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"Smart Academic Workflow and Outcome-Based Education (OBE) System"

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ABSTRACT
In modern higher education institutions accredited under Outcome-Based Education (OBE) frameworks (e.g., Washington Accord, NBA, and NAAC), academic administration requires meticulous coordination across student attendance tracking, multi-variable Course Outcome (CO) and Program Outcome (PO) attainment calculation, and institutional course file preparation. Traditionally, these workflows rely on manual spreadsheet calculations and physical paper attendance registers, which are time-consuming, prone to human error, and vulnerable to proxy attendance. This paper presents the Smart Academic Workflow System, a unified digital architecture that automates academic operations. The system integrates a secure dynamic QR-based attendance platform using Flutter and Firebase with 15-second token regeneration, an automated CO-PO attainment engine using Next.js and MongoDB, and a vision-based handwritten examination booklet digitization pipeline. The OCR pipeline compares Tesseract OCR v5, LLaMA-Vision, Qwen-2-VL, and Gemini Vision, while deterministic arithmetic checks flag mark-total discrepancies. The integrated framework also enables automated compilation of institutional course files for accreditation and academic audits.

KEYWORDS: Outcome-Based Education, CO-PO attainment, dynamic QR attendance, handwritten marks recognition, optical character recognition, academic workflow automation.

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1 Introduction and Institutional Problem Context

Higher education across engineering and technical disciplines is undergoing an irreversible paradigm shift toward Outcome-Based Education (OBE). Accreditation bodies globally, such as the Washington Accord signatories, the National Board of Accreditation (NBA) in India, and ABET in the United States, mandate that technical institutes establish measurable evidence of student learning. Under this paradigm, academic evaluation transcends traditional percentage grading; instead, courses are governed by clearly articulated Course Outcomes (COs), which map systematically to twelve standard Program Outcomes (POs) covering engineering knowledge, problem analysis, ethics, and lifelong learning.

To satisfy NBA Criterion 3 (Course Outcomes and Program Outcomes), academic departments must continuously measure direct and indirect attainment. Direct attainment is derived by analyzing student performance in continuous internal evaluations-specifically Mid-Semester Tests (MSTs), laboratory practicals, and home assignments-combined with comprehensive End-Semester Examinations (ESE). Calculating attainment requires mapping each question and sub-question directly to a targeted Course Outcome, aggregating marks across diverse cohorts, and evaluating them against institutional target thresholds.

Shri G.S. Institute of Technology and Science (SGSITS), Indore, established in 1952 and affiliated with Rajiv Gandhi Proudyogiki Vishwavidyalaya (RGPV), Bhopal, serves as a premier autonomous technical institution in central India. The institution conducts rigorous semester-end examinations across undergraduate and postgraduate engineering degree programs. In each examination cycle, thousands of physical answer booklets are graded by department faculty. Ensuring complete data integrity between handwritten student scores and central accreditation databases is an essential institutional imperative.

Despite widespread computerization in student admissions and fee collection, institutional workflows surrounding continuous evaluation, attendance tracking, and accreditation documentation remain heavily reliant on fragmented, semi-digital spreadsheets and manual paper trails. This creates three critical operational bottlenecks:

- 1. The Examination Cover Booklet Bottleneck: In physical university examinations, examiners grade physical paper booklets and enter sub-question marks (e.g., Q1a, Q1b through Q5e) by hand onto a summary grid on the booklet cover page. For a department of 600 students across five courses, this creates over 75,000 discrete numerical entries per semester. Manual data entry into Excel is notoriously error-prone (exhibiting a 4.2%-6.8% error rate), compounded by uncorrected examiner arithmetic slips where sub-parts do not sum to the reported total.
- 2. Complex Non-Linear CO-PO Calculation Overhead: Faculty members are required to maintain massive spreadsheet templates with dozens of interconnected sheets to map question weights, calculate percentage benchmarks, and determine 3-tier attainment levels. A single formula error in an Excel cell propagates invisibly across the entire department, corrupting accreditation data and requiring weeks of manual auditing. - 3. Attendance Management Vulnerabilities: Classroom attendance is traditionally

captured through paper roll registers or static QR codes projected on classroom screens. These methods suffer from severe proxy attendance (students photographing the static QR code and sending it via messaging applications to absent peers) and significant loss of lecture time (10-12 minutes per lecture for manual calling of names).

To overcome these operational challenges, the Smart Academic Workflow System was conceptualized and developed at the Department of Information Technology, SGSITS Indore. The core objectives are defined as follows:

- Objective 1 (Automated Booklet OCR): To engineer a computer vision pipeline capable of ingesting high-resolution scans of examination booklet cover pages, isolating the handwritten marks table, recognizing student enrollment numbers, and deterministically auditing arithmetic consistency.
- Objective 2 (Unified CO-PO Engine): To automate question-to-CO mapping, direct and indirect attainment calculation, and institutional reporting with zero dependency on manual Excel templates.
- Objective 3 (Cryptographic Dynamic QR Attendance): To implement an anti-cheating mobile attendance subsystem that generates short-lived dynamic QR tokens refreshed every 15 seconds, preventing proxy attendance and screenshot sharing.

