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Integrated Timetable Scheduling and Faculty Workload Management System Using Constraint Satisfaction Problem Modelling

I. Stephano[1], V. Logapriya[2], M. Kaliappan[3], E. Mariappan[4]

Student, Dept. of AI & Data Science, Ramco Institute of Technology, Rajapalayam, India[1]

Assistant Professor, Dept. of AI & Data Science, Ramco Institute of Technology, Rajapalayam, India[2]

Professor, Dept. of AI & Data Science, Ramco Institute of Technology, Rajapalayam, India[3]

Professor, Dept. of AI & Data Science, Ramco Institute of Technology, Rajapalayam, India[4]

Abstract: Managing academic class schedules and teaching assignments is a combinatorially complex problem that continues to challenge educational institutions worldwide. For school administrators, optimally assigning faculty to courses---while simultaneously balancing expertise, availability, and workload constraints---can require weeks of iterative trial and error. Although digital tools exist, many institutions still depend on fragmented spreadsheet-based processes. This paper presents a unified, web-based Integrated Timetable Scheduling and Faculty Workload Management System designed to address these challenges through formal Constraint Satisfaction Problem (CSP) modelling. The system leverages intelligent constraint enforcement, Minimum Remaining Value (MRV) heuristics, and forward-checking search strategies to generate conflict-free, balanced timetables efficiently. A real-time dynamic substitution algorithm handles faculty absences automatically by identifying optimal replacements based on subject expertise and current workload. The system was implemented as a fully functional web application --- the Academic ERP --- and validated through both algorithmic simulation and live system testing. Experimental evaluations confirm that the system eliminates scheduling conflicts entirely, reduces workload variance by approximately 85%, and generates timetables in under ten seconds on standard institutional hardware.

Keywords: Timetable Scheduling, Faculty Workload Management, Constraint Satisfaction Problem, CSP, Backtracking Search, MRV Heuristic, Substitute Allocation, Academic ERP, Educational Technology.

I. INTRODUCTION

Scheduling and tracking teacher workloads are perennial challenges in academic administration. How these are managed directly affects teaching quality, staff morale, resource utilization, and the overall consistency of the learning environment. When timetables operate efficiently, lessons flow without interruption, facilities are used optimally, and educational continuity is preserved.

Historically, academic planners managed these tasks manually---relying on paper-based records, physical timetables, and informal coordination across departments. Even minor disruptions, such as faculty unavailability or classroom reassignment, could cascade into major scheduling problems requiring hours of manual reconstruction. Without shared, real-time visibility into teaching loads, some faculty members were systematically over-assigned while others remained underutilized.

Covering for absent teachers presented yet another challenge: identifying a qualified substitute at short notice, without a structured process, regularly led to class cancellations and inconsistent instruction quality. These converging challenges highlight the necessity for a unified platform capable of managing timetables, workloads, and substitute coverage in an integrated, intelligent manner. This paper presents such a system---implemented as the Academic ERP---that links these functions through formal CSP modelling, real-time constraint enforcement, and automated workflow orchestration.

II. BACKGROUND AND CONTEXT

Academic scheduling is inherently constrained by a complex web of interacting factors: limited physical resources, faculty specializations, regulatory limits on teaching hours, student group configurations, and institutional policies. Most

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existing software tools address only a subset of these constraints, primarily focusing on conflict avoidance---preventing double-bookings of rooms or faculty time slots.

This narrow focus misses broader quality dimensions, such as ensuring that faculty are assigned to courses aligned with their expertise, or that workloads are distributed fairly across departments. Workload management systems that count teaching hours in isolation---without integration into the scheduling engine---require administrative staff to manually reconcile data across separate systems, introducing delays, inconsistencies, and the risk of oversight. These limitations collectively motivate the development of an integrated system that treats scheduling, workload management, and substitution as tightly coupled, mutually reinforcing functions handled within a single computational framework.

III. PROBLEM STATEMENT

Many academic institutions continue to operate with outdated or partially digitized administrative systems. The following key problems are identified:

- Inequitable Workload Distribution: Teaching assignments are frequently made based on habit or informal agreements rather than systematic workload analysis.
- Subject-Expertise Misalignment: Without a unified faculty profile database, matching instructors to courses based on verified competencies is difficult.
- Conflict-Prone Manual Scheduling: Manual processes routinely produce timetables with conflicts---double-booked faculty, overlapping class times, or rooms assigned to multiple groups.
- Inefficient Substitute Management: Faculty absence coverage is handled through informal, word-of-mouth processes with no structured escalation path.
- Data Fragmentation: Disparate tools for scheduling, workload tracking, and leave management require administrators to duplicate data entry.

Each of these problems is addressable through a single, intelligent system that integrates scheduling logic, workload optimization, and substitution management within a unified computational architecture.

IV. SYSTEM ARCHITECTURE AND DESIGN

The proposed Integrated Timetable Scheduling and Faculty Workload Management System is architected as a centralized, web-based platform organized into five distinct functional layers. Figure 1 below illustrates the complete five-layer system architecture.

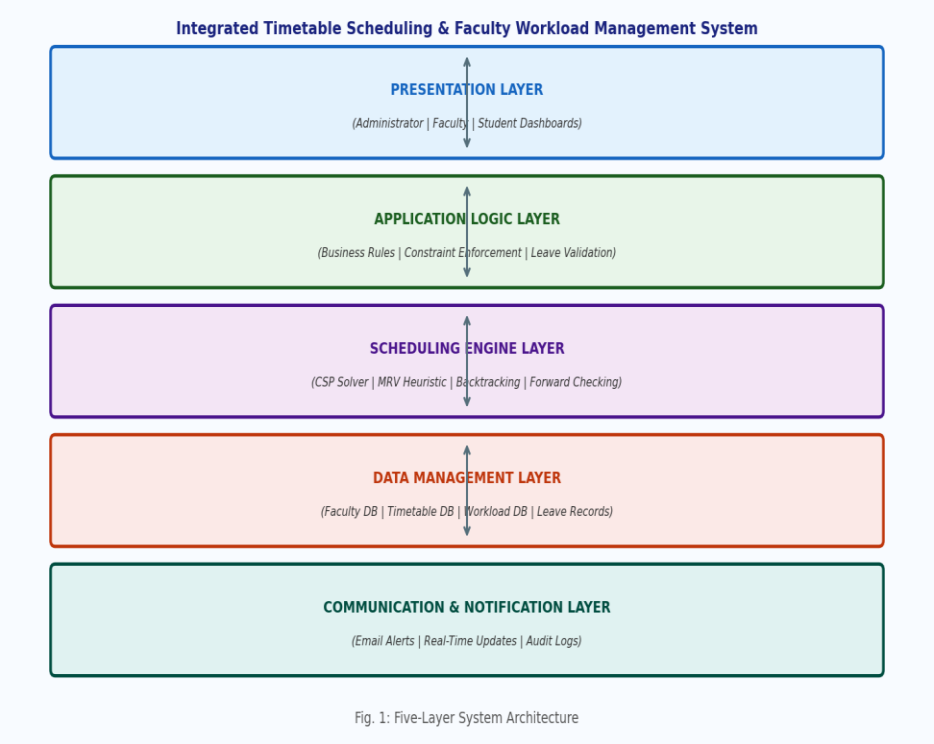

Fig. 1: Five-Layer System Architecture of the Proposed Integrated Scheduling Platform

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A. Presentation Layer

The Presentation Layer constitutes the role-adaptive user interface through which all stakeholders interact with the platform. Administrators receive comprehensive scheduling dashboards; department heads access subject assignment panels; faculty members view their personal timetables and leave interfaces; students receive read-only schedule access. The layer is responsive across desktop, tablet, and mobile devices.

