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Smart Classroom and Timetable Scheduler with Optimized Scheduling

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Abstract: *The preparation of academic timetables in higher education institutions is a complex combinatorial optimization problem that demands consideration of numerous constraints including classroom availability, faculty workload, subject allocation, and student preferences. Manual methods of timetable scheduling frequently result in scheduling conflicts, unbalanced workloads, and inefficient utilization of institutional resources. This paper presents a Smart Classroom and Timetable Scheduler, an intelligent webbased platform developed to automate and optimize the generation of academic timetables for higher education institutions. The system leverages a rule-based algorithmic approach incorporating constraint satisfaction techniques to generate conflict-free, resource-optimized timetables. The platform supports multi-department and multi-shift scheduling, provides multiple timetable alternatives, and incorporates a review and approval workflow for institutional administrators. Implemented using PHP, MySQL, and Bootstrap, the system targets full alignment with the flexible and multidisciplinary learning objectives mandated by NEP 2020. Experimental evaluation demonstrates that the system successfully eliminates scheduling conflicts, reduces timetable preparation time by over 80%, and substantially improves faculty workload distribution and classroom utilization.*

Keywords: Timetable Scheduling, Constraint Satisfaction, Web-Based System, NEP 2020, Academic Resource Optimization, Rule-Based Algorithms, Automated Scheduling, Higher Education.

I. INTRODUCTION

Timetable scheduling is one of the most critical and resource-intensive administrative functions in higher education institutions. The complexity of the problem arises from the need to simultaneously satisfy multiple hard and soft constraints: assigning subjects to classrooms, allocating faculty according to workload and availability, accommodating student preferences, and ensuring no two events conflict in time or space [1]. Traditionally, this process is carried out manually by administrative staff using spreadsheets, whiteboards, or basic scheduling tools, often taking days or weeks to finalize a single semester timetable [2].

The introduction of the National Education Policy (NEP) 2020 has further amplified the complexity of scheduling in Indian higher education institutions. NEP 2020 mandates flexible, multidisciplinary curricula with multiple entry and exit points, minor and major specialization tracks, and elective-heavy coursework [3]. These requirements introduce dynamic scheduling demands that are beyond the capacity of conventional manual methods. The result is frequent scheduling conflicts, underutilized classrooms, faculty overloading in some departments while others remain underutilized, and overall poor academic resource management.

Recent advances in web technologies, database management systems, and algorithmic optimization have opened avenues for developing intelligent automated scheduling systems. Constraint Satisfaction Problems (CSPs) and meta-heuristic algorithms such as Genetic Algorithms and Simulated Annealing have been widely applied to timetable scheduling with significant success [4]. However, many existing solutions are either commercially expensive, technically rigid, or fail to account for the specific multidisciplinary and multi-shift requirements of NEP 2020 institutions.

This paper presents the Smart Classroom and Timetable Scheduler, a web-based intelligent scheduling system designed specifically for higher education institutions operating under NEP 2020. The system automates timetable generation using a rule-based constraint satisfaction engine, supports multi-department and multi-shift scheduling, and provides an intuitive interface for administrators, faculty, and students. The proposed system is built on a PHP, MySQL, HTML, CSS, and Bootstrap technology stack, ensuring lightweight deployment, cross-platform accessibility, and ease of customization.

The contributions of this work are as follows:

- We propose an intelligent web-based timetable scheduling system that automates conflict-free timetable generation for higher education institutions.
- The system addresses the multi-constraint scheduling problem by incorporating classroom availability, faculty workload, subject requirements, and student preferences simultaneously.
- Our platform provides multi-department and multi-shift scheduling support with review and approval workflows, fully aligned with NEP 2020 requirements.
- Experimental results demonstrate a reduction in scheduling time by over 80% and complete elimination of scheduling conflicts in all test scenarios.

The remainder of this paper is organized as follows: Section II surveys related work on automated timetabling systems. Section III describes the materials and methodology used. Section IV presents experimental results and analysis. Section V concludes the paper with directions for future work.

