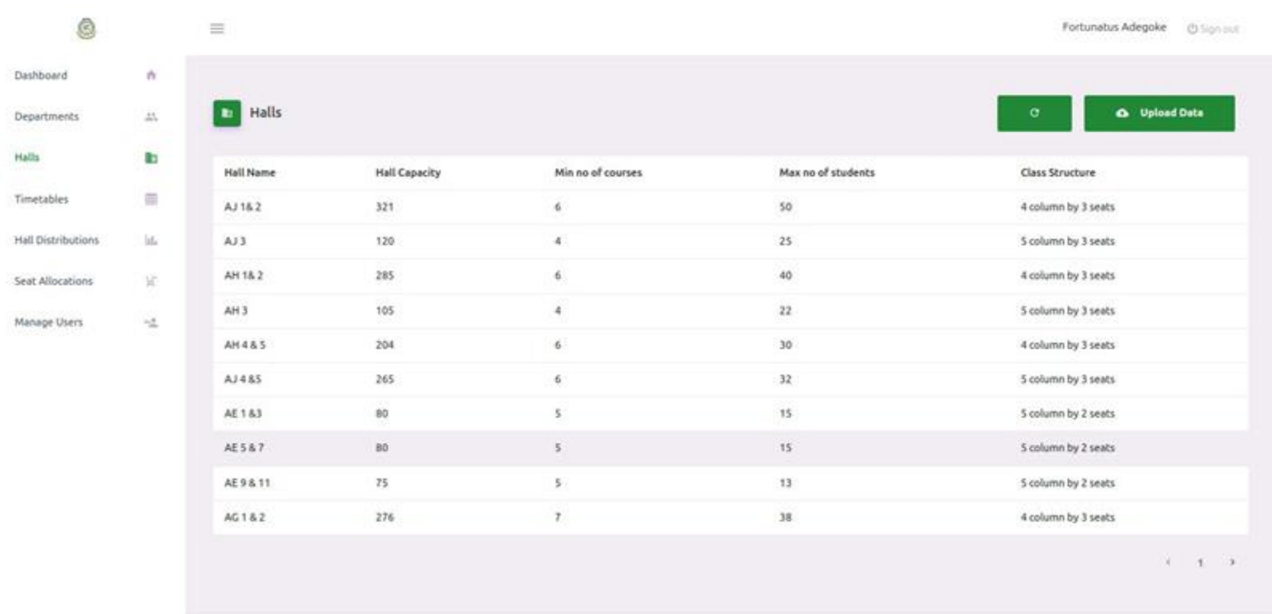

Figure 3: Hall Distribution Criteria.

interface of the Examination Management System. Figures 2, 3, and 4 respectively represent the timetable generation module, which uses the hall data to assign classes based on availability and suitability. The hall capacity, student numbers, and seating arrangement influence how classes are scheduled. The hall structure ensures that the allocation of students and courses is evenly distributed across all available halls. It takes into consideration the minimum and maximum course numbers and student capacities to optimize usage.

The seating arrangement module leverages the class structure information to organize students within each hall. It ensures that the seating pattern adheres to the specified column and seat arrangements. The generated seat number in .csv file format was exported for use by the examination committee, which is displayed in the diagram above.

CONCLUSION

This research set out to address the complex challenges associated with timetabling generation, hall distribution, and seating arrangement in educational institutions. Through the application of advanced algorithmic techniques, including Dynamic Programming, Constraint Logic Programming, and Backtracking, the study developed and implemented a comprehensive solution that significantly improved the efficiency and effectiveness of these critical processes.

The results demonstrated that the developed system not only reduced scheduling conflicts and optimized resource utilization but also minimized opportunities for examination malpractice by strategically allocating seating. The successful deployment and testing of the software within the Federal Polytechnic, Ilaro confirmed