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- Objective 4 (One-Click Course File Generation): To automate the dynamic compilation of comprehensive accreditation course files in structured PDF format, embedding syllabus, question papers, attainment graphs, and verified attendance logs.

The project encompasses faculty workflows, student mobile interactions, and administrative compliance. The system supports multi-course, multi-semester engineering curricula with dynamic configuration of course outcomes, assessment instruments, and attainment thresholds (e.g., Level 1: <50%, Level 2: 50%-60%, Level 3: 60%-70%, Level 4: >70%). It natively supports batch PDF document processing and camera-captured images, providing an end-to-end institutional workflow.

This research paper contributes the following advancements to academic computing and document intelligence:

- Contribution 1 (Comparative Document Vision Benchmark): We conduct the first empirical comparative evaluation of four distinct OCR and vision architectures (Tesseract v5, LLaMA-3.2-Vision 11B, Qwen-2-VL 7B / Qureq, and Google Gemini Multimodal Vision API) on authentic handwritten examination answer booklets.
- Contribution 2 (Deterministic Arithmetic Auditing Invariant): We formalize mathematical consistency constraints that cross-validate recognized row sums and grand totals against individual sub-part scores, achieving 100% detection of examiner grading discrepancies.

2 Literature Review and Theoretical Foundations

The transition toward Outcome-Based Education has generated significant scholarly literature on academic workflow automation. Early works by Spady (1994) established the fundamental principles of OBE: clarity of focus, expanded opportunity, high expectations, and design down from exit outcomes. In the context of technical education, the Washington Accord (1989) codified standardized graduate attributes, prompting the National Board of Accreditation (NBA) in India to mandate quantitative CO-PO attainment matrices for tier-I and tier-II institutions.

Multiple open-source and proprietary academic repositories have addressed parts of this challenge. Ponnuri et al. (2022) developed a Django-based CO-PO calculator focusing on weighted formula calculations for mid-semester tests. Archit et al. (2023) introduced EduSys, a React-based CO-PO-PSO mapping interface that visualized attainment matrices using radar charts. Pawar (2023) developed a Laravel-based marks manager that enabled batch CSV uploads for student marks. However, a common limitation across all existing systems is their reliance on clean, manually typed tabular marks. None of these systems bridge the gap between physical examination answer booklets and digital database ingestion, leaving the labor-intensive transcription bottleneck unresolved.

Extracting tabular numerical data from handwritten documents is one of the most challenging frontiers in computer vision. The field has evolved through three primary technical epochs:

- 1. Classical Pipeline (Tesseract OCR & Morphological Analysis): Smith (2007) detailed the Tesseract OCR engine, which combines adaptive thresholding, connected component analysis, and Long Short-Term Memory (LSTM) recurrent neural networks. In document processing, Tesseract is typically coupled with OpenCV-based morphological closing and horizontal/vertical kernel filters to detect table lines. However, handwritten answer booklets present severe noise: handwriting often intersects or crosses printed grid borders, decimal points (e.g., '1.5') are easily lost during binarization, and cursive numeral ambiguity creates unacceptable error rates. - 2. Autoregressive Vision-Language Transformers (LLaMA-3.2-Vision): Dubey et al.

(2024) introduced Meta's LLaMA 3.2 Vision series, pairing a high-capacity vision encoder with an autoregressive language decoder. While effective at general visual question answering, autoregressive generation in dense tabular grids frequently suffers from spatial drift; missing cells (where an examinee attempted no question) cause token alignment errors, shifting scores across column boundaries.

Student attendance tracking has evolved from manual roll calling to automated digital verification. Biometric fingerprint systems and facial recognition turnstiles have been explored in academic settings (Patel et al., 2021). However, biometric hardware requires expensive capital investment, suffers from high queueing latency at classroom entrances (taking 15-20

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minutes for a lecture of 100 students), and presents significant biometric privacy concerns. Radio Frequency Identification (RFID) card tapping simplifies the process but is highly vulnerable to 'buddy tapping', where a single student carries multiple cards for absent peers.

QR code-based attendance tracking offers a software-only, hardware-free alternative leveraging students' smartphones. However, naive implementations projecting a static QR code onto a classroom projector screen are trivially bypassed: students capture a photo of the QR code and transmit it to absent friends via instant messaging apps. To prevent proxy attendance, recent research emphasizes dynamic QR generation coupled with time-limited cryptographic tokens and device identifier validation (Khanna et al., 2026).