II. RELATED WORK

Considerable research has been devoted to automated timetable scheduling over the past two decades. Early approaches relied on constraint-based programming and integer linear programming (ILP) to model and solve scheduling problems [5]. While these methods produce optimal solutions, they suffer from poor scalability when the problem size increases, making them impractical for large universities with hundreds of courses, classrooms, and faculty.

Genetic Algorithms (GAs) have emerged as a popular heuristic approach for timetable scheduling. Abramson et al. [4] demonstrated that GAs can efficiently explore large solution spaces and produce near-optimal timetables within acceptable computation time. However, the quality of results is highly sensitive to parameter tuning and initialization strategies. Similarly, Simulated Annealing and Particle Swarm Optimization have been explored with promising results but suffer from slow convergence.

Web-based timetabling systems have gained traction as institutional scheduling tools. A 2024 IEEE study [6] on a web-based timetable management system for a university of vocational technology employed Angular JS, Bootstrap 3, PHP, MySQL, and a Genetic Algorithm backend, reporting efficient management of class schedules and last-minute changes. However, the system was noted for technical complexity in deployment and limitations in conflict resolution across large departments.

A Smart Timetable Generator proposed in 2024 [7] employed Flutter, Firebase, and Dart to build a mobile-first scheduling application that relied on advanced algorithms for schedule generation. While effective for small-scale scheduling, the system exhibited limitations in handling large and complex scheduling scenarios with numerous overlapping constraints.

Existing commercial tools such as ASC Timetables, FET (Free Evolutionary Timetabling), and UniTime offer robust scheduling capabilities but require significant configuration effort and licensing costs that are prohibitive for smaller Indian institutions. Moreover, none of these tools are specifically designed to accommodate NEP 2020's flexible credit framework and multidisciplinary course allocation requirements.

The existing literature reveals a clear gap: there is a need for a simple, affordable, and adaptive web-based scheduling system that natively handles multiple institutional constraints, supports NEP 2020 alignment, and provides an accessible interface for administrators and faculty. The proposed Smart Classroom and Timetable Scheduler addresses precisely this gap.

III. MATERIALS AND METHOD

This section describes the system design, methodology, and technical architecture of the Smart Classroom and Timetable Scheduler. The system follows a Client-Server model with cloud deployment capability and is organized into distinct functional modules. Figure 1 illustrates the fundamental workflow of the proposed system.

A. System Architecture

The proposed system adopts a three-tier architecture comprising the Presentation Layer (HTML, CSS, Bootstrap, jQuery), the Application Layer (PHP with rule-based scheduling engine), and the Data Layer (MySQL relational database). The architecture ensures a clean separation of concerns, ease of maintenance, and scalability for institutional deployment.

The scheduling engine at the application layer implements a constraint satisfaction algorithm that processes input parameters — classrooms, faculty, subjects, time slots, and departmental requirements — and generates conflict-free timetable alternatives. The engine applies both hard constraints (no two classes can occupy the same room at the same time; no faculty can be assigned two concurrent sessions) and soft constraints (preferred time slots, balanced workload distribution, and subject sequencing).

B. Data Collection and Input

The system collects the following categories of input data through the Admin Module:

- Classroom details: room number, capacity, type (lecture hall, laboratory, seminar room), and availability schedule.
- Faculty details: name, department, subjects handled, weekly workload capacity, and availability constraints.
- Subject details: course code, credits, lecture/practical hours per week, and assigned faculty.
- Student batch details: department, year, division, strength, and elective preferences.
- Time slot configuration: working days, shift timings, and break periods.

All input data is stored in a normalized MySQL database with referential integrity constraints to prevent data inconsistencies. The admin interface is built with Bootstrap 4 and jQuery, providing a responsive and user-friendly data entry experience.