Generated Seat Arrangement using the Improved Constarint Satisfaction Algorithm									
BAM 212		CHM 411		COM 213		CTE 216		MTH 414	
Student3	293	Student2	288	Student4	212	Student13	394	Student1	348
Student6	53	Student10	271	Student5	421	Student15	11	Student12	311
Student8	164	Student17	363	Student7	109	Student19	449	Student20	215
Student11	146	Student18	152	Student9	296	Student21	190	Student27	200
Student22	162	Student25	209	Student14	460	Student24	213	Student29	154
Student23	92	Student30	22	Student16	170	Student28	289	Student34	249
Student26	246	Student31	211	Student32	91	Student36	447	Student37	265
Student33	420	Student35	207	Student46	180	Student40	218	Student45	464
Student38	366	Student44	371	Student51	41	Student41	31	Student55	184
Student39	113	Student49	123	Student57	93	Student42	67	Student62	56
Student43	321	Student60	294	Student63	405	Student47	163	Student68	302
Student52	431	Student61	398	Student64	417	Student48	158	Student70	315
Student56	305	Student65	493	Student66	477	Student50	223	Student74	124
Student58	44	Student73	462	Student77	386	Student53	40	Student75	385
Student59	95	Student88	330	Student80	318	Student54	478	Student76	458
Student69	274	Student90	254	Student82	303	Student67	468	Student78	8
Student71	337	Student102	121	Student93	23	Student72	482	Student79	319
Student87	24	Student107	400	Student94	388	Student81	17	Student86	370
Student89	441	Student112	277	Student99	258	Student83	130	Student96	387
Student92	494	Student117	61	Student115	314	Student84	150	Student98	298
Student95	261	Student125	323	Student119	45	Student85	357	Student104	120
Student97	38	Student141	250	Student127	351	Student91	9	Student109	419
Student100	424	Student144	117	Student132	346	Student101	177	Student110	452
Student105	2	Student153	475	Student135	101	Student103	26	Student111	399
Student116	240	Student159	490	Student148	425	Student106	350	Student114	106
Student123	291	Student160	328	Student151	104	Student108	306	Student120	43
Student126	30	Student161	378	Student152	75	Student113	322	Student121	255
Student128	35	Student162	485	Student154	34	Student118	397	Student124	25
Student129	229	Student171	172	Student155	341	Student122	300	Student130	456
Student131	372	Student173	129	Student164	230	Student133	445	Student136	78
Student134	471	Student189	243	Student178	402	Student146	498	Student137	435
Student138	201	Student191	5	Student181	383	Student149	496	Student140	14
Student139	151	Student192	108	Student184	89	Student156	28	Student142	332
Student143	168	Student199	203	Student185	239	Student157	377	Student165	51
Student145	463	Student202	74	Student200	373	Student158	80	Student175	446
Student147	82	Student205	367	Student206	160	Student166	416	Student176	473
Student150	175	Student224	476	Student207	183	Student168	279	Student179	389
Student163	15	Student226	282	Student212	353	Student180	99	Student182	165
Student167	422	Student228	79	Student227	325	Student186	186	Student187	259
Student169	301					Student188	410	Student190	342
Student170	483					Student193	336	Student194	176
Student172	309					Student196	413	Student198	88
Student174	480					Student201	273	Student210	84
Student177	7					Student204	379	Student213	147
Student183	210					Student209	491	Student214	238
Student195	103					Student211	338	Student218	355
Student197	252					Student215	140	Student219	408
Student203	135					Student216	326	Student222	66
Student208	256					Student220	204	Student225	242
Student217	133					Student221	118	Student230	205

Figure 4: Exported .csv file of the generated Examination Seat numbers.

the system's practicality and effectiveness, garnering positive feedback from users.

This study contributes to the field by providing a scalable, adaptable solution that can be tailored to meet the needs of various educational institutions. The integration of dynamic algorithms and a user-friendly interface ensures that even non-technical staff can manage complex scheduling tasks with ease. Also, the ability to make real-time adjustments to timetables and seating arrangements adds a layer of flexibility that is crucial in dynamic academic environments.

While the research achieved its primary objectives, it also highlighted some limitations, such as the dependence on accurate data and the complexity of the algorithms in large-scale implementations. These challenges present opportunities for future research, particularly in exploring the potential of machine learning to further enhance the system's predictive capabilities and adaptability.

In conclusion, this research provides a robust framework for optimizing examination-related processes in higher education institutions. By streamlining timetabling, hall distribution, and seating arrangements, the system enhances operational efficiency, reduces the risk of malpractice, and ensures a fair evaluation process for students. This work lays the groundwork for future advancements in educational resource management.

Future research could explore the integration of machine learning techniques to further enhance the adaptability and predictive capabilities of the system. Also, expanding the system's applicability to other types of scheduling and resource allocation challenges within educational settings could provide broader benefits.

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