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Development of Algorithm Model of Real-time Monitoring and Controlling System of Academic Process at Manado State University

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ABSTRACT

This study aims to develop a system-based assessment model for SMK graduates in ICT that is adjusted to the industrial occupation map. Specific objectives include: (1) designing a system-based assessment model, (2) determining the level of model feasibility, and (3) testing the usability of the assessment model. This study uses a development method (research and development) with the Design Science Research Methodology (DSRM) approach. The research procedure consists of four stages: needs analysis, system design, system creation, and evaluation and testing of the assessment model. Data collection techniques are carried out through observation, interviews, documentation studies, and the distribution of USE questionnaires for usability testing. The study results indicate that the developed assessment model has met the feasibility aspects based on expert assessment and has high usability, ease of use, and user satisfaction, as indicated by the USE Questionnaire test results. This model can also map graduate competencies more accurately and objectively based on industry needs. In conclusion, the developed system-based competency assessment model has proven to be both feasible and effective in measuring and mapping the competencies of vocational high school graduates in the field of ICT, aligning with the needs of the world of work. The implementation of this model is expected to increase the competitiveness of vocational high school graduates and strengthen the quality of vocational education in Indonesia.

Keywords: competency assessment, information and communication technology, system-based assessment model

INTRODUCTION

Higher education in the 21st century is at the intersection of academic tradition and technological disruption. Globalization and the demands of the Industrial Revolution 4.0 have set new standards for universities, not only as centers of knowledge transfer but also as entities that must be able to guarantee quality, accountability, and operational efficiency. At the heart of these operations lies the academic process, a complex workflow that maps each student's journey from the beginning to the end of their studies. The success of this process, as measured by key performance indicators (KPIs) such as on-time graduation rates (ATW) and dropout rates, reflects the vitality and competitiveness of an institution.

The world of higher education, including Manado State University (UNIMA), continues to adapt to the demands of the digital era. The Academic Information System (SIAKAD) has become the backbone of administration, but conventional system architecture often creates a "real-time gap". Academic data, such as exam scores, absences, or tuition payments, is entered into the system, but the process of analyzing and evaluating the data is generally carried out periodically or in batch processing (for example, recapitulation at the end of the semester). This batch processing model causes significant information latency. Students who begin to show a downward trend in achievement, academic supervisors (PA) who need to monitor dozens of students, and study program management tasked with maintaining the quality of graduates, all work with "outdated" data. Decisions and interventions become reactive, not proactive. Academic problems are only identified after they become serious, whereas early intervention is the key to the success of student studies. To manage this complexity, almost all modern universities, including leading universities in Indonesia, have adopted the Academic Information System (SIAKAD). SIAKAD has succeeded in digitizing previously manual administrative processes, functioning as a reliable system of records for crucial data such as registration, Study Plan Cards (KRS), Semester Credit Units (SKS), Semester Achievement Index (IPS), and Cumulative (IPK) calculations.

However, the fundamental architecture of most of the existing SIAKAD still operates in a reactive paradigm. Academic data is recorded transactionally, but analysis for strategic decision-making purposes is often carried out retrospectively or post-mortem. Progress reports, student success evaluations, and academic risk identification are typically produced at the end of a cycle, usually the end of a semester. Consequently, an information-intervention latency gap is created, which is the critical time between when an academic problem begins to emerge and when it is detected by those who can intervene (the student, the academic advisor, or management).

This latency gap has detrimental systemic impacts: 1. For Students, they do not receive instant feedback on their performance. A decline in performance or a study planning error is only realized when the impact is already significant, narrowing the opportunity for improvement. 2. For University Management: Strategic decision-making, such as resource allocation, curriculum evaluation, or student policies, is based on historical data, rather than on a real-time picture of the institution's academic condition.

Recognizing these limitations, this study proposes a fundamental shift from a reactive paradigm to a proactive and predictive academic ecosystem. The proposed solution is the development of an algorithmic model for monitoring and controlling academic processes in real time. This model does not aim to replace the existing SIAKAD, but rather to act as an intelligence layer on top of it. Leveraging an event-driven architecture and real-time data processing, this model is designed to "listen" to any changes in academic data (e.g., new grade entries), analyze its impact instantly based on predefined rules, and trigger actions—such as early warning notifications, personalized recommendations, and analytics dashboard updates—automatically.

Thus, this study seeks to bridge the information-intervention latency gap, transforming academic data from mere historical records into living strategic assets to support agile and timely decision-making for all stakeholders in the university environment.

The choice of technology is fundamental in realizing this real-time model. Cloud Firestore is specifically designed for real-time data synchronization with low latency, high scalability, and reliable query capabilities. A key feature that will be the foundation of the proposed algorithm model is the onSnapshot listener.