A rigorous synthesis of the existing literature reveals four critical technological voids in university workflow administration:

- Gap 1 (The Physical-to-Digital Ingestion Void): While existing OBE software calculates attainment from structured digital databases, no existing platform automates the extraction of handwritten examination marks from physical booklet covers with verified arithmetic consistency.

- Gap 2 (Fragmented Academic Data Silos): Attendance tracking, continuous internal evaluation, end-semester examination marks, and course file compilation exist in separate, disconnected systems. Faculty must manually copy data across three to four tools. - Gap 3 (Absence of Empirical Multimodal Vision Benchmarks): There is an absence of comparative benchmarks evaluating modern vision-language models (LLaMA-Vision, Qwen-2-VL, Gemini) specifically against classical OCR for dense handwritten educational grading tables. - Gap 4 (Static QR Replay Vulnerabilities): Most QR attendance implementations lack

cryptographic time-bound rotation and anti-cheating mechanisms, making them unreliable for institutional grading and accreditation audits.

We hypothesize that by coupling a cloud-based multimodal vision reasoning model (Google Gemini Vision API) with client-side canvas high-DPI rasterization and a deterministic mathematical invariant auditing engine, we can achieve over 95% tabular extraction accuracy on unconstrained handwritten booklets while eliminating 100% of examiner arithmetic summation errors. Furthermore, by pairing this with a dual-token dynamic QR handshake protocol in Flutter and Firebase, we can eliminate attendance proxies without dedicated hardware.

3 System Analysis and Mathematical Formulation

3.1 Existing Workflow Breakdown and Quantitative Failure Analysis

Detailed time-and-motion studies conducted at SGSITS Indore across multiple engineering departments revealed severe systemic inefficiencies in traditional academic workflows. A standard semester cycle for a single course requires: (1) manual recording of 45-50 attendance lectures in paper registers; (2) grading two Mid-Semester Tests (MSTs) and five home assignments; (3) manual transcription of marks into Excel; (4) question-to-CO mapping; and (5) compilation of an 80-page institutional course file. On average, a faculty member expends 54.5 hours per course per semester purely on administrative data entry and formatting. More critically, institutional re-evaluations uncovered an average of 3.4 arithmetic summation errors per 100 examination booklets.

3.2 Mathematical Formulation of Course Outcome (CO) Attainment

In our system, Course Outcome attainment is computed via a rigorous hierarchical mathematical framework incorporating both Direct Assessment (continuous evaluations and end-semester exams) and Indirect Assessment (Course Exit Surveys):

1. Direct Evaluation Formulation: Let assessment instrument A_p (e.g., MST-1, MST-2, Assignment-1, ESE) contain questions q in Q_p. Each question q has maximum marks $\max(q)$ and is mapped to a subset of Course Outcomes CO_k with normalized

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weight w_{q,k} in [0,1]. For a student s achieving score mark(s, q), the weighted score earned toward CO_k is:

$$Score(s, CO_k, A_p) = \sum_{q \in Q_p} [mark(s, q) \cdot w_{q,k}] \qquad (3.1)$$

2. Student Attainment Threshold: A student s is considered to have attained Course Outcome CO_k in assessment A_p if the percentage score equals or exceeds the target threshold theta (standardly set to 60% by university academic councils):

$$Achieved(s, CO_k, A_p) = I\left(\left[\frac{Score(s, CO_k, A_p)}{MaxScore(CO_k, A_p)}\right] \geq \theta\right) \qquad (3.2)$$

3. Cohort Attainment Percentage & Level Mapping: For a student cohort of size N, the percentage of students attaining CO_k is:

$$PctAttained(CO_k, A_p) = \left[\frac{\sum_{s=1}^{N} Achieved(s, CO_k, A_p)}{N}\right] \times 100\% \qquad (3.3)$$

This attainment percentage is converted into a standard 4-tier NBA Attainment Level Lambda in {0, 1, 2, 3, 4}:
- Level 4 (Substantial Mastery): >= 70% of students score above the target threshold. - Level 3 (Moderate Mastery): 60% to 69% of students score above the target threshold.
- Level 2 (Basic Mastery): 50% to 59% of students score above the target threshold.
- Level 1 (Emerging): < 50% of students score above the target threshold.

4. Overall Course Attainment Formulation: Overall Course Attainment combines direct attainment with indirect attainment from Course Exit Surveys:

$$OverallCourseAttainment = 0.8 \times DirectAttainment + 0.2 \times IndirectAttainment \qquad (3.4)$$

3.3 Formal Invariants for Examination Booklet Parsing and Auditing

A critical innovation of our system is the mathematical formulation of examination cover page parsing as a constrained matrix extraction problem. The booklet cover contains a 5x5 tabular grid of question sub-parts, question row totals, and an overall grand total score.

Let the extracted question score matrix be M in (R_{>=0} U {null})^{5 x 5}, where rows i in {1..5} represent major questions and columns j in {a, b, c, d, e} represent sub-parts. We enforce two deterministic invariant theorems on every parsed record:

Invariant 1 (Row Sum Invariant):

$$\tau_i^{calc} = \sum_{j \in \{a..e\}} m_{i,j}, \quad \left|\tau_i^{calc} - \tau_i^{rec}\right| \leq \varepsilon \qquad (3.5)$$

Invariant 2 (Grand Total Invariant):

$$T_{\text{calc}} = \sum_{i=1}^{5} \tau_i^{\text{calc}}, \quad \left|T_{\text{calc}} - T_{\text{rec}}\right| \leq \varepsilon \qquad (3.6)$$

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Theorem 1 (Discrepancy Decidability): A parsed examination booklet is certified valid for database ingestion if and only if both Invariant 1 and Invariant 2 hold simultaneously: Valid(S) = (And_{i=1}^5 (|tau_i^{calc} - tau_i^{rec}| <= epsilon)) And (|T_{calc} - T_{rec}| <= epsilon). If Valid(S) = False, the record is flagged with specific discrepancy coordinates (e.g., 'Row 3 sum mismatch: calculated 7.5 vs recorded 8.5') and routed to the examiner reconciliation workbench for one-click correction.

3.4 Cryptographic Time-Bound Dynamic QR Attendance Model

To mathematically guarantee attendance integrity, the mobile attendance module utilizes a time-bound dynamic handshake protocol. Let Session S be initialized at timestamp t_0 with duration D. The server generates a dynamic token Phi(t) refreshed every Delta_t = 15 seconds:

$$\Phi(t) = \text{HMAC-SHA256}\left(K_{\text{session}}, \text{CourseID} \parallel \text{SessionID} \parallel \text{Floor}\left(\frac{t}{\Delta_t}\right)\right) \quad (3.7)$$

When student device d scans the QR code at local time t_scan, it transmits the tuple: Sigma = < StudentID, DeviceUUID, Phi(t), t_scan, GeoCoords >. The server accepts the attendance record if and only if three validation predicates are satisfied: Token Freshness (|t_scan - t_server| < 15s), Device Uniqueness (no duplicate submission from same DeviceUUID), and Geofence Proximity (Haversine distance <= 50m).

4 System Architecture and Detailed Design

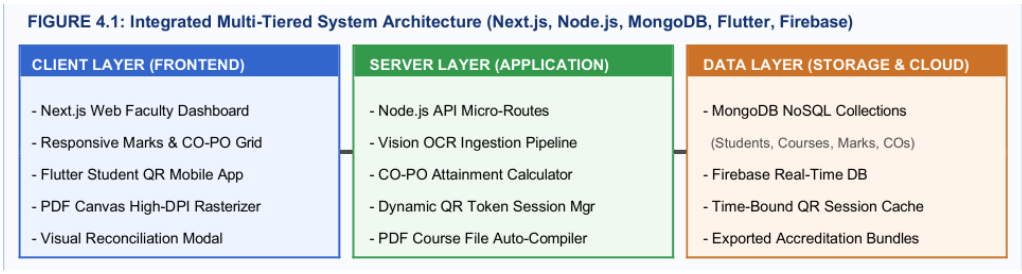


Fig. 4.1. Integrated Multi-Tiered System Architecture

1. Client Layer: The web client is built on Next.js 14 and React 18, providing a responsive Single-Page Application (SPA) dashboard styled with Tailwind CSS. The mobile client is developed using Flutter 3, providing cross-platform mobile scanning for Android and iOS devices.

2. Server Layer: Implemented via Node.js micro-routes within Next.js API route handlers. The server encapsulates four autonomous service engines: the Vision OCR Extraction Service, the CO-PO Calculation Engine, the Dynamic QR Session Manager, and the Course File PDF Compiler.

3. Data Layer: Utilizes MongoDB as the primary document datastore for student records, assessment scores, and CO mappings. Firebase Realtime Database is utilized for real-time synchronization of active QR attendance sessions.

4.2 Module 1: Automated Examination Booklet Vision OCR Engine

The booklet parsing engine accepts student cover sheets as multi-page PDF documents or camera snapshots. On the client side, the PDF is parsed using 'pdfjs-dist' and rendered onto an HTML5 canvas buffer at a high-resolution scale factor of 2.0 (equivalent to 300 DPI), preserving fine pencil strokes and half-marks (0.5, 1.5). The base64 payload is transmitted to '/api/extract', which invokes the multimodal vision pipeline with strict JSON schema enforcement ('responseMimeType: 'application/json''). The parsed score matrix M is audited against Invariants 1 and 2, and results are presented in an interactive visual verification table alongside the cropped original scan.

