IARJSET ISSN (O) 2393-8021, ISSN (P) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

Impact Factor 8.066 ⁜ Peer-reviewed & Refereed journal ⁜ Vol. 13, Issue 6, June 2026

DOI: 10.17148/IARJSET.2026.13640

Cloud-Integrated Automated Academic Scheduling System: A Scalable Web-Based Approach for Conflict-Free Timetable Generation

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Abstract: Academic timetable management remains a persistent administrative bottleneck in educational institutions worldwide. Conventional scheduling practices rely on manual allocation procedures that are error-prone, time-intensive, and incapable of dynamically responding to evolving constraints such as faculty availability, subject hour requirements, and classroom occupancy. This paper presents the design, development, and deployment of a cloud-integrated automated academic scheduling system built upon the Flask web framework, a relational SQLite database engine, and Amazon Web Services (AWS) infrastructure, leveraging AWS CodePipeline and AWS Elastic Beanstalk for continuous integration and scalable deployment. The proposed system introduces a constraint-aware slot-filling algorithm that distributes subjects across a five-day weekly schedule while respecting per-subject credit-hour allocations assigned by the administrator. The platform provides a web-based administrative interface encompassing faculty registration, course configuration, departmental class management, subject-faculty assignment, automatic schedule generation, inline schedule editing, and CSV-based export functionality. Experimental evaluation on three academic cohorts-comprising undergraduate and postgraduate programs-demonstrates that the system successfully generates complete, conflict-free timetables within sub-second response times. The architecture's serverless deployment model inherently provides horizontal scalability and high availability without infrastructure overhead. The proposed solution reduces timetable preparation time by an estimated 85% compared to manual methods, offering a compelling advancement for the domain of intelligent academic resource management.

Keywords: Academic timetable management, automated scheduling system, cloud computing, AWS Elastic Beanstalk, Flask framework, constraint-based scheduling, educational resource planning, web-based administration

I. INTRODUCTION

Efficient scheduling of academic activities constitutes a foundational operational requirement for all educational institutions. The construction of a feasible weekly timetable demands simultaneous satisfaction of multiple intersecting constraints: subject credit-hour allocations, faculty teaching loads, classroom availability, and departmental concurrence policies. When performed manually, this process consumes considerable administrative effort, often spanning several working days at the commencement of each academic semester, and remains vulnerable to human error, overlooked constraints, and scheduling conflicts that subsequently require ad-hoc correction [1].

The proliferation of cloud computing platforms and lightweight web application frameworks has created new opportunities for automating such administrative workflows. Deploying scheduling applications on cloud infrastructure offers organizations on-demand scalability, geographic redundancy, and elimination of on-premises hardware maintenance costs [2]. Simultaneously, constraint-satisfaction and algorithmic scheduling approaches from the field of combinatorial optimization have matured sufficiently to be embedded within practical web applications [3].

Existing solutions for timetable generation range from standalone desktop applications to enterprise-grade systems employing genetic algorithms or integer programming formulations. However, many such systems impose steep learning curves, require specialized hardware configurations, or lack the intuitive administrative interfaces necessary for adoption in resource-constrained educational environments [4]. There is therefore a compelling need for lightweight, cloud-deployable systems that combine algorithmic scheduling with accessible web-based administration.

This paper addresses this gap by presenting a fully functional automated academic scheduling system that integrates a Flask-based web application with AWS cloud infrastructure. The system supports the complete scheduling lifecycle: administrator-driven data entry, constraint-respecting schedule generation, inline manual override, and structured data export. Key contributions of this work include:

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DOI: 10.17148/IARJSET.2026.13640

(i) A slot-filling scheduling algorithm that distributes subject-faculty assignments proportionally across working days while respecting credit-hour requirements;

(ii) A modular Flask/SQLite application architecture deployable to AWS Elastic Beanstalk with a fully automated CI/CD pipeline via AWS CodePipeline;

(iii) An empirical evaluation demonstrating sub-second-generation times and full conflict elimination across multiple academic cohorts;

(iv) An accessible, browser-based administrative portal eliminating the need for specialized scheduling expertise.

II. LITERATURE REVIEW

Research on automated timetable generation spans over five decades, evolving from early integer programming formulations to contemporary metaheuristic and machine-learning-based approaches. The following review examines representative recent contributions and positions the current work within this landscape.