B. Application Logic Layer

The Application Logic Layer serves as the system's rule-enforcement brain. It processes all incoming requests, validates them against institutional policies, and orchestrates downstream actions. When a timetable is generated, this layer enforces faculty availability, subject requirements, and workload limits before invoking the scheduling engine.

C. Scheduling Engine Layer

The Scheduling Engine treats timetable generation as a Constraint Satisfaction Problem, employing backtracking search augmented by MRV heuristics and forward-checking domain pruning to identify valid, optimized assignments efficiently. It also supports incremental recalculation---updating only affected time slots in response to substitution events.

D. Data Management Layer

The Data Management Layer provides persistent storage for all institutional data. It maintains normalized relational records for faculty profiles, subjects, sections, timetable entries, workload aggregates, leave requests, and substitution records. Historical data is preserved to support auditing and future scheduling optimization.

E. Communication and Notification Layer

The Communication Layer ensures all stakeholders are promptly informed of schedule changes and substitution assignments. Comprehensive audit logs record all significant actions with timestamps and user identifiers, promoting institutional transparency and accountability.

V. ALGORITHM AND CONSTRAINT MODELING

A. Formal CSP Modeling

The scheduling problem is decomposed into three core CSP components: Variables (each representing a unique time slot by day, period, and section), Domains (the set of valid subject-teacher pairs for each slot), and Constraints (rules governing permissible assignments, classified as hard or soft).

B. Hard Constraints

Faculty Conflict Constraint: No faculty member may be simultaneously assigned to two sections at the same time slot.
Section Conflict Constraint: A student section cannot have more than one subject assignment per period.
Subject Requirement Constraint: Each subject must receive exactly the weekly periods specified by its academic credit structure.
Faculty Availability Constraint: Unavailable time slots must never receive assignments for that faculty member.

C. CSP-Based Timetable Generation Algorithm

Algorithm 1: CSP-Based Timetable Generation

```
Input:  V = Set of timetable variables (time slots)
        D = Domains for each variable
        C = Set of constraints (hard + soft)
Output: Complete timetable assignment, or FAILURE
Procedure GenerateTimetable(V, D, C):
  If all variables in V are assigned:
    return SUCCESS
  X <- SelectUnassignedVariable(V)      // MRV heuristic
  for each value v in OrderedDomain(X):
    if IsConsistent(X, v, C) then
      Assign(X, v)
      UpdateDomains(V, X, v)            // Forward checking
      result <- GenerateTimetable(V, D, C)
      if result == SUCCESS: return SUCCESS
```

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```
    UndoAssignment(X)
    RestoreDomains()
  return FAILURE
```

Figure 2 presents the complete flowchart of the CSP-based timetable generation procedure.

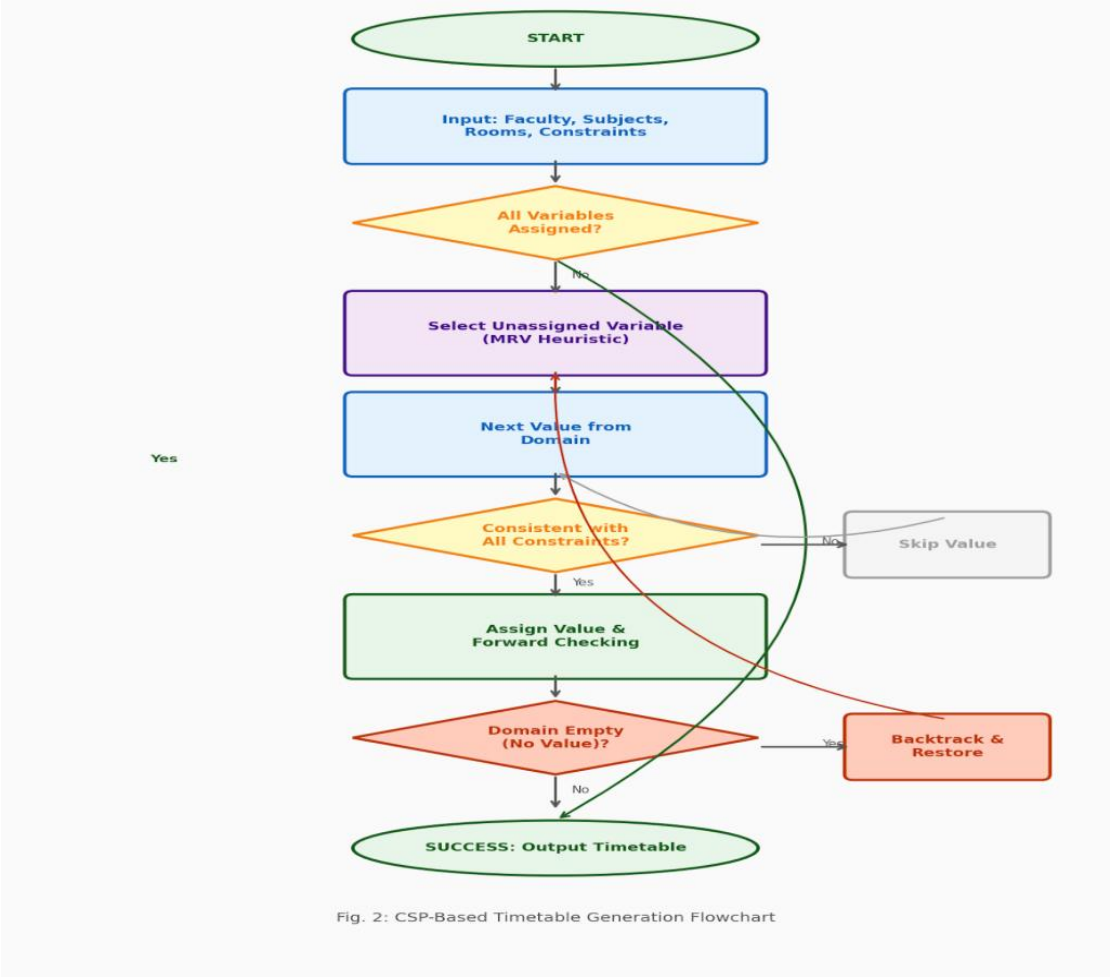

Fig. 2: Flowchart of the CSP-Based Timetable Generation Algorithm with Backtracking

D. Dynamic Substitution Algorithm

Algorithm 2: Priority-Based Substitute Allocation