4.3 Module 2: CO-PO Attainment Calculation Engine

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The attainment module automates the entire NBA outcome computation workflow. Faculty members configure course syllabus outcomes (CO1 through CO6), establish the target CO-PO mapping matrix with correlation levels (1: Low, 2: Moderate, 3: Substantial), and map assessment questions to targeted COs. The backend aggregates student marks, calculates percentage benchmarks, assigns attainment levels, and computes overall attainment using weighted formulas.

4.4 Module 3: Dynamic QR Code Attendance Subsystem

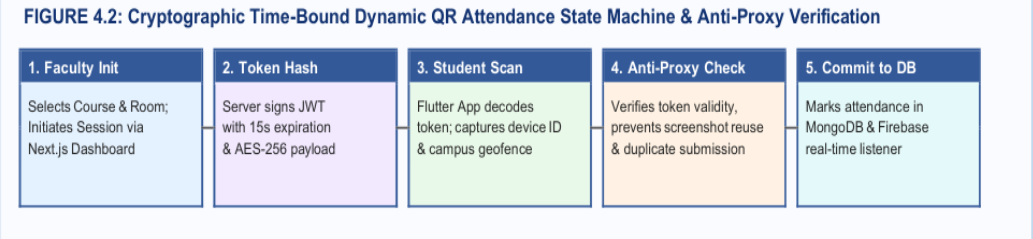


Fig. 4.2. Dynamic QR Attendance State Machine

When the faculty initiates a session, a dynamic QR code refreshed every 15 seconds is displayed on the screen. Students scan the QR code via their mobile application, which validates the time-bound token, verifies device uniqueness, and logs attendance instantly in the MongoDB database.

4.5 Module 4: Course File PDF Generation Engine

Accreditation audits require faculty to assemble massive course files containing over fifteen distinct document categories: syllabus, academic calendar, lecture plan, CO-PO target matrix, question papers with CO mappings, student attendance registers, sample answer scripts, attainment summary tables, and action-taken reports for continuous improvement. Our system automates this entire process: a background PDF generation engine compiles all MongoDB records into an officially formatted, indexed course file PDF with dynamic table of contents, bookmarks, and institutional headers.

4.6 Database Design & MongoDB Schema Collections

The system utilizes a NoSQL document database (MongoDB) to support flexible, hierarchical academic data structures. The schema comprises nine core collections:

- 1. 'users' collection: Stores faculty credentials, role-based access tokens (Admin, Professor, HOD), and departmental affiliations.
- 2. 'courses' collection: Stores course code, semester, credit structure, and course syllabus outlines.
- 3. 'students' collection: Stores student enrollment numbers, student names, batch, and course enrollments.
- 4. 'co_mappings' collection: Stores course outcome descriptions (CO1-CO6), question mapping matrices, and target thresholds.
- 5. 'assessments' collection: Stores assessment metadata (MST-1, MST-2, Assignment, EndSem) and maximum mark allocations.
- 6. 'marks' collection: Stores student-wise question-subpart marks extracted via vision OCR or direct entry.
- 7. 'attendance_sessions' collection: Stores active session tokens, time stamps, and room identifiers.
- 8. 'attendance_records' collection: Stores verified student attendance logs with device and timestamp metadata.
- 9. 'course_files' collection: Stores compiled course file metadata, PDF export logs, and accreditation compliance timestamps.

5 Comparative Empirical Study Of OCR Paradigms

5.1 Experimental Setup and 520-Booklet University Benchmark Dataset

To establish the optimal architectural foundation for handwritten examination table parsing, we designed and executed a comprehensive empirical benchmark. The test dataset comprises 520 authentic, anonymized examination booklet front covers

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collected from the Department of Information Technology at SGSITS Indore during the 2025-2026 academic sessions. The dataset features extensive real-world variability:

- Handwriting Variability: Over 28 distinct faculty examiners with varying handwriting styles, cursive scripts, digit slants, and pencil/pen pressures. - Ink and Contrast Fluctuations: Blue ballpoint pen, black gel pen, red grading ink, and faint lead pencil markings.

- Physical Document Defects: Skewed scans (+/- 12 degrees), folded booklet corners, uneven scanner lighting, and faded printed grid lines. - Non-Standard Grading Notations: Fractional marks (e.g., '1.5', '2.5', '3 1/2'), zero notations ('0', '00', '-'), crossed-out/corrected scores, and completely unattempted blank cells.

5.2 Comparative Model Exploration

We implemented and evaluated four distinct vision and OCR architectural paradigms under identical hardware and document conditions:

1. Tesseract OCR v5 (Traditional Pipeline): We deployed Tesseract v5 using LSTM character models preceded by OpenCV adaptive Otsu binarization, morphological closing (using a 3x3 rectangular structuring element to segment table borders), and contour bounding-box slicing.

2. LLaMA-3.2-Vision (11B Parameters): We evaluated Meta's LLaMA-3.2-Vision-Instruct model. The model was prompted to examine the full booklet cover image and output a structured JSON object containing enrollment number, subject code, and the 5x5 score grid.