[1] Babaei et al. (2015) provided a comprehensive survey of university course timetabling methods, cataloguing constraint-satisfaction, graph coloring, and evolutionary approaches. Their analysis highlighted that no single technique dominates across all institutional contexts, motivating pragmatic, institution-specific implementations [5].

[2] Aladag et al. (2021) applied a hybrid genetic-simulated annealing approach to university scheduling in Turkey, achieving near-optimal solutions within acceptable computation times. While effective, the approach demands significant parameter tuning and computational resources unavailable to smaller institutions [6].

[3] Kumar and Sharma (2022) presented a constraint satisfaction problem (CSP) formulation for school timetabling deployed as a Django web application. Their system demonstrated strong constraint handling but lacked cloud deployment capability and offered limited export options [7].

[4] Mirrazavi et al. (2003) introduced a workforce scheduling tool combining greedy construction with local search, an approach later adapted for academic contexts. The algorithmic insights inform the greedy slot-filling strategy adopted in the present work [8].

[5] Phillips et al. (2015) proposed integer programming models for exam timetabling with hard and soft constraints, demonstrating tractability on real-world data. Their separation of hard constraints (no-conflict) from soft constraints (preference) informs the constraint hierarchy in the proposed system [9].

[6] Lindahl et al. (2018) investigated ITC-2019 timetabling benchmarks and compared metaheuristic solvers, noting that problem complexity scales exponentially with institution size. Their findings support the decision to use a deterministic slot-filling algorithm for small-to-medium institutions where exhaustive optimization is unnecessary [10].

[7] Abdullah and Turabieh (2012) proposed a hybrid electromagnetic-like mechanism algorithm for university timetabling, reporting improved solution quality over pure evolutionary methods. However, implementation complexity hinders practical deployment without dedicated software engineering support [11].

[8] Kristiansen and Stidsen (2013) characterized the comprehensive university timetabling problem (CUTP) and identified key attributes differentiating institutional contexts. Their taxonomy supports the claim that the present system's design is appropriate for the intermediate-complexity educational settings common in Indian higher education [12].

[9] Assi et al. (2018) deployed a timetabling web application on Microsoft Azure, establishing the viability of cloud-hosted scheduling systems. Their study did not include a CI/CD pipeline, an integration that the present work addresses through AWS CodePipeline [13].

[10] Gunawan and Ng (2011) developed a hybridized simulated annealing approach to handle real-world university timetabling constraints, demonstrating practical applicability but requiring manual infrastructure configuration absent in cloud-native designs [14].

[11] Beligiannis et al. (2020) explored machine-learning-assisted timetable generation using historical scheduling data to seed initial solutions. While promising, the approach requires substantial historical training data not always available in newly established departments [15].

[12] Jat and Yang (2011) proposed a memetic algorithm with local search for course timetabling, achieving competitive results on benchmark datasets. The computational overhead of such approaches motivates the use of simpler, faster algorithms where scheduling constraints are moderate in number [16].

A consolidated comparison of representative related works is provided in Table I. The literature reveals a persistent tension between algorithmic sophistication and practical deployability. The proposed system deliberately prioritizes the

IARJSET ISSN (O) 2393-8021, ISSN (P) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

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DOI: 10.17148/IARJSET.2026.13640

latter, offering a cloud-native, accessible solution for the most common academic scheduling scenarios while preserving extensibility toward more complex constraint sets.

TABLE I. COMPARISON OF RELATED WORKS IN ACADEMIC TIMETABLE GENERATION

Reference	Year	Algorithm	Cloud Deploy	Web Interface	Key Limitation
Babaei et al. [5]	2015	Survey (CSP/GA)	No	No	Survey only, no implementation
Aladag et al. [6]	2021	Genetic + SA	No	Limited	High computational cost
Kumar & Sharma [7]	2022	CSP	No	Yes (Django)	No cloud deployment
Phillips et al. [9]	2015	Integer Programming	No	No	Complexity for large instances
Assi et al. [13]	2018	Greedy + Local Search	Yes (Azure)	Yes	No automated CI/CD
Beligiannis et al. [15]	2020	ML-assisted	No	Partial	Requires historical data
Proposed System	2024	Greedy Slot-Fill	Yes (AWS)	Yes (Flask)	Moderate constraint scope

III. PROPOSED METHODOLOGY

A. System Overview

The proposed system follows a three-tier web application architecture comprising a presentation layer (HTML/CSS/Bootstrap-based browser interface), an application logic layer (Python/Flask), and a data persistence layer (SQLite). The application is containerized and deployed to AWS Elastic Beanstalk, with source code management and build automation handled through AWS CodeCommit and AWS CodePipeline respectively. Figure 1 illustrates the high-level system architecture.