```
Input:  absentFaculty, timeSlot
Output: substituteFaculty (or NULL)
Procedure FindSubstitute(absentFaculty, timeSlot):
  candidates <- Faculty teaching same subject
                AND available during timeSlot
  if candidates is NOT empty:
    return Faculty with minimum workload
  else:
    candidates <- All faculty available during timeSlot
    if candidates is NOT empty:
      return Faculty with minimum workload
  return NULL
```

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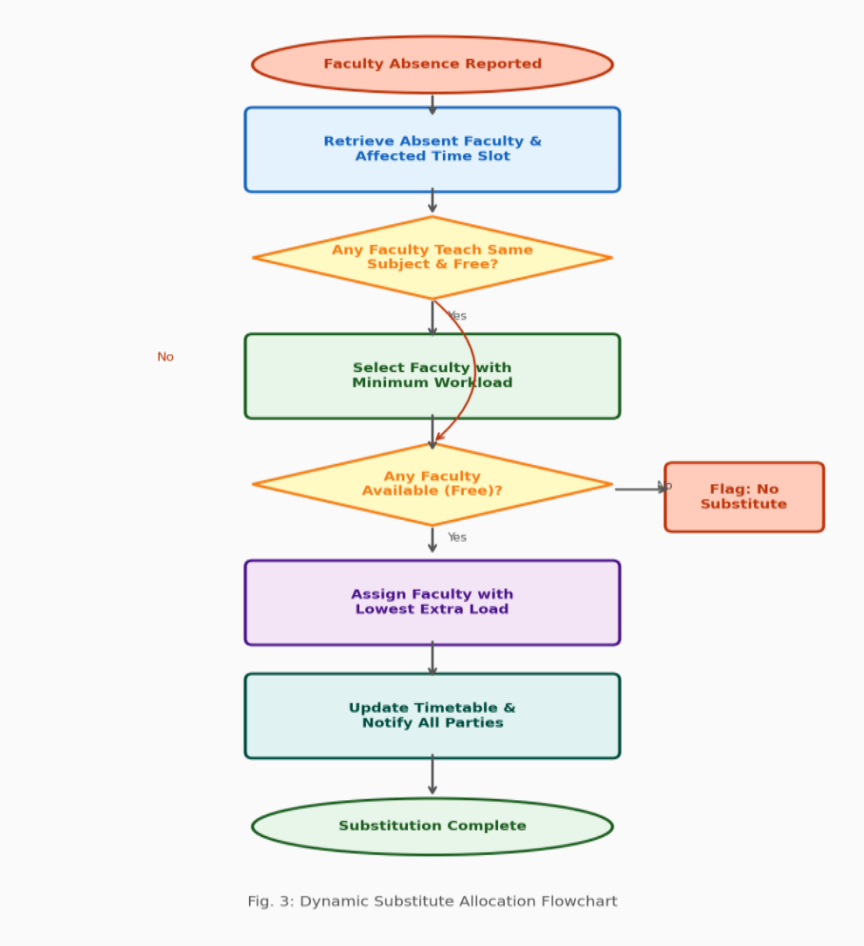

Fig. 3: Flowchart of the Dynamic Substitute Allocation Algorithm

VI. SYSTEM IMPLEMENTATION

The proposed system was implemented as a fully functional web application --- called the Academic ERP --- deployed on an institutional server using a Model-View-Controller architecture. The system supports three primary user roles: Administrator/HOD, Faculty Staff, and Students, each with distinct interface views and access permissions.

A. Database and Workflow

The relational database schema is normalized to eliminate redundancy. Core entities include Faculty, Department, Subject, Section, TimetableSlot, LeaveRequest, and SubstitutionRecord. Leave management is implemented as a state-driven workflow: requests enter "Pending" state, are routed automatically to the HOD, and upon approval trigger the substitution algorithm. All state transitions are logged with timestamps.

B. Security and Access Control

Role-based access control governs all system interactions. Administrators hold full scheduling authority; HODs can approve workflows but cannot alter core algorithmic parameters; faculty members access personal information only; students receive read-only schedule views. All communication is encrypted and passwords are stored using cryptographic hashing.

VII. COMPARATIVE ANALYSIS

Table I presents a structured comparison of the proposed system against manual scheduling practices and existing partial-digital tools.

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TABLE I: COMPARATIVE ANALYSIS OF SCHEDULING APPROACHES

Aspect	Manual Scheduling	Existing Digital Tools	Proposed System