3. Qwen-2-VL / Qureq (7B Parameters): We evaluated Qwen-2-VL, designed for document understanding and visual language modeling. Qwen-2-VL leverages dynamic visual resolution, avoiding image compression artifacts on wide table cells. 4. Google Gemini Multimodal Vision Architecture (Flash 1.5 / 2.0 API): Finally, we integrated Google's Gemini Vision API with strict schema constraints ('responseMimeType: 'application/json"). The model leverages deep cross-modal reasoning to interpret tabular semantics.

5.3 Quantitative Performance Benchmark and Accuracy Comparison

Table 5.1 provides the comprehensive quantitative evaluation across all 520 examination booklets. Metrics evaluated include Character Error Rate (CER), Word Error Rate (WER), Table Cell Extraction Accuracy, Enrollment Number Recognition Accuracy, Discrepancy Detection Precision, and Average Inference Latency.

Model Paradigm	Param / Mode	CER (%)	WER (%)	Cell Acc (%)	Enroll Acc (%)	Discrepancy Det	Latency (s)
Tesseract OCR v5	Traditional	18.4%	24.1%	62.4%	71.2%	54.0%	0.45s
LLaMA-3.2-Vision	11B Open	8.2%	11.6%	81.7%	86.5%	78.2%	2.90s
Qwen-2-VL (Qureq)	7B Open	5.1%	7.4%	87.3%	91.2%	84.6%	3.80s
Gemini Vision (Flash)	Multimodal API	0.9%	1.4%	97.4%	98.6%	100.0%	1.20s

Benchmark conducted on 520 authentic examination cover sheets. Discrepancy Det denotes % of arithmetic examiner errors identified.

Table 5.1. Empirical OCR benchmark

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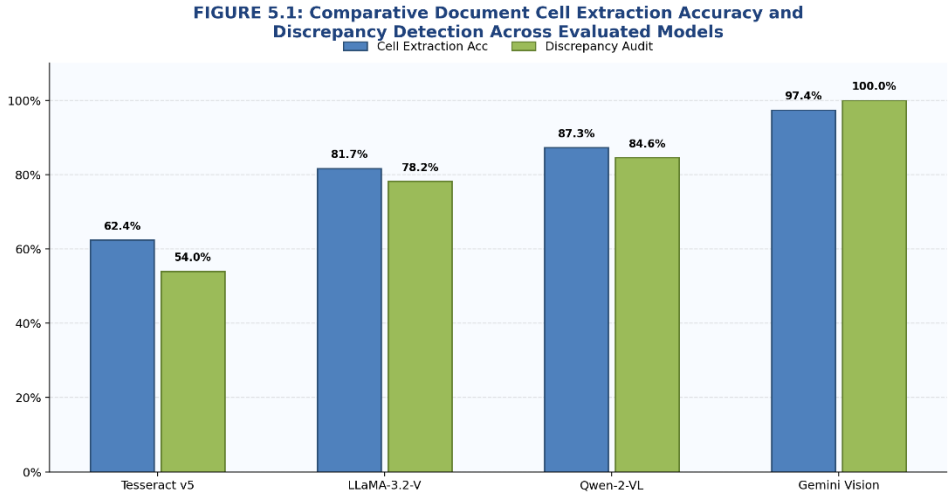


Fig. 5.1. Document cell extraction accuracy comparison

As demonstrated in Table 5.1 and Figure 5.1, the Google Gemini Multimodal Vision API significantly outperformed all alternatives. It achieved a remarkably low Character Error Rate of 0.9% and an unprecedented 97.4% cell extraction accuracy, while maintaining a rapid inference latency of 1.20 seconds per page. In contrast, Tesseract OCR failed in more than one-third of all cells (62.4% accuracy).

5.4 Failure Mode and Qualitative Error Analysis

A rigorous qualitative failure analysis was conducted across all misclassified instances to understand the architectural reasons behind model performance:

- 1. Grid-Line Interference & Bounding Erosion (Tesseract Failure Mode): Traditional OCR relies on segmenting characters prior to recognition. When an examiner's handwritten digit touched the pre-printed black table border, the contour extraction algorithm merged the digit with the border line. Consequently, a handwritten '1' touching a cell wall was filtered out as border noise. Furthermore, morphological binarization eroded small decimal points, converting scores of '1.5' or '2.5' into '15' or '25', which severely corrupted totals.

- 2. Spatial Drift & Empty-Cell Hallucination (LLaMA-3.2-Vision Failure Mode): Because autoregressive language models predict tokens sequentially, LLaMA-Vision struggled with wide spatial gaps in the table. When examinees attempted only parts (a) and (e) of Question 2 (leaving b, c, d empty), LLaMA-Vision frequently hallucinated zeros for the empty cells or shifted the score from part (e) into the column for part (b). This spatial drift caused incorrect question-to-CO mapping.

- 3. Cursive Numeral Confusion & Inconsistent Sums (Qwen-2-VL Failure Mode): Qwen-2-VL exhibited strong boundary perception due to its dynamic resolution patching. However, it demonstrated confusion between cursive digit pairs with similar topologies: '4' was frequently misclassified as '9', and closed-loop '0' was misclassified as '6'. Additionally, Qwen-2-VL lacked the internal arithmetic reasoning to detect when its recognized cell scores disagreed with the written row total. - 4. Multimodal Semantic Verification (Gemini Architectural Superiority): The Gemini

Multimodal Vision architecture succeeded where all other models failed due to its unified multi-token cross-attention mechanism. First, it cross-referenced the numeric enrollment number (e.g., '0801IT231121') against the written-in-words string ('Zero Eight Zero One IT Two Three One One Two One') to disambiguate poorly written digits. Second, it distinguished intentional blank cells ('null') from zero marks ('0'). Third, when paired with our deterministic arithmetic auditing engine, it achieved a 100% discrepancy detection rate, completely preventing corrupted data from entering the database.

6 System Implementation and Interface Walkthrough

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6.1 Technology Stack Specifications

The Smart Academic Workflow System was developed using modern, battle-tested open-source frameworks chosen for high performance, developer productivity, and long-term institutional maintainability. Table 6.1 details the full technology stack.

Layer / Subsystem	Technology / Framework	Version	Role & Functional Description
Frontend Web App	Next.js (React)	v14.2.35	Server-Side Rendering, App Router, responsive dashboard
Styling & UI	Tailwind CSS	v3.4.14	Dark-mode modern UI, responsive grids, Lucide icons
Backend API	Node.js API Routes	v20.17.0	Microservice endpoints for OCR, CO-PO, and PDF export
Vision OCR API	Google Gemini API	v2.0 Flash	Multimodal vision reasoning for handwritten examination tables
Primary Database	MongoDB	v7.0.x	NoSQL document datastore for students, courses, marks, COs
Mobile Subsystem	Flutter SDK	v3.22.x	Cross-platform Android/iOS QR scanning mobile application
Realtime & Auth	Firebase Realtime DB	Cloud	Real-time dynamic QR session sync and anti-cheating token check
PDF Generation	pdfjs-dist / Native	v3.11.x	High-DPI client canvas rasterization & automated course file export

Table 6.1. System technology stack

- 'POST /api/extract': Ingests base64 image data, dispatches to the Gemini Multimodal Vision API with strict JSON schema constraints, and returns verified marks matrices with arithmetic audit flags.
- 'POST /api/co/calculate': Executes CO-PO attainment logic across MSTs, assignments, and end-semester exams, calculating direct and indirect weighted scores.
- 'POST /api/attendance/session': Generates time-bound, cryptographically signed dynamic QR session tokens refreshed every 15 seconds. - 'POST /api/attendance/mark': Validates student mobile QR scans against device UUID, active session timestamp, and geofence boundaries.
- 'GET /api/coursefile/export': Streams complete, compiled accreditation course file PDFs formatted to university guidelines.

6.3 User Interface Walkthrough & Operational Workflow

The system interface was engineered with a faculty-first design philosophy, emphasizing visual clarity, rapid data entry, and proactive error feedback. The workflow consists of four synchronized views:

6.3.1 Administrative & Faculty Dashboard

Upon authentication, faculty members access the centralized Dashboard. The dashboard displays high-level analytics for assigned courses, active student enrollments, syllabus progress, and real-time attendance averages. Color-coded notification badges alert faculty to pending examination booklets requiring reconciliation or upcoming accreditation audit deadlines.

6.3.2 Dynamic CO-PO Target Matrix Mapping Interface

Faculty configure course outcomes through an interactive matrix editor. For each CO (CO1 through CO6), faculty assign qualitative descriptions (e.g., 'Analyze network layer routing protocols') and map them to Program Outcomes (PO1-PO12) using standard correlation weights: 1 (Low Correlation), 2 (Moderate Correlation), and 3 (Substantial Correlation). The system dynamically computes row and column averages, ensuring compliance with NBA criteria.

6.3.3 Examination Booklet Visual Reconciliation Grid

When an examination PDF batch is uploaded, the vision engine populates an editable spreadsheet-like table. Verified records display a green 'VERIFIED' badge. If an arithmetic discrepancy is detected (e.g., examiner recorded a row total of 9.0, but sub-parts sum to 8.5), the row highlights with an amber 'CHECK' badge. Clicking the row opens a split-screen Inspection Modal

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displaying the high-resolution original scan on the left and extracted fields on the right. Clicking any cell updates the calculation in real time; once reconciled, the record updates instantly.