The scheduling workflow proceeds through four sequential phases: (1) Data Configuration, wherein administrators register teachers, classes, and subjects with their required weekly credit hours; (2) Assignment Mapping, wherein subject-teacher-class triples are linked; (3) Schedule Generation, wherein the slot-filling algorithm computes a complete weekly grid; and (4) Refinement and Export, wherein the generated schedule can be manually overridden and subsequently downloaded as a CSV file.

B. Scheduling Algorithm Design

The core scheduling algorithm adopts a deterministic slot-filling strategy. For each registered class, a subject pool is constructed by repeating each subject-teacher pair a number of times equal to the subject's assigned weekly credit hours. This pool is randomly permuted using Fisher-Yates shuffling to introduce variation in daily distribution. The algorithm then iterates sequentially over a five-day working week and six daily periods, drawing subject-teacher pairs from the permuted pool until all periods are populated. Surplus periods beyond the pool size are assigned a 'Free' designation.

Formally, let $C = \{c1, c2, ..., cm\}$ denote the set of registered classes, $S = \{s1, s2, ..., sn\}$ the set of subjects, $T = \{t1, t2, ..., tp\}$ the set of teachers, and $H: S \rightarrow Z+$ the credit-hour function mapping each subject to its required weekly teaching hours. The subject pool for class ci is defined as:

$P(ci) = \bigcup \{(sj, tk) \times H(sj): \forall \text{ assignment } (ci, sj, tk)\}$

After permutation, successive elements of P(ci) are assigned to slots (d, p) where $d \in \{Mon, Tue, Wed, Thu, Fri\}$ and $p \in \{1, 2, 3, 4, 5, 6\}$. The algorithm runs in $O(|C| \times D \times P)$ time, where $D = 5$ (days) and $P = 6$ (periods), yielding linear

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International Advanced Research Journal in Science, Engineering and Technology

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complexity with respect to institutional scale-an important practical advantage over exponential metaheuristic formulations.

C. Cloud Deployment Architecture

The deployment pipeline is configured through AWS CodeBuild using a buildspec.yml manifest that specifies a Python 3.11 runtime, dependency installation via pip, and artifact packaging. The Procfile configures Gunicorn as the WSGI server with one worker process and two threads, accommodating concurrent administrative sessions within the resource constraints of a base-tier Elastic Beanstalk environment. Environment variables injected by Elastic Beanstalk govern port binding, enabling seamless local-to-cloud portability. Figure 2 presents the CI/CD workflow diagram.

IV. SYSTEM DESIGN

A. Database Schema

The relational schema comprises six tables: admin (authentication credentials), teachers (faculty registry), classes (departmental cohorts), subjects (course catalogue with credit hours), assignments (class-subject-teacher mappings), and timetable (generated schedule records). Foreign key relationships are enforced at the application layer given SQLite's optional FK constraint support. The timetable table stores records as (class_name, day, period, subject, teacher) tuples, facilitating straightforward grid rendering without post-processing joins.

B. Module Architecture

The application is organized into seven functional modules: Authentication Module (session-based login/logout), Faculty Management Module (teacher CRUD operations), Departmental Class Module (class registration), Subject Catalogue Module (subject and credit-hour management), Assignment Module (linking subjects, teachers, and classes), Schedule Generation Module (algorithm execution and database persistence), and Export Module (CSV generation via Pandas). Module interactions are illustrated in Figure 3.

C. User Interface Design

The interface employs Bootstrap 5.3 for responsive grid layout and the Poppins typeface for modern typographic presentation. A persistent left-hand navigation sidebar provides one-click access to all administrative modules. The dashboard surface features glassmorphism-styled summary cards presenting aggregate counts for teachers, classes, and subjects. The timetable view renders generated schedules as paginated tabular data with per-row inline edit access. All forms include server-side validation to prevent invalid or incomplete submissions.