METHOD

This study uses the Prototyping software development model. This model was chosen because it allows iterative feature development and gets quick feedback from users (students and lecturers) for system improvement. The Prototyping stages include:

1) Needs Analysis: Identifying functional needs from students, lecturers, and administrators.
2) System Design & Architecture: Designing data flow, database model in Firestore, and user interface (UI/UX).
3) Implementation & Prototyping: Developing functional prototypes based on the design.
4) Testing: Conducting real-time functionality testing and user testing.
5) Evaluation & Iteration: Evaluating results and making improvements.

System Architecture and Technology

The system architecture is designed to maximize speed and real-time functionality. UNIMA Academic Monitoring and Controlling System Architecture Diagram. The details of the technology used are as follows:

1. Programming Language

a) TypeScript: Used on the front-end web (Next.js) to ensure type-safety, reduce bugs, and improve code readability.

b) Dart: The main language for cross-platform mobile application development with Flutter.

2. Front-End Technology (Web)

Next.js 14: The React framework chosen for its Server-Side Rendering (SSR) and Static Site Generation (SSG) features for fast loading performance, as well as App Router for modern routing.

3. Back-End Technology

1) Firebase: Used as the main backend that provides:

- Firebase Authentication: To manage user logins and access rights (students, lecturers, admins).
- Cloud Firestore: A document-based NoSQL database that is the core of the system.

4. API and Web Service

1) Next.js API Routes: Build API endpoints directly within the Next.js project for server-side logic such as data recapitulation or third-party integration.
2) Vercel: The hosting platform chosen to deploy the Next.js application and its API, with seamless CI/CD integration from Git.

5. Mobile Technology

1) Flutter: Google's framework for building native Android (and iOS) apps from a single codebase.
2) Android Studio: Used as the main IDE and for building apps into APK format for Android devices.

6. Real-time Algorithm

Firestore Snapshot Listener (onSnapshot): This is the core of the real-time mechanism. Client apps (web and mobile) will install a listener to a specific document or collection in Firestore. Every time there is a change (create, update, or delete) to that data on the server, Firestore will automatically send a snapshot of the latest data to all connected clients. The client will then reactively update its UI.

7. Database

1) Cloud Firestore: Used for all academic transactional data, such as student data, courses, KRS status, and guidance logs.

2) Shared Hosting Storage: To overcome the cost of storing large files in Firebase Storage, files such as student profile photos and documents (eg, payment slips) are uploaded to a separate hosting server, and only the URL is stored in Firestore.

The system architecture is designed to separate the user interface, business logic, and data, as illustrated below:

1) User (Students): Uses the Flutter application on an Android device. This application interacts directly with Firestore to read data and listen for real-time changes ($onSnapshot()$).
2) User (Lecturer/Admin): Uses the Next.js web dashboard accessed through a browser.
3) Web Interaction: The Next.js dashboard authenticates through Firebase Auth. For Create, Read, Update, Delete (CRUD) operations and complex business logic (for example, validating KRS approval), the dashboard calls the Next.js API Routes deployed in Vercel.
4) Back-End Logic: The API Routes in Vercel are what run the controlling logic. For example, when a lecturer presses the "Approve KRS" button, the API will validate the request and then change the status of the KRS document in Firestore.
5) Real-time synchronization: Status changes in Firestore are automatically pushed to the student mobile application that is listening to the KRS document, so that notifications or statuses in the student application change instantly.
6) File Storage: When a user uploads a photo or document, the application will send the file to the Shared Hosting server via a special API endpoint, and the file URL will be stored as a string in Firestore.

RESULTS AND DISCUSSION

System Architecture Implementation

Following the design in the methodology chapter, the system architecture has been successfully implemented in full.

- The Front-End Web Application (Next.js 14 & TypeScript) has been successfully deployed to the Vercel platform, which provides optimal performance through Edge Network and seamless CI/CD integration.
- The Mobile Application (Flutter & Dart) has been successfully built into an Android application package (APK) using Android Studio and can be installed on physical devices.
- The Back-End and Database services run entirely on the Firebase platform, with Cloud Firestore as the real-time data center and Firebase Authentication as the authentication manager.

- File storage (images and documents) has been successfully integrated with Shared Hosting Storage, where the application stores file URLs in Firestore, proving to be a cost-effective and efficient solution.

All of these components communicate synchronously and in real-time, forming a cohesive digital ecosystem for the academic process.

Prototype Form of the Developed System

The main results of this research are two interconnected functional application prototypes:

1. Lecture Monitoring Module (Platform: Next.js 14) This web application is designed as a control and monitoring center for lectures. Its main features are:

- Main Dashboard: Displays a summary of statistics such as lectures and lecture schedules.
- Course List Page: Displays a List of Courses based on Study Programs
- Course Detail Page: Displays course details starting from RPS, attendance, materials, and others.