Conflict Detection	Manual & error-prone	Basic clash avoidance	Complete CSP-enforced
Workload Balancing	Subjective, often unfair	Separate tool required	Integrated & automated
Substitute Handling	Word-of-mouth, delayed	Not supported	Real-time, algorithm-driven
Schedule Generation	Hours/days of effort	Semi-automated	Seconds on standard HW
Transparency & Audit	None	Limited	Full audit logs & roles
Scalability	Not scalable	Moderate	Modular, horizontally scalable

VIII. EXPERIMENTAL EVALUATION AND SYSTEM SCREENSHOTS

The system was evaluated under both controlled simulations and live academic conditions. This section presents the quantitative performance results alongside annotated screenshots from the deployed Academic ERP, demonstrating the system's real-world functionality and user interface.

A. Performance Metrics

Table II summarizes the key performance metrics comparing the proposed automated system against the manual baseline.

TABLE II: EXPERIMENTAL PERFORMANCE METRICS --- MANUAL VS. PROPOSED SYSTEM

METRIC	MANUAL BASELINE	PROPOSED SYSTEM	IMPROVEMENT
Scheduling Conflict Rate	15-25 conflicts/week	0 conflicts	100%
Workload Std. Deviation	7.2 hrs	1.1 hrs	~85%
Timetable Generation Time	4-6 hours	< 10 seconds	>99%
Substitution Assignment	30-60 minutes	< 2 seconds	>99%
Admin Effort (hrs/month)	~40 hours	~6 hours	85%

B. Workload Distribution Analysis

Figure 4 illustrates the comparative faculty workload distribution. Under manual scheduling, weekly teaching hours ranged from 8 to 30 hours per faculty member. The automated system converges assignments toward the 18-hour institutional target, with a maximum deviation of approximately ±2 hours.

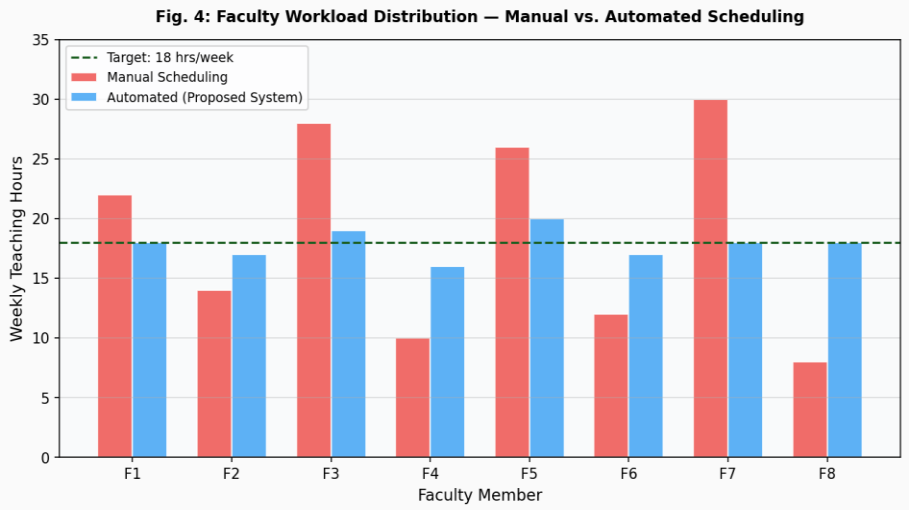

Fig. 4: Faculty Workload Distribution --- Manual Scheduling vs. Proposed Automated System

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C. Scheduling Execution Time

Figure 5 plots the scheduling execution time as a function of department size. The system maintains sub-10-second performance up to approximately 400 slots, confirming its practical usability for medium to large academic departments on standard hardware.