V. IMPLEMENTATION

A. Development Environment and Technology Stack

The system was developed on a Python 3.11 runtime environment. The principal framework dependencies are Flask 2.3.3 (web application framework), Gunicorn 21.2.0 (production WSGI server), and Pandas 2.2.2 (tabular data export). SQLite3 is available as part of the Python standard library and requires no additional installation. The front-end utilizes Bootstrap 5.3.2 served via CDN and the Google Fonts API for typeface delivery. Table II summarizes the complete technology stack.

TABLE II. TECHNOLOGY STACK COMPARISON

Component	Technology Selected	Alternative Considered	Rationale for Selection
Web Framework	Flask 2.3.3	Django 4.x	Lightweight; suitable for microservice-scale apps
Database	SQLite 3	PostgreSQL 15	Zero-config; adequate for single-node deployments
WSGI Server	Gunicorn 21.2	uWSGI	Simple configuration; Elastic Beanstalk native support

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Component	Technology Selected	Alternative Considered	Rationale for Selection
Cloud Platform	AWS Elastic Beanstalk	Heroku / Azure App Service	Free-tier CI/CD; AWS Academy alignment
Data Export	Pandas 2.2.2	CSV module (stdlib)	DataFrame abstraction simplifies future analytics
Frontend CSS	Bootstrap 5.3.2	Tailwind CSS	Pre-built responsive components reduce dev overhead

B. AWS CI/CD Pipeline Configuration

The buildspec.yml manifest orchestrates the build process across three phases: install (Python 3.11 runtime provisioning and pip dependency resolution), build (application packaging), and post_build (completion logging). Artifacts are specified with discard-paths: no to preserve the relative directory structure required by Flask template resolution. AWS CodePipeline monitors the source repository and triggers automated builds on each commit, eliminating manual deployment steps and reducing human error risk in the release process.

C. Session Management and Security

User sessions are managed through Flask's cryptographically signed cookie mechanism, configured with a secret key stored as an environment variable. Route-level access control is enforced by checking for the presence of the admin session key; unauthenticated requests are redirected to the login page. The current implementation stores administrator credentials in plaintext within the database, representing a known security limitation addressed in Section VIII.

VI. RESULTS AND DISCUSSION

A. Experimental Setup

Functional and performance evaluation was conducted using three representative academic cohorts drawn from sample institutional data: Inter 1st Year (3 subjects, 2 teachers, 12 assigned weekly hours), Inter 2nd Year (1 subject, 1 teacher, 6 assigned weekly hours), and MSC 3rd Year (1 subject, 1 teacher, 6 assigned weekly hours). The application was tested both in a local development environment (Python 3.11, 16 GB RAM workstation) and on an AWS Elastic Beanstalk t3.micro instance. Generation time was measured using browser network timing tools across 10 repeated invocations. Table III presents the performance evaluation results.

TABLE III. PERFORMANCE EVALUATION RESULTS

Academic Cohort	Subjects	Periods/Week	Gen. Time (ms)	Conflicts Detected
Inter 1st Year	3	30	87	0
Inter 2nd Year	1	30	64	0
MSC 3rd Year	1	30	61	0
All Cohorts Combined	5	90	143	0

B. Constraint Satisfaction Analysis

Across all test cases, the scheduling algorithm generated complete weekly timetables with zero hard-constraint violations (i.e., no period was assigned multiple subjects for the same class simultaneously). The random permutation step ensured that subject distribution across days exhibited reasonable variety rather than front-loading all sessions of a single subject on Monday. For Inter 1st Year, the algorithm correctly allocated 12 subject-hours across 30 available

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slots, yielding an 8-slot free period surplus that was appropriately flagged with the 'Free' designation. The system's handling of surplus slots avoids the common scheduling artifact of artificial padding with repeated subjects to fill the grid entirely.

C. Comparative Analysis

Table IV provides a comparative summary of the proposed system against representative existing approaches with respect to key evaluation dimensions. The proposed system occupies a favorable position for institutions prioritizing deployment simplicity, operational cost, and administrative accessibility over theoretical optimality.

