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Daftar Manajemen Arsip Berbasis Digital Untuk Mahasiswa Baru (Studi Kasus: SDN Pasar Baru 05 Tangerang)

(Digital-Basedarchive Management Register For New Student (Study Cases: SDN Pasar Baru 05 Tangerang)

Rahul Raihan Pratama[1]✉, Dewi Setiowati[2]
rahulraihan951@student.esaunggul.ac.id[1], dewi.setiowati@esaunggul.ac.id[2]
[12] Teknik Informatika, Fakultas Ilmu Komputer, Universitas Esa Unggul, Indonesia
ORCID ID[2]: 0009-0005-5747-1094

Abstract

Archives are an important component in the educational administration process. At SDN Pasar Baru 5 Tangerang, the management of new student re-registration archives is still carried out manually, which causes various problems such as difficulty in searching data, the risk of losing documents, and inefficient time in storage. This research was conducted to develop a digital-based archive management system using the Laravel framework to make the administrative process more effective, efficient, and safe. The method used in this study is the Waterfall Model, which consists of the stages of needs analysis, design, implementation, testing, and maintenance. The test results show that the system can manage documents digitally well, simplify the search process, and improve data accuracy and security.

Keywords: Digital Archives; Laravel; Waterfall; SDN Pasar Baru 5 Tangerang.

Abstrak

Arsip merupakan komponen penting dalam proses administrasi pendidikan. Di SDN Pasar Baru 5 Tangerang, pengelolaan arsip pendaftaran ulang siswa baru masih dilakukan secara manual sehingga menimbulkan berbagai masalah, seperti sulitnya pencarian data, risiko kehilangan dokumen, serta ketidakefisienan waktu dalam penyimpanan. Penelitian ini dilakukan untuk mengembangkan sistem pengelolaan arsip berbasis digital menggunakan *framework* Laravel agar proses administrasi menjadi lebih efektif, efisien, dan aman. Metode yang digunakan dalam penelitian ini adalah *Waterfall Model*, yang terdiri atas tahapan analisis kebutuhan, perancangan, implementasi, pengujian, dan pemeliharaan. Hasil pengujian menunjukkan bahwa sistem dapat mengelola dokumen secara digital dengan baik, mempermudah proses pencarian, serta meningkatkan akurasi dan keamanan data.

Kata kunci: Arsip Digital; Laravel; Waterfall; SDN Pasar Baru 5 Tangerang.

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Korespondensi Penulis:
Rahul Raihan Pratama
Teknik Informatika, Fakultas Ilmu Komputer, Universitas Esa Unggul, Indonesia
Jl. Arjuna Utara No.9, Duri Kepa, Kec. Kb. Jeruk, Kota Jakarta Barat, Daerah Khusus Ibukota Jakarta 11510
Email: rahulraihan951@student.esaunggul.ac.id

PENDAHULUAN

Pengelolaan arsip merupakan bagian penting dalam proses administrasi sebuah lembaga pendidikan. Arsip digunakan sebagai bukti, referensi, dan data pendukung dalam pengambilan keputusan. Seiring perkembangan teknologi informasi, pengelolaan arsip mulai beralih dari sistem konvensional menuju sistem digital. Alamsyah et al. (2023) menunjukkan bahwa digitalisasi arsip dapat membantu mengoptimalkan proses pengelolaan dan penyimpanan arsip. Selain itu, Wulandari dan Ismaya (2023) menjelaskan bahwa pengelolaan arsip elektronik menjadi salah satu bentuk pemanfaatan teknologi dalam mendukung pengelolaan dokumen di era digital.

Namun, pada praktiknya, masih banyak sekolah yang menggunakan sistem pengarsipan manual, termasuk SDN

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Pasar Baru 5 Tangerang. Prosedur pendaftaran ulang siswa baru di sekolah tersebut masih bergantung pada penyimpanan berkas fisik seperti fotokopi Kartu Keluarga, Akta Kelahiran, dan KTP orang tua. Sistem manual ini sering menimbulkan kendala, di antaranya kesulitan dalam proses pencarian dokumen, tingginya risiko kerusakan atau kehilangan berkas, serta kurang efisiennya waktu yang dibutuhkan untuk memverifikasi data siswa. Kondisi ini menunjukkan bahwa sekolah membutuhkan solusi yang lebih modern dan efektif dalam mengelola dokumen administrasi.