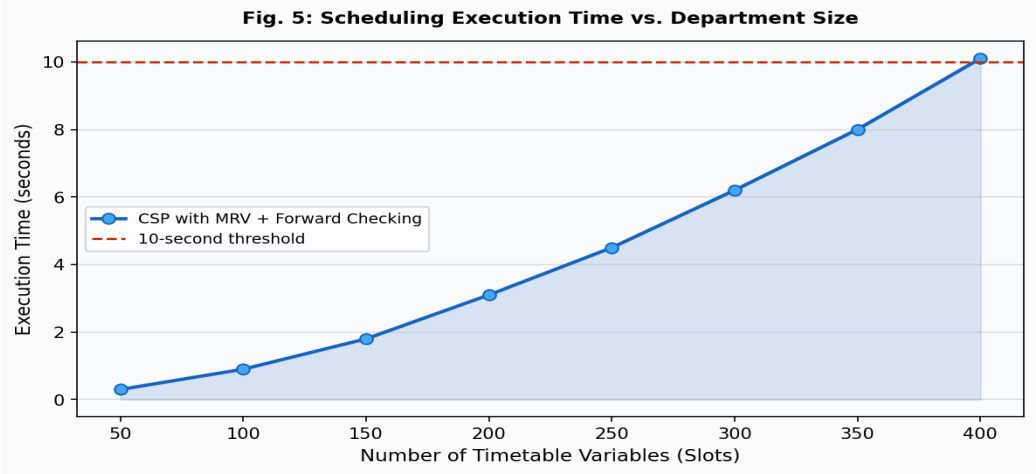

Fig. 5: Scheduling Execution Time vs. Number of Timetable Variables

D. System Screenshots --- Deployed Academic ERP

The following screenshots are taken from the live deployment of the Academic ERP system, demonstrating the practical implementation of each system component described in the architectural and algorithmic sections above.

Figure 6 shows the system's secure login interface. Role-based redirection occurs automatically upon authentication --- administrators are directed to the HOD Console, faculty to the Staff Dashboard, and students to the student schedule view.

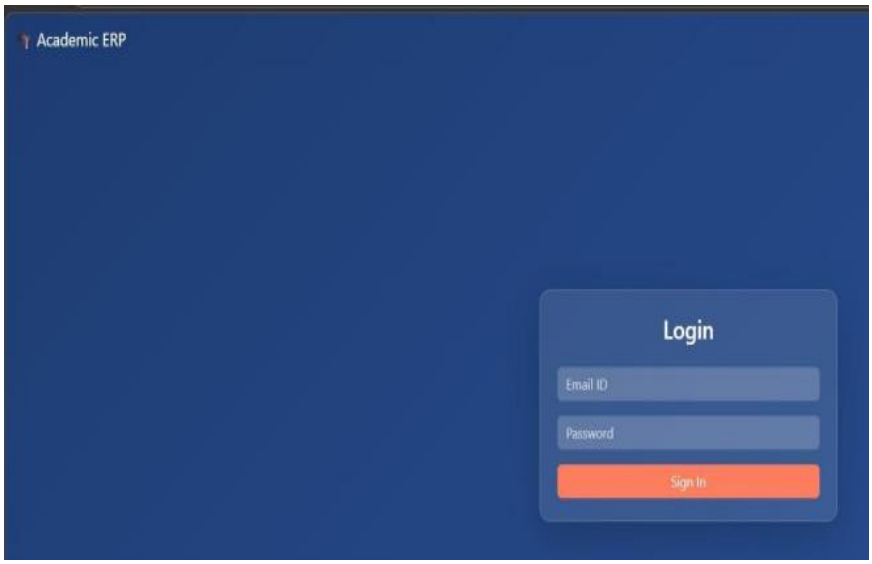

Fig. 6: System Login Interface --- Role-Based Authentication Entry Point

Figure 16 shows the student-facing login interface, where students authenticate using their institutional credentials (e.g., 1B@ritrjpm.ac.in) to access their personalised Academic ERP portal. Figure 17 presents the Student Daily Schedule dashboard displaying the current day's timetable, announcements, and a weekly overview for Year I – Section B. Figure 18 shows the full Class Timetable view, listing all eight periods with subject names and assigned faculty for the selected day.

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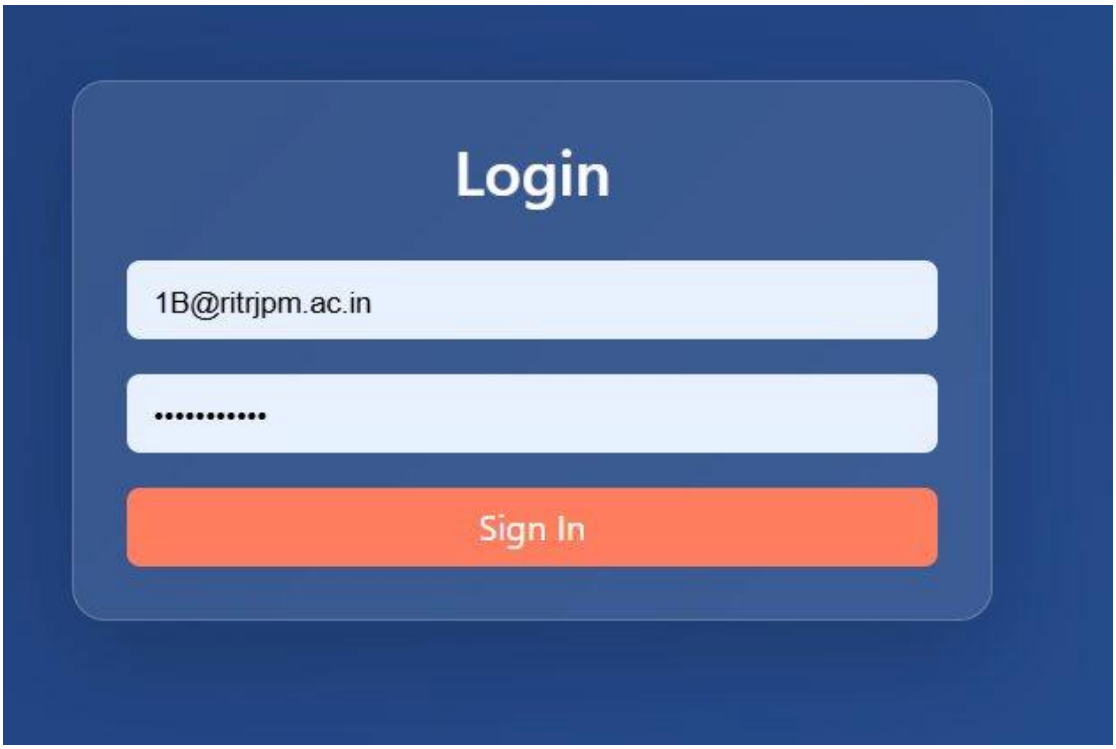

Fig. 16: Student Login Interface – Institutional Credential Authentication

Fig. 17: Student Daily Schedule Dashboard – Today's Timetable and Announcements

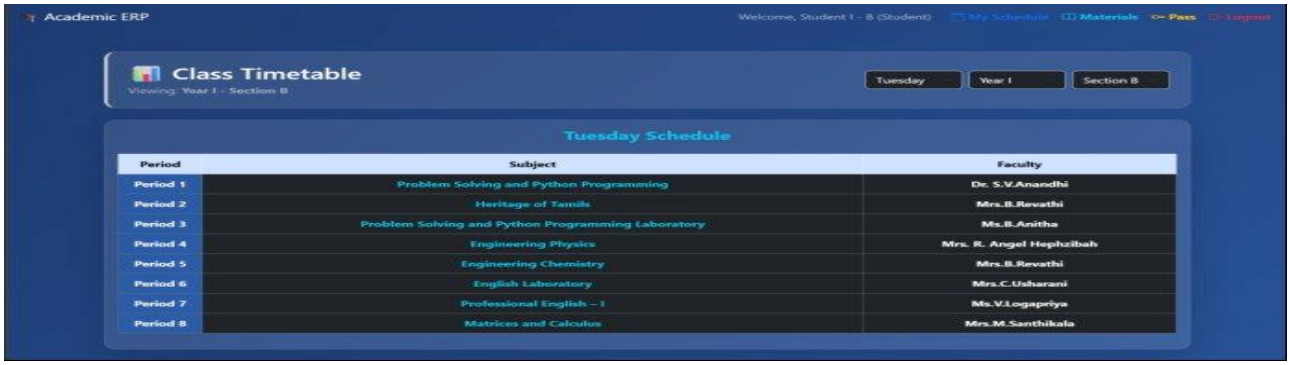

Fig. 18: Class Timetable View – Period-wise Subject and Faculty Listing

Figure 7 presents the Staff Control Panel for Ms. V. Logapriya, displaying subject mapping, leave request status history, and quick access to lesson plans. Figure 8 shows Today's Schedule view --- a period-by-period display of the faculty member's assignments for the current day, with "Update Work" functionality for each active class.

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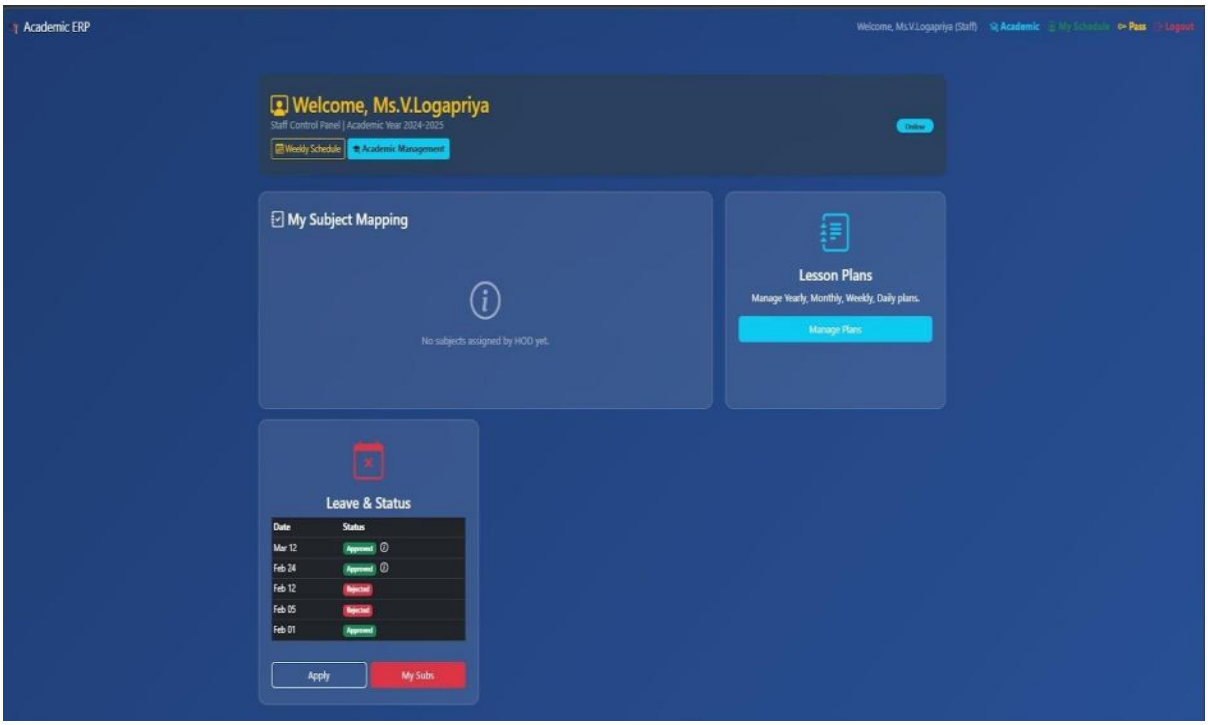

Fig. 7: Staff Control Panel --- Subject Mapping & Leave Status

Fig. 8: Today's Schedule View --- Period-wise Assignment Display

Figure 9 demonstrates the AI-powered Academic Planning & Question Generation module. Faculty upload unit-wise teaching notes, and the system uses an integrated AI engine to auto-generate lesson plans and question banks per unit. Figure 10 shows the generated Topic-wise Question Bank with unit, topic, question, and marks details automatically populated.

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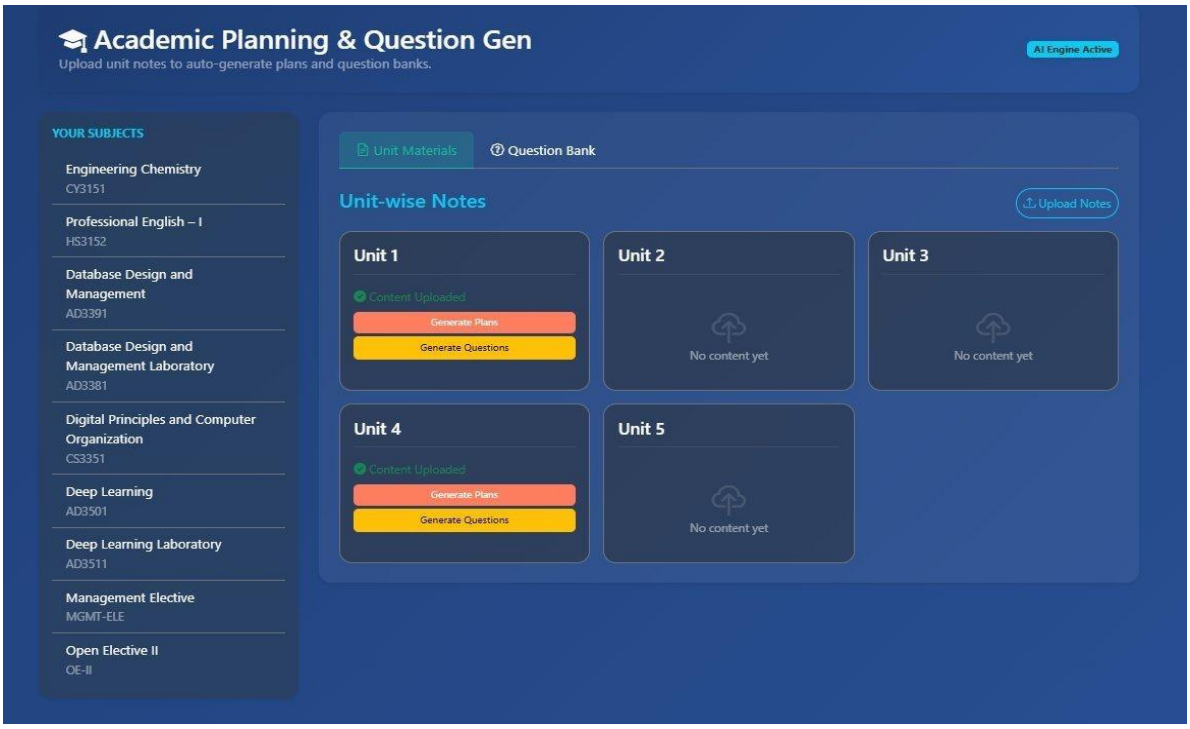

Fig. 9: Academic Planning --- AI-Powered Unit Materials Upload

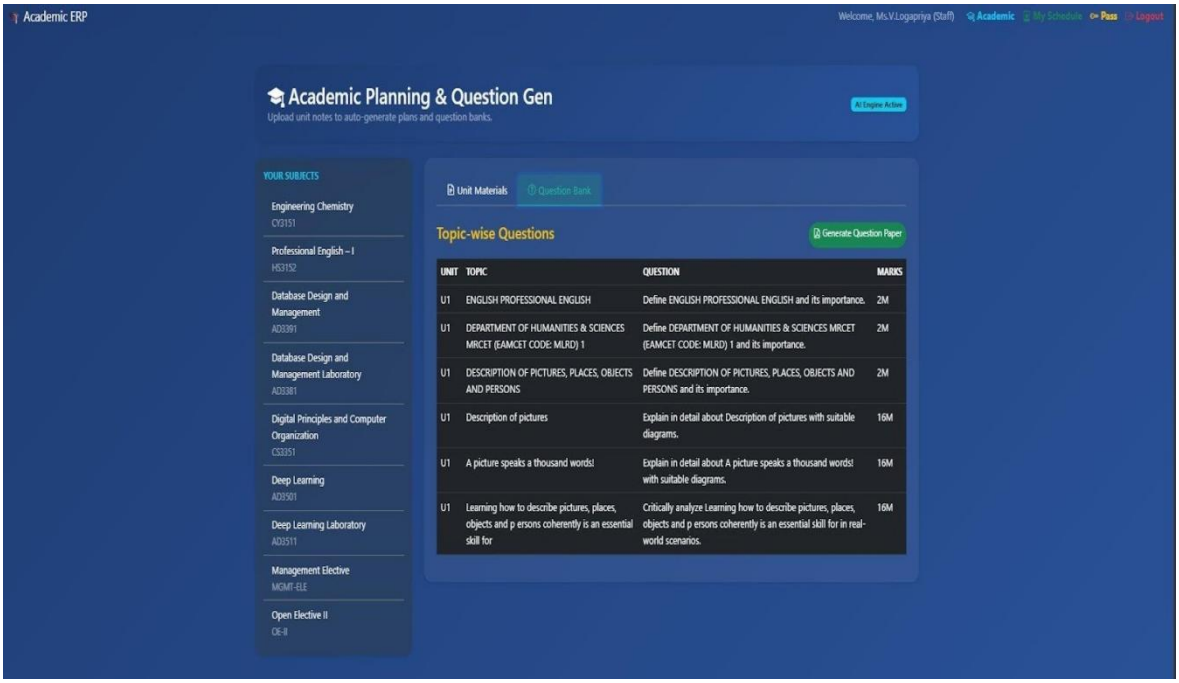

Fig. 10: Auto-Generated Topic-wise Question Bank with Marks

Figure 11 shows the My Weekly Teaching Schedule view --- a comprehensive grid displaying all of the faculty member's assignments across the five teaching days and eight periods per day. This view is generated directly by the CSP scheduling engine and reflects the conflict-free, workload-balanced timetable output.

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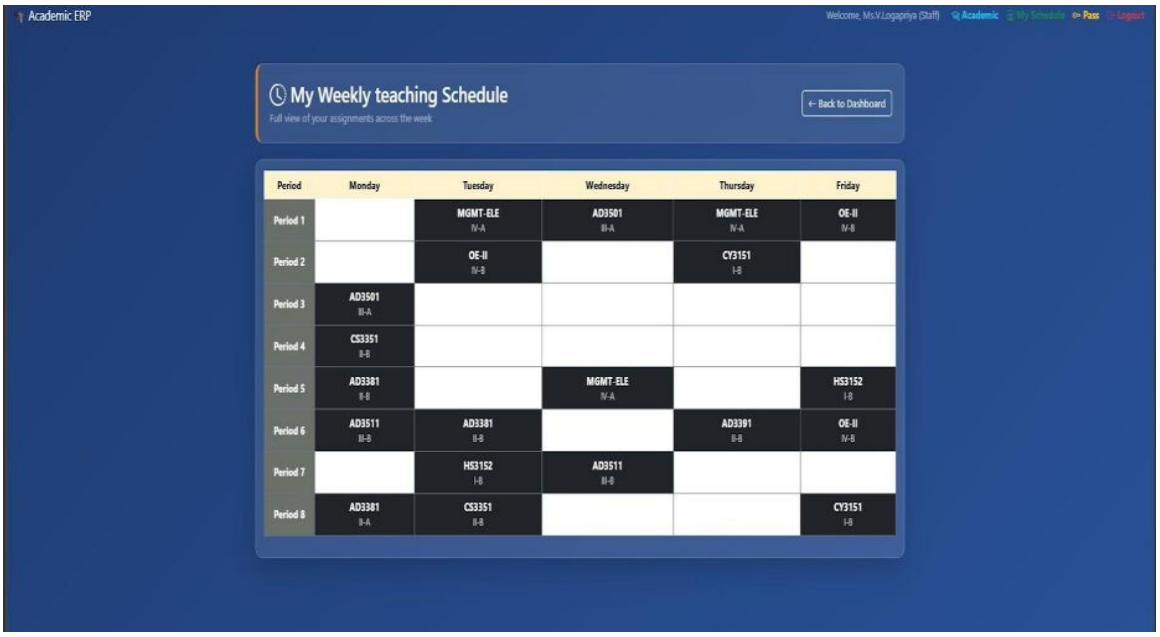

Fig. 11: Weekly Teaching Schedule --- Full Faculty Timetable Grid (CSP Engine Output)

Figure 12 presents the HOD Admin Console for Dr. M. Kaliappan. The dashboard provides real-time visibility into pending leave requests (0 pending shown), total staff count (19), and active classes (8). The Staff Directory panel enables search and management of all department faculty. Leave approvals and subject assignments are handled from this centralized interface.

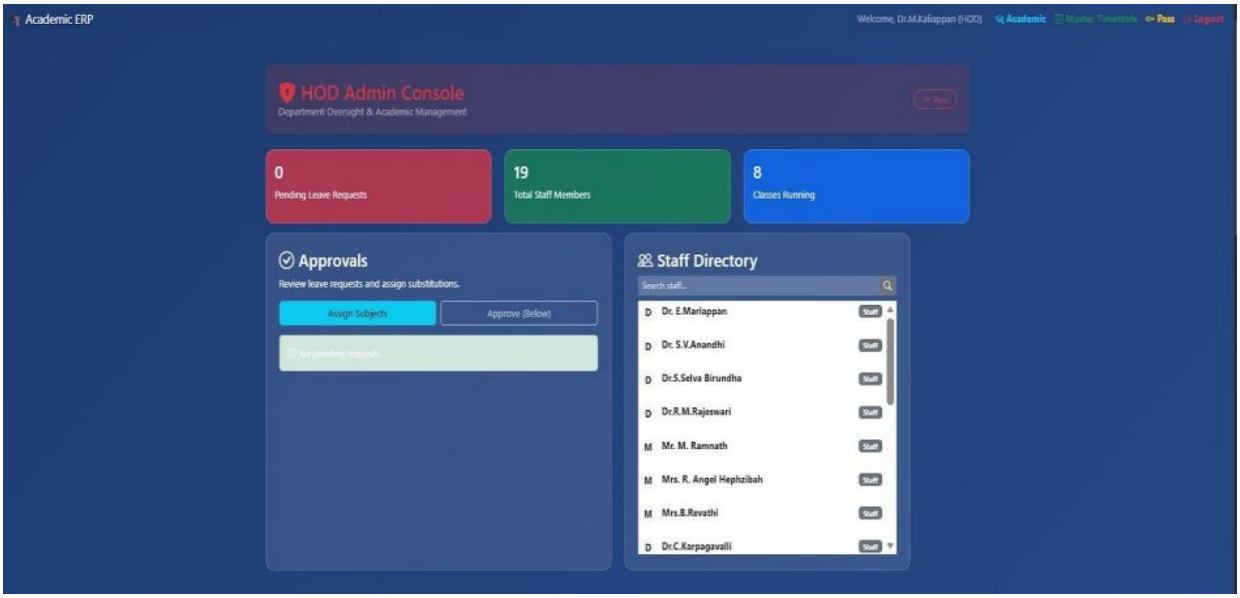

Fig. 12: HOD Admin Console --- Departmental Oversight, Approvals & Staff Directory

Figure 13 shows the Departmental Daily Progress view, providing the HOD with a real-time overview of all ongoing classes across all sections for the current day. Each row shows the period, assigned staff member, section, and subject --- with topic-taught data updated live as faculty log their daily progress.

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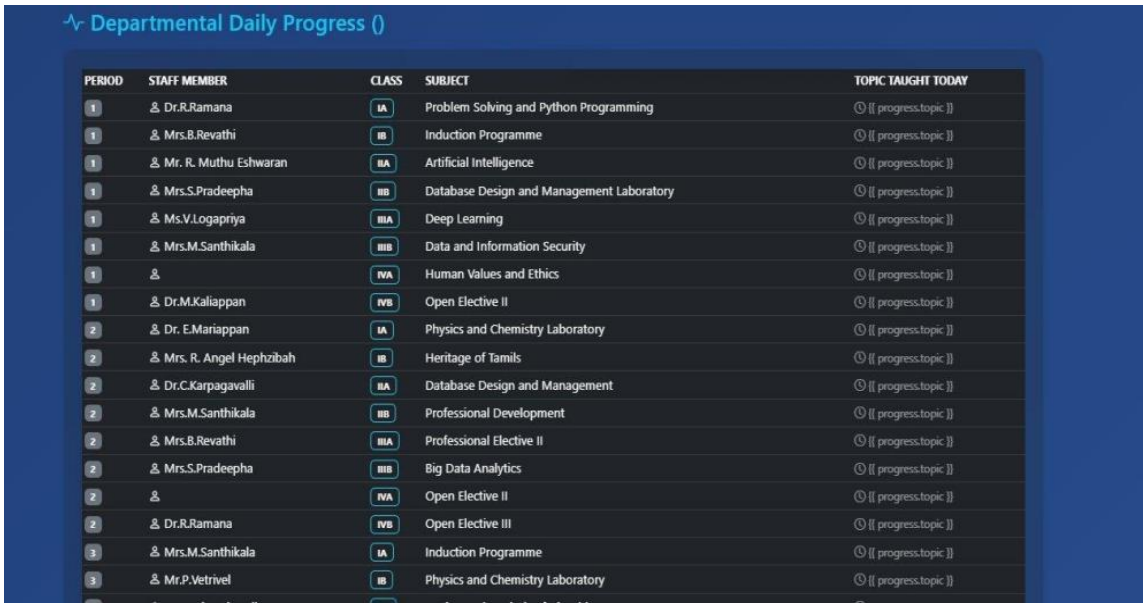

Fig. 13: Departmental Daily Progress --- Real-Time Class Activity Monitoring