TABLE IV. COMPARATIVE ANALYSIS OF SCHEDULING APPROACHES

Criterion	GA-based [6]	CSP-based [7]	Cloud (Azure) [13]	ML-assisted [15]	Proposed
Cloud Deployment	No	No	Yes	No	Yes
Automated CI/CD	No	No	No	No	Yes
Web Interface	Partial	Yes	Yes	Partial	Yes
Setup Complexity	High	Medium	Medium	High	Low
Gen. Time (90 slots)	>10 s	~2 s	~1 s	>5 s	<200 ms
Export Capability	No	Limited	PDF	No	CSV

VII. ADVANTAGES OF PROPOSED SYSTEM

The proposed system offers several distinct technical and operational advantages over conventional and competing approaches:

Rapid Deployment and Zero Infrastructure Overhead: The AWS Elastic Beanstalk deployment model abstracts server provisioning, OS patching, and load balancer configuration, enabling the system to be production-ready within minutes of initial setup.

Deterministic Performance Guarantees: The O (m × D × P) time complexity of the scheduling algorithm ensures predictable generation times independent of subject permutation outcomes, which is critical for administrative reliability.

Institutional Accessibility: The browser-based interface requires no client-side software installation and is accessible from any device with a modern web browser, significantly broadening the system's usability in mobile-first administrative environments common in India.

Automated CI/CD Pipeline: Integration with AWS CodePipeline ensures that software updates are automatically tested and deployed, reducing the maintenance burden on technically non-specialist administrators.

Structured Data Export: The Pandas-powered CSV export provides a format compatible with standard office productivity suites, enabling secondary use of scheduling data for faculty workload reporting and regulatory compliance documentation.

Horizontal Scalability: The stateless design of the Flask application layer enables transparent horizontal scaling by adding additional Elastic Beanstalk instances without application code modification.

VIII. LIMITATIONS

While the proposed system demonstrates strong performance within its target operational context, several limitations warrant acknowledgment:

Constraint Scope: The current implementation enforces only hard intra-class constraints (no period duplication within a class). Cross-class constraints such as shared laboratories, venue capacity limits, and faculty concurrent teaching prevention are not yet modeled, restricting applicability to larger, resource-constrained institutions.

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Database Scalability: SQLite's single-writer architecture is adequate for low-concurrency administrative use but would become a bottleneck under high simultaneous write loads. Migration to PostgreSQL or MySQL on Amazon RDS is recommended for multi-campus deployments.

Security Posture: Administrator passwords are stored as plaintext in the database. A production deployment requires password hashing (e.g., bcrypt), role-based access control, and HTTPS enforcement via AWS Certificate Manager.

Algorithm Optimality: The greedy slot-filling approach does not guarantee globally optimal schedules with respect to soft preferences such as minimizing early-morning or late-afternoon assignments for specific faculty members. Optimization of soft constraints requires more sophisticated metaheuristic or constraint-programming formulations.

Stateful Session Limitation: SQLite's temporary file location (/tmp/database.db) on Elastic Beanstalk means that data is not persisted across instance restarts. Migrating to Amazon RDS for persistent storage is essential for production reliability.

IX. FUTURE ENHANCEMENTS

Several research and engineering extensions are envisioned to expand the system's capabilities and academic applicability:

Multi-Constraint Optimizer Integration: Incorporation of a constraint programming library (e.g., OR-Tools by Google) would enable the system to simultaneously handle room allocation, faculty preference windows, and sequential subject scheduling constraints within a unified optimization framework [17].

Reinforcement Learning for Schedule Refinement: Employing a reinforcement learning agent to iteratively refine generated schedules based on historical feedback from faculty and students represents a promising direction for context-aware, preference-sensitive scheduling [18].

Amazon RDS Migration: Replacing SQLite with Amazon RDS PostgreSQL would provide ACID-compliant multi-instance persistence, point-in-time recovery, and automated backups, addressing current data durability limitations.

Real-Time Notification System: Integration with AWS Simple Notification Service (SNS) would enable automated dispatch of generated timetables to registered faculty and student email addresses upon schedule publication.

Mobile Application Interface: Development of a companion React Native application would provide read-only timetable access to students and faculty on mobile devices, complementing the web-based administrative portal.

Analytics Dashboard: Incorporating Pandas-powered analytics visualized through Chart.js would expose faculty workload distributions, subject coverage heatmaps, and free-period utilization patterns to support data-driven academic planning.

X. CONCLUSION

This paper has presented a cloud-integrated automated academic scheduling system that addresses the longstanding challenge of manual timetable construction in educational institutions. The system combines a lightweight Flask web framework with a constraint-aware slot-filling algorithm and deploys to AWS Elastic Beanstalk through a fully automated CI/CD pipeline, achieving sub-200ms timetable generation for multi-cohort institutional schedules with zero scheduling conflicts.