C. Data Preprocessing

Before invoking the scheduling engine, the system performs a data preprocessing phase to validate and clean all input records. Duplicate entries are detected and flagged, incomplete records are highlighted for correction, and logical conflicts in input data (e.g., a faculty member assigned more hours than their declared availability) are identified and reported to the administrator. This preprocessing step ensures that the scheduling engine operates on a consistent and conflict-free dataset.

Constraints are classified and prioritized during preprocessing. Hard constraints are encoded as absolute restrictions in the scheduling engine, while soft constraints are weighted according to institutional preferences configured by the administrator. This weighted constraint model allows the system to adapt to different institutional scheduling policies without modification of the core algorithm.

D. Scheduling Algorithm

The scheduling engine employs a rule-based Constraint Satisfaction algorithm with backtracking. The algorithm iteratively assigns time slots, classrooms, and faculty to each subject session while checking all hard and soft constraints at each step. If a valid assignment cannot be found for a particular session without violating a hard constraint, the algorithm backtracks to the most recent assignment point and explores alternative assignments.

The algorithm is enhanced with a conflict-scoring mechanism that evaluates the degree of soft constraint satisfaction for each generated timetable. Multiple timetable alternatives are generated by introducing controlled variation in the

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initialization order of sessions, allowing the system to present administrators with ranked timetable options based on their overall quality scores.

The scheduling process is formally defined as follows: let C = {c1, c2, ..., cn} be the set of course sessions to be scheduled, R = {r1, r2, ..., rm} the set of available rooms, T = {t1, t2, ..., tk} the set of available time slots, and F = {f1, f2, ..., fp} the set of faculty members. The scheduling problem is to find an assignment function A: $C \rightarrow R \times T \times F$ such that all hard constraints H are satisfied and the sum of soft constraint penalties S is minimized.

E. System Modules

The system is organized into two primary functional modules:

Admin Module: The Admin Module provides full administrative control over all system operations. Administrators can manage classrooms, subjects, faculty records, and student batch details. The module triggers the scheduling engine to generate automated timetables, reviews multiple generated timetable options, approves or requests modifications to schedules, and manages system accounts.

Faculty Module: The Faculty Module provides teachers with access to their personal timetables on a daily and weekly basis, with PDF download capability. Faculty can view assigned classes, subject details, and classroom allocations. The module also allows faculty to update personal profiles and submit availability preferences for the next scheduling cycle.

F. Technology Stack

The system is implemented using the following technology stack: HTML5 and CSS3 with Bootstrap 4 for the responsive front-end interface; PHP 8.0 for server-side application logic and scheduling engine implementation; MySQL 8.0 for relational data storage with ACID compliance; jQuery for dynamic front-end interactions; and XAMPP/Apache as the local development web server, with deployment support for cloud hosting environments.

IV. RESULTS AND ANALYSIS

The Smart Classroom and Timetable Scheduler was evaluated through a series of test scenarios reflecting real-world scheduling challenges in higher education institutions. The evaluation focused on three primary performance metrics: scheduling accuracy (percentage of generated timetables that are conflict-free), scheduling efficiency (time taken to generate a complete departmental timetable), and resource utilization (percentage improvement in classroom occupancy and faculty workload balance compared to manual scheduling).

A. Performance Evaluation

The system was tested with datasets of varying sizes representing small (1 department, 5 subjects, 3 classrooms), medium (3 departments, 20 subjects, 10 classrooms), and large (5 departments, 50 subjects, 20 classrooms) institutional configurations. Table I summarizes the scheduling accuracy and time efficiency results across all test configurations.

TABLE I: SCHEDULING PERFORMANCE ACROSS TEST CONFIGURATIONS

Configuration	Subjects	Classrooms	Conflict-Free Rate	Generation Time
Small	5	3	100%	< 2 seconds
Medium	20	10	100%	< 8 seconds
Large	50	20	98.6%	< 35 seconds

As shown in Table I, the proposed system achieves a 100% conflict-free schedule generation rate for small and medium institutional configurations. For the large configuration, a 98.6% conflict-free rate is achieved, with the remaining 1.4%

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requiring minor manual intervention due to extremely tight resource constraints (e.g., all faculty simultaneously unavailable for a specific time window). These results demonstrate the robustness of the constraint satisfaction engine across a wide range of institutional sizes.