2. Module for monitoring lectures for Students (Platform: Flutter) The mobile application is the main interface for students to interact with the academic system practically and instantly.

Key Performance Analysis: Realtime Firestore Snapshot Algorithm

To validate the "real-time" claim, end-to-end latency testing was conducted. The test scenario is to measure the time it takes from when the PA Lecturer presses the "Approve" button on the web application until the interface on the student's mobile application is updated. The test was carried out 50 times under stable 4G network conditions. See Table 1.

Table 1. End-to-End Latency Test Results

Testing Metrics	**Results**
Number of Trials	50 times
Minimum Latency	112 milliseconds (ms)
Maximum Latency	430 milliseconds (ms)
Average Latency	215 milliseconds (ms)
Standard Deviation	68 ms

Interpretation: With an average latency of 215 ms, the system is well below the human perception threshold for a delay (around 500 ms). This quantitatively proves that the Firestore Snapshot mechanism is very effective and can provide a user experience that feels instantaneous and synchronous.

Functionality Testing Results (Black-Box Testing)

Functionality testing was conducted by an internal team to ensure all major workflows were running as expected.

Table 2. Black-Box Test Results on Key Scenarios

ID Test	Test Scenario	Steps	Expected results	Actual Results	Status
BB-01	KRS Submission by Students	Students log in, select MK, click 'Submit'	KRS data is stored in Firestore with the status 'submitted'.	Data saved, status 'submitted'.	Passed
BB-02	Monitoring by PA Lecturers	Lecturer logs in, opens monitoring page	KRS application from students (BB-01) appears in the list.	New KRS application appears in real time.	Passed
BB-03	KRS Approval by PA Lecturers	Lecturer clicks 'Approve' on KRS submission.	KRS status in the database changes to 'approved'.	Status changes to 'approved'.	Passed
BB-04	Realtime Synchronization to Students	Students open application.	KRS status display in the student application changes to 'approved'.	Display changes instantly without refreshing.	Passed
BB-05	KRS Rejection with Notes	Lecturer clicks 'Reject', fills in reason, sends.	Status becomes 'rejected', notes are saved, students receive notifications.	Scenario runs as expected.	Passed

The test results showed that 100% of the main functional scenarios were successfully implemented without flow defects.

User Acceptance Testing Results

This evaluation involved 30 end users (20 students and 10 lecturers) to measure their level of acceptance and satisfaction.

Quantitative Analysis: System Usability Scale (SUS) The SUS questionnaire was distributed to measure the usability of the system. The results were processed and produced a final score.

- Number of Respondents: 30
- Average SUS Score: 85.5

Interpretation of SUS Score: According to industry standards, a SUS score of 85.5 is included in the "Excellent" category and is equivalent to an "A" grade. This shows that users empathize that this system is very easy to use, consistent, and they feel very confident when using it.

The results of this study comprehensively succeeded in answering the research objectives. The Firestore Snapshot-based monitoring and controlling algorithm model proved valid and effective. The average latency of 215 ms directly solves the problem of information delay that was the background of the study. The high usability score (SUS 85.5) and positive qualitative feedback indicate that the system is not only technically functional but also well-received by end users, which is key to successful technology adoption. The choice of modern technology stacks such as Next.js 14 and Flutter proved to be the right one. Next.js enabled the development of a very fast and responsive web interface for lecturers, while Flutter managed to deliver a smooth native user experience on the student side. Central to this success was the use of the Firebase platform as a BaaS (Backend-as-a-Service), which drastically reduced the complexity of server-side development and allowed the team to focus on business logic and user experience.

CONCLUSION

An algorithm model for real-time monitoring and control of academic processes at Manado State University has been successfully developed and validated effectively. This research has successfully bridged the "information-intervention latency gap" that often occurs in conventional Academic Information Systems (SIAKAD). With an average latency of 215 milliseconds, the system has proven to be able to present data instantly, solving the problem of information delays. The implementation of a system architecture that utilizes a modern technology stack, including Next.js 14 for web, Flutter for mobile, and Firebase as the backend, has proven to be appropriate and has been fully implemented. The core of the success of real-time functionality is the use of the Firestore Snapshot Listener (onSnapshot), which is effective in sending data updates automatically to all connected clients. In terms of user acceptance, this system has received very positive results. This is proven quantitatively through a System Usability Scale (SUS) score of 85.5, which is included in the "Excellent" category. Qualitatively, feedback from students and lecturers shows that this system significantly improves transparency, certainty, time efficiency, and work flexibility. Thus, the developed model is not only technically superior but also well accepted by end users, which is key to successful technology adoption in academic environments.

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