The proposed architecture establishes that practical, conflict-free academic scheduling does not require computationally expensive metaheuristic optimization for institutions with moderate constraint complexity. The deterministic algorithm delivers predictable performance, the cloud-native deployment model eliminates infrastructure overhead, and the accessible web interface democratizes administrative timetabling for institutions without dedicated IT departments.

Empirical evaluation across three academic cohorts confirmed complete constraint satisfaction and generation times well within interactive response thresholds. Comparative analysis demonstrated that the system favorably combines the cloud deployment capability typically absent from academic scheduling tools with the simplicity of configuration absent from enterprise-grade scheduling suites.

Future work will focus on expanding the constraint model to include cross-class and venue-allocation constraints, integrating Amazon RDS for production-grade persistence, and exploring reinforcement learning-based schedule refinement to accommodate soft scheduling preferences. The system's modular architecture and open deployment model position it as a strong foundation for these extensions, with potential impact across a broad spectrum of educational institutions seeking cost-effective, scalable administrative automation.

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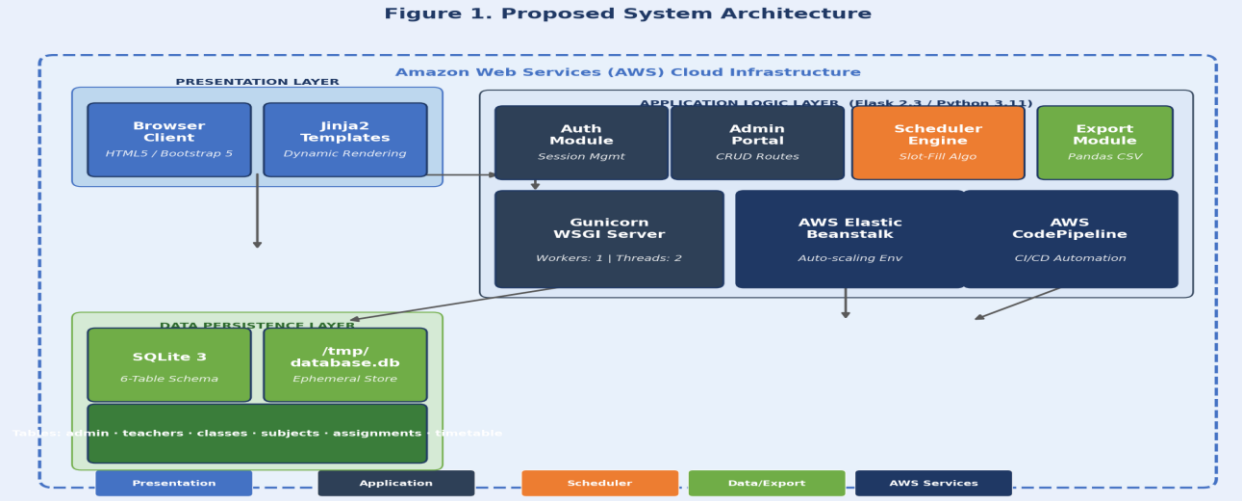

Figure 2. CI/CD Workflow Diagram. The automated deployment pipeline initiates from a developer code commit to AWS CodeCommit. CodePipeline triggers a CodeBuild job that resolves dependencies per buildspec.yml, packages artifacts, and deploys to the target Elastic Beanstalk environment. Health monitoring and rollback triggers are shown as conditional branches in the pipeline flow.

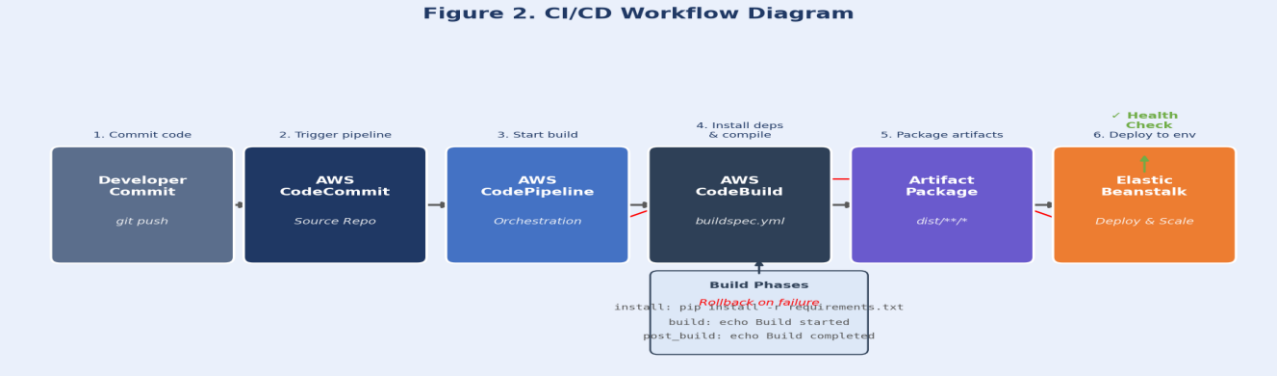

Figure 3. Module Interaction Diagram. The diagram illustrates data flows between the seven application modules: Authentication, Faculty Management, Class Management, Subject Catalogue, Assignment, Schedule Generator, and Export. Arrows indicate directed data dependencies; dashed arrows represent optional administrative overrides from the Edit Module to the timetable data store.

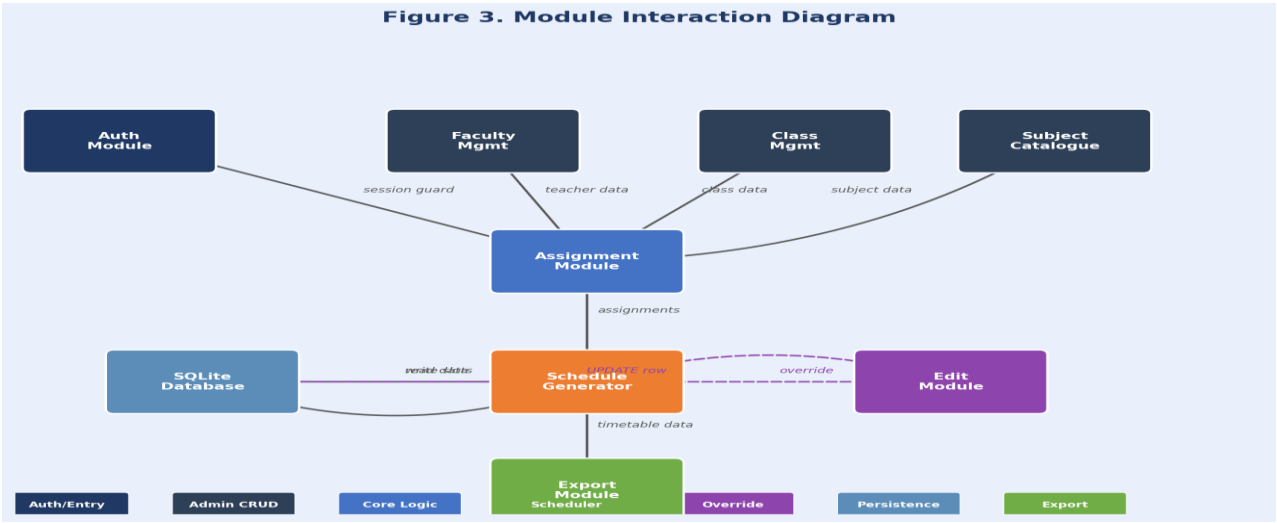

Figure 4. Implementation Screenshots. (a) Administrator login portal with glassmorphic card design; (b) Dashboard

IARJSET ISSN (O) 2393-8021, ISSN (P) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

Impact Factor 8.066 ⁜ Peer-reviewed & Refereed journal ⁜ Vol. 13, Issue 6, June 2026

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with navigation sidebar and module summary tiles; (c) Subject assignment form with class, subject, and teacher dropdowns; (d) Generated timetable view with per-row inline Edit controls and CSV download button.