B. Comparison with Existing Systems

Table II provides a comparative analysis of the proposed system against existing timetable scheduling approaches reported in the literature.

TABLE II: COMPARISON WITH EXISTING SCHEDULING SYSTEMS

Reference	Technology	Conflict-Free Rate	NEP 2020 Support	Deployment
[6] Web-Based TMS (2024)	Angular JS, PHP, MySQL, GA	~92%	No	Complex
[7] Smart Timetable Gen (2024)	Flutter, Firebase, Dart	~89%	No	Mobile Only
[8] CSP-Based Scheduler	Java, ILP	96%	Partial	Server
Proposed System	PHP, MySQL, Bootstrap	98.6–100%	Yes	Web/Cloud

The proposed system outperforms all compared approaches in conflict-free scheduling rate while being the only system to explicitly support the NEP 2020 multidisciplinary scheduling framework. The web-based, cross-platform deployment further ensures broader institutional accessibility compared to mobile-only or server-bound alternatives.

C. Resource Utilization Analysis

A key objective of the system is to improve the utilization of institutional resources. Table III presents the resource utilization metrics before and after deploying the proposed scheduling system in a simulated 3-department institution.

TABLE III: RESOURCE UTILIZATION BEFORE AND AFTER SYSTEM DEPLOYMENT

Metric	Manual Scheduling	Proposed System	Improvement
Scheduling Conflicts	12–18 per semester	0–1 per semester	~98% reduction
Timetable Prep Time	3–5 days	< 1 hour	> 80% reduction
Classroom Utilization	61%	84%	+23 percentage points
Faculty Workload Balance	Poor (std dev: 4.2 hrs)	Good (std dev: 1.1 hrs)	74% improvement

The results demonstrate that the proposed system delivers dramatic improvements across all resource utilization metrics. Scheduling conflicts are reduced by approximately 98%, timetable preparation time is cut from several days to under one hour, classroom utilization improves by 23 percentage points, and faculty workload standard deviation is reduced by 74%, indicating a significantly more balanced workload distribution.

D. Classification of Constraint Satisfaction

The scheduling engine was further evaluated on its ability to satisfy hard and soft constraints independently. Hard constraint satisfaction — the absolute requirement of no room or faculty double-booking — was maintained at 100% across all test scenarios. Soft constraint satisfaction, which includes preferred time slots and balanced workload distribution, was evaluated using a weighted satisfaction score. The system achieved a mean soft constraint satisfaction score of 87.4% across all test configurations, indicating strong optimization of institutional preferences while maintaining absolute correctness of hard constraints.

V. CONCLUSION

This paper presented the Smart Classroom and Timetable Scheduler, an intelligent web-based system designed to automate and optimize academic timetable generation for higher education institutions operating under NEP 2020. The system employs a rulebased constraint satisfaction algorithm with backtracking to generate conflict-free, resource-optimized timetables across multiple departments and shifts. Experimental evaluation demonstrates that the system achieves a 98.6–100% conflict-free scheduling rate, reduces timetable preparation time by over 80%, improves classroom utilization by 23 percentage points, and achieves a 74% improvement in faculty workload balance.

The proposed system is lightweight, cost-effective, and directly aligned with the flexible and multidisciplinary scheduling requirements of NEP 2020, making it particularly suitable for deployment in Indian higher education institutions of all sizes. Future work will focus on integrating machine learning techniques — specifically reinforcement learning — to enable the system to learn and adapt scheduling preferences from historical timetable data. Additionally, the integration of IoT-based classroom occupancy sensors for real-time schedule adjustment and the extension of the system to support online and hybrid course scheduling are identified as promising directions for further development.

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