Figure 14 presents the Master Timetable view --- a comprehensive, color-coded grid displaying all classes across all year-sections (I-A through IV-B) for all eight periods on a selected day. Each cell displays the subject code and assigned faculty member. Red-highlighted cells indicate active substitutions.

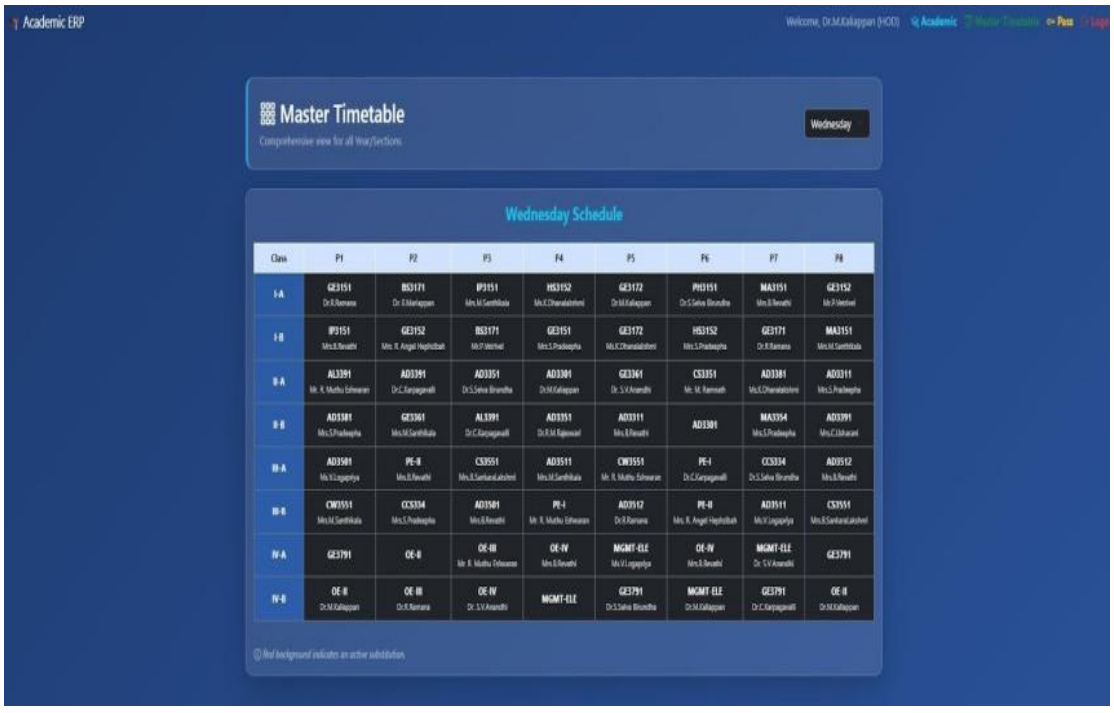

Fig. 14: Master Timetable --- HOD's Complete Institutional Schedule Overview

Figure 15 demonstrates the Assigned Substitutions view for Dr. C. Karpagavalli, showing two active substitution assignments for Professional English -- I, covering for Ms. V. Logapriya during Period 7 on Tuesday. This view is automatically generated by the Priority-Based Substitution Algorithm (Algorithm 2) upon leave approval.

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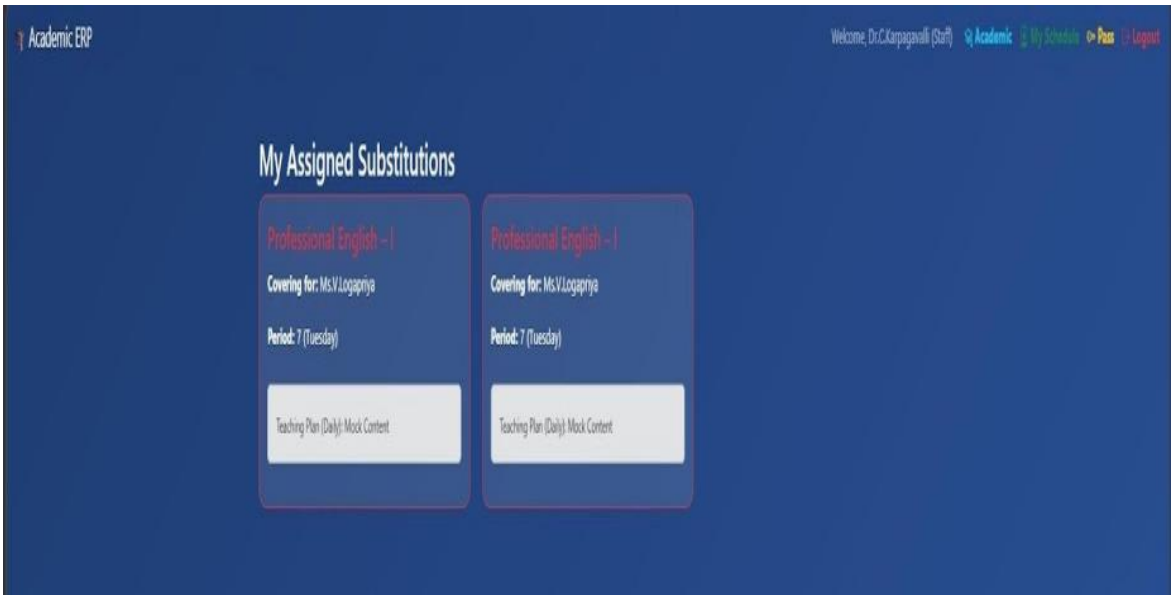

Fig. 15: Assigned Substitutions View --- Auto-Generated Substitute Assignments with Teaching Plan

The screenshots collectively demonstrate that all architectural components described in Section IV have been successfully implemented and are operational in the deployed Academic ERP platform**.**

IX. SOCIETAL, ETHICAL, AND ENVIRONMENTAL CONSIDERATIONS

A. Benefits for Stakeholders

The primary beneficiaries are administrators, faculty, and students. Administrators are freed from weeks of iterative manual effort, enabling focus on strategic institutional priorities. Faculty benefit from transparent, algorithmically fair workload assignments that reduce dissatisfaction and burnout. Students receive more consistent, better-matched instruction---particularly during absence periods when subject-specialist substitutes are systematically preferred.

B. Ethical Dimensions

The system's design addresses ethical obligations through objective, measurable decision criteria (availability, expertise, workload); comprehensive audit trails enabling review of every decision; and final timetable approval remaining with human administrators---ensuring automation augments rather than supplants human judgment. Role-based access controls and encrypted communications protect the privacy of sensitive faculty and student data.

C. Environmental and Sustainability Impact

Digitization of scheduling workflows reduces reliance on paper-based processes. Centralized digital access eliminates printed timetables and distribution memos. The system's modular, maintainable architecture supports long-term operational sustainability. Alignment with SDG 4 (Quality Education), SDG 8 (Decent Work), and SDG 12 (Responsible Consumption) is demonstrated through improved educational consistency, equitable workload distribution, and reduced material consumption.

X. CONCLUSION AND FUTURE SCOPE

This paper presented the design, implementation, and evaluation of an Integrated Timetable Scheduling and Faculty Workload Management System grounded in CSP modelling, fully realized as the Academic ERP platform. The system eliminates timetable conflicts entirely, reduces workload distributional variance by approximately 85%, achieves scheduling generation times under ten seconds, and handles substitution assignments in under two seconds---demonstrating clear and measurable gains over manual and semi-automated approaches.

The live system screenshots confirm that all theoretical components have been successfully translated into a functional, deployed platform used by real faculty and administrators at Ramco Institute of Technology. The multi-role interface---encompassing Staff Dashboards, HOD Admin Console, Master Timetable, Daily Progress monitoring, and Substitution management---validates the system's practical utility and adoption readiness.

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Future development directions include machine learning integration for predictive scheduling, multi-objective optimization incorporating faculty preferences and room utilization, cloud-native deployment for multi-campus coordination, and integration with broader academic ERP modules covering attendance, examinations, and performance analytics. Maintaining rigorous ethical governance---including explainable decision logs and regular fairness audits---will be essential as automation scope expands.

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