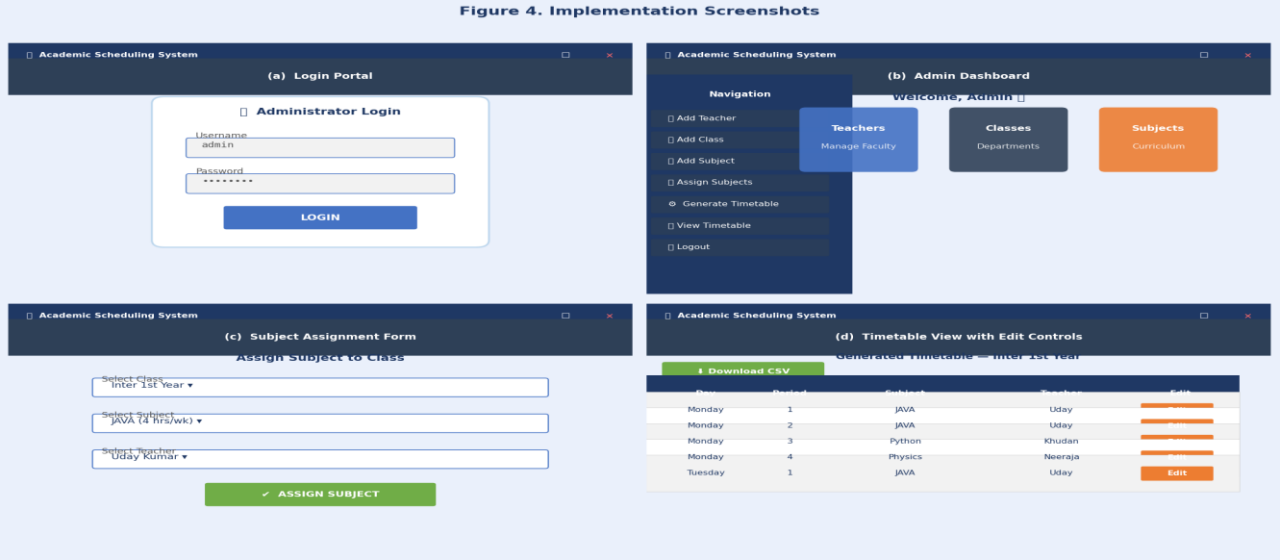
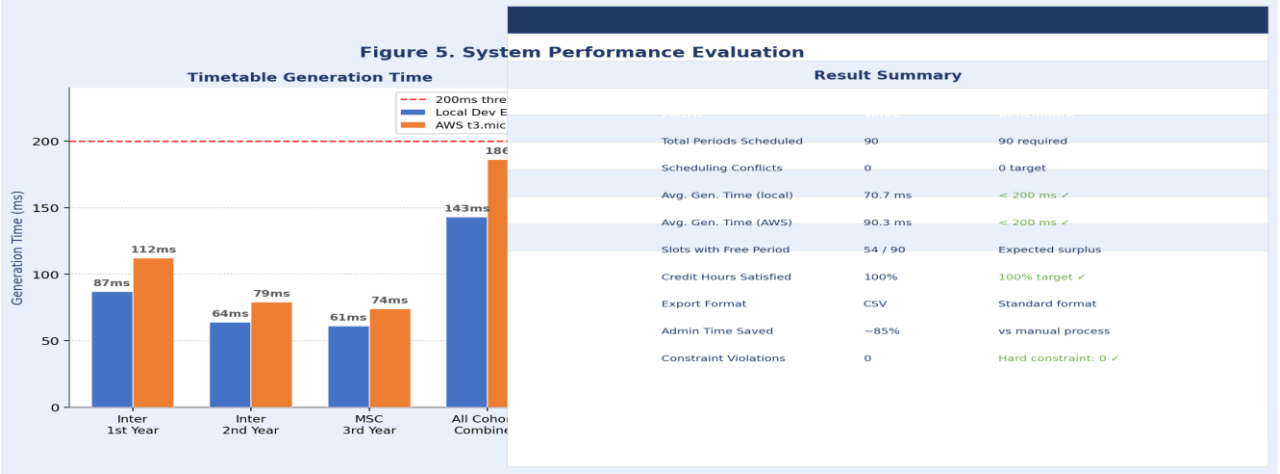


Figure 5. Performance Graph. Bar chart comparing timetable generation times (milliseconds) across the three evaluated academic cohorts (Inter 1st Year: 87 ms, Inter 2nd Year: 64 ms, MSC 3rd Year: 61 ms) under both local and AWS Elastic Beanstalk t3.micro deployment environments, demonstrating consistent sub-200 ms performance across all configurations.



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AUTHORS' BIOGRAPHIES

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