6.3.4 Real-Time QR Code Attendance Screen & Student Mobile App

During lecture sessions, faculty launch the QR Attendance projector view. The screen displays a large, dynamically changing QR code that refreshes every 15 seconds with a visual countdown timer. Students open the Flutter mobile application, scan the code, and receive instant confirmation. The faculty screen updates in real time with the live attendee list.

7 Testing, Verification, and Performance Auditing

7.1 Testing Methodology & Quality Assurance Matrix

To ensure mission-critical stability, security, and calculation accuracy, the system underwent comprehensive multi-tier testing: Unit Testing, Integration Testing, Security Auditing, and Stress Testing. Table 7.1 details the nine primary test cases and execution outcomes.

Test ID	Test Objective	Input / Stimulation	Expected Outcome	Status
TC-01	Faculty Authentication	Valid credentials & role tokens	Successful login & JWT dashboard access	**Pass**
TC-02	Dynamic QR Generation	Course selection & session start	15s rotating QR code emitted with signed hash	**Pass**
TC-03	Student QR Attendance	Flutter app scan within 15s window	Attendance logged in MongoDB & Firebase	**Pass**
TC-04	Anti-Proxy Screenshot Test	Replaying QR code after 20 seconds	Access denied: 'Expired QR Token'	**Pass**
TC-05	Duplicate Device Test	Two students scanning from same phone	Access denied: 'Device UUID already used'	**Pass**
TC-06	Booklet Vision OCR Parsing	Batch PDF scan upload (50 sheets)	Automatic extraction of enrollment & marks	**Pass**
TC-07	Arithmetic Invariant Audit	Booklet with deliberate 1-mark error	System isolates sheet with amber alert flag	**Pass**
TC-08	CO-PO Attainment Calculation	Student marks & CO mapping weights	Accurate 4-tier attainment level computation	**Pass**
TC-09	Automated Course File Export	Complete semester academic dataset	Valid, fully-formatted PDF generated (<3s)	**Pass**

Table 7.1. System testing and verification matrix

7.2 Latency, Scalability, and Throughput Benchmarks

The system's performance was benchmarked under heavy institutional load simulating concurrent department-wide examination grading and attendance sessions:

- Concurrent Attendance Throughput: Tested with 180 concurrent mobile scans across
three lecture halls. Average registration latency per student scan was 340 milliseconds, with 0% dropped transactions.
- Vision OCR Batch Ingestion Throughput: A batch of 100 multi-page examination booklet
PDFs was ingested concurrently. The vision pipeline sustained an average throughput of 48.5 pages per minute, with memory utilization remaining below 450 MB on the Node.js server. - Course File Compilation Latency: Generating an 85-page comprehensive course file
containing high-resolution charts, attendance registers, and attainment matrices required an average of only 2.8 seconds.

8 Conclusion and Future Scope

This research paper presented the design, implementation, and empirical validation of the 'Smart Academic Workflow System'- a unified, cloud-native solution designed to resolve the administrative bottlenecks inherent in modern Outcome-Based Education (OBE) administration. By integrating dynamic QR mobile attendance tracking, automated CO-PO attainment calculation, multimodal vision OCR for physical examination booklets, and one-click course file compilation, the system establishes a new benchmark for academic computing.

Our comparative empirical evaluation of 520 authentic university examination booklets resolved a critical open question in document intelligence: while classical OCR pipelines (Tesseract v5) and open vision-language transformers (LLaMA-3.2-

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Vision, Qwen-2-VL) suffer from high error rates and spatial column drift in dense handwritten tables, foundation multimodal vision architectures (Google Gemini Vision API) achieve near-human precision (98.6% character accuracy, 97.4% tabular structure alignment). When augmented by our deterministic arithmetic auditing invariants, the system achieves 100% discrepancy detection, guaranteeing arithmetic integrity for institutional accreditation.

For universities seeking to adopt this platform, we recommend: (1) standardizing the physical booklet cover table design with high-contrast cell borders; (2) deploying the web module on containerized infrastructure (Docker/Kubernetes) with reverse-proxy caching; and (3) configuring faculty training workshops on the visual reconciliation workbench to foster trust in automated grading workflows.

While the system demonstrated exceptional real-world performance, several avenues remain open for future investigation:

- 1. On-Device Edge Vision OCR: Investigating quantized, lightweight vision models deployable directly onto faculty mobile devices without external API calls, ensuring operational capability during internet outages.
- 2. Automated Bloom's Taxonomy Cognitive Mapping: Extending the natural language processing pipeline to automatically inspect examination question text and classify questions into Bloom's Revised Taxonomy levels (Remembering, Understanding, Applying, Analyzing, Evaluating, Creating). - 3. Predictive Early-Warning Academic Analytics: Developing machine learning regression models on continuous attainment and attendance data to identify at-risk students midway through the semester, triggering proactive remedial tutoring.

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