Perkembangan teknologi informasi membuka kesempatan besar bagi sekolah untuk bertransformasi menuju pengarsipan digital. Melalui memanfaatkan teknologi aplikasi berbasis web, proses pendaftaran ulang dapat dilakukan dengan lebih cepat, akurat, dan terpusat. Melihat kebutuhan tersebut, penelitian ini dilakukan untuk mengembangkan sistem pengelolaan arsip digital menggunakan framework Laravel. Sistem ini dirancang agar siswa dapat mengunggah dokumen secara mandiri dari perangkat masing-masing, sementara operator sekolah dapat melakukan verifikasi dan pengelolaan arsip melalui satu sistem terintegrasi. Digitalisasi ini diharapkan dapat mengurangi ketergantungan pada dokumen fisik, meminimalkan kesalahan administrasi, serta meningkatkan efisiensi kerja di lingkungan sekolah. Diharapkan penelitian dan pengembangan sistem ini mampu meningkatkan efisiensi dan efektivitas dalam proses administrasi pendaftaran ulang siswa baru. Sistem tersebut juga menjadi tahap awal bagi sekolah dalam beradaptasi dengan era digital seiring pesatnya perkembangan teknologi. Dengan demikian, pengelolaan arsip menjadi lebih praktis, aman, cepat, serta mampu memenuhi tuntutan administrasi modern.

METODOLOGI PENELITIAN

Metode yang diterapkan dalam pengembangan sistem pengelolaan arsip digital ini adalah metode Waterfall, yaitu model pengembangan perangkat lunak yang memiliki tahapan terstruktur dan berurutan dari analisis hingga tahap pemeliharaan. Metode ini dipilih karena sistem membutuhkan perencanaan yang terstruktur serta dokumentasi yang lengkap, sehingga pendekatan ini memastikan bahwa setiap tahapan pengembangan telah diselesaikan terlebih dahulu sebelum proses berlanjut ke tahapan berikutnya. Model Waterfall dinilai paling sesuai untuk penelitian ini karena kebutuhan pengguna telah terdefinisi dengan jelas dan bersifat spesifik, serta proses pengembangannya memerlukan alur yang terkontrol dan tidak berubah secara dinamis. Dalam menyusun kerangka dan alur sistem, peneliti memanfaatkan Unified Modeling Language (UML) untuk menggambarkan desain sistem secara visual. UML dipilih karena dapat menampilkan interaksi antar elemen dengan cara yang sistematis melalui berbagai jenis diagram. Diagram yang digunakan meliputi use case, activity, dan class diagram selama tahap pengembangan. Penggunaan UML memfasilitasi komunikasi antara tim pengembang dan pihak terkait, sehingga setiap tahapan pengembangan dapat dilaksanakan secara terfokus dan terdokumentasi dengan baik.

Pada tahap implementasi, sistem dikembangkan menggunakan Laravel Framework berbasis PHP sebagai framework untuk membangun aplikasi dan mengelola proses sistem, seperti autentikasi serta pengelolaan data arsip. Laravel menggunakan konsep Model-View-Controller (MVC) sehingga struktur aplikasi menjadi lebih terorganisir. Sementara itu, MySQL digunakan sebagai database untuk menyimpan dan mengelola data pengguna, arsip, serta data pendukung lainnya. Laravel diintegrasikan dengan MySQL untuk menjalankan proses pengelolaan data seperti menambah, menampilkan, mengubah, dan menghapus data (CRUD).

HASIL DAN PEMBAHASAN

UML (Unified Modelling Languange)

Unified Modelling Languange (UML) merupakan bahasa pemodelan standar yang digunakan untuk merancang, memvisualisasikan, serta mendokumentasikan sistem perangkat lunak sebelum sistem tersebut diimplementasikan.

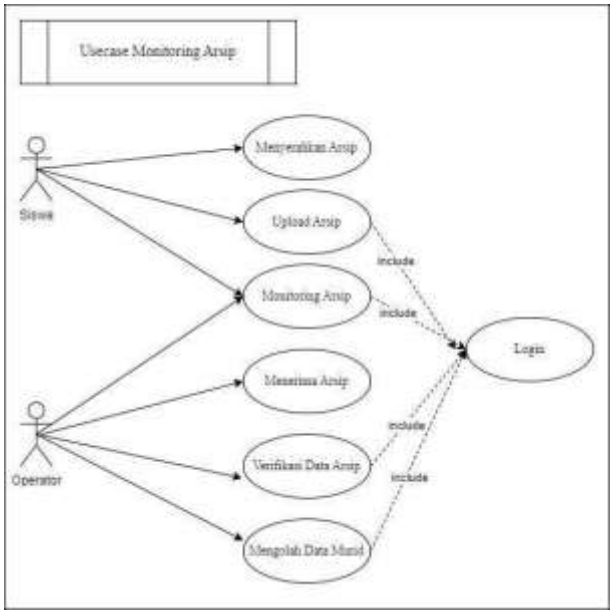
UML dipilih karena memiliki kemampuan untuk mengilustrasikan keterkaitan antar komponen secara terstruktur melalui berbagai tipe diagram. Diagram yang digunakan mencakup use case, activity, dan class diagram selama proses pengembangan. Penggunaan UML berkontribusi pada peningkatan komunikasi antara tim pengembang dan pihak terkait, sehingga alur proses pengembangan menjadi lebih terfokus dan terdokumentasi dengan baik.

Use Case Diagram

Use Case Diagram merupakan gambaran visual yang menampilkan bagaimana sebuah sistem informasi berperilaku serta berinteraksi dengan para penggunanya. Diagram ini digunakan untuk menguraikan fungsi-fungsi utama yang tersedia di dalam sistem serta mengidentifikasi peran dan hak akses setiap pengguna ketika

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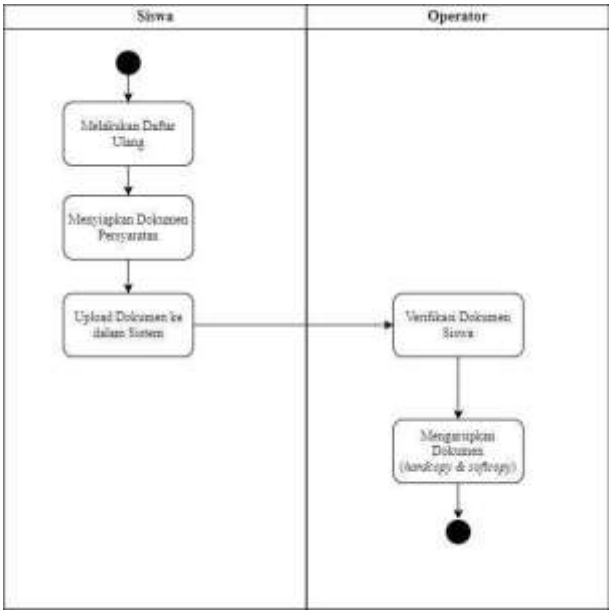
menjalankan fitur yang disediakan. Dengan adanya Use Case, pengembang dapat memahami alur aktivitas secara lebih jelas dan memastikan bahwa kebutuhan setiap aktor dalam sistem telah terpenuhi.



Gambar 1. Diagram Use Case

Berdasarkan use case diagram diatas terdapat 2 aktor, yaitu Siswa dan Operator.

Siswa adalah aktor yang bisa menyerahkan arsip dan melakukan upload arsip, arsip yang dimaksud adalah dokumen pendaftaran ulang Siswa baru. Selanjutnya adalah Operator yang mempunyai use case untuk menerima arsip dari Siswa, mengolah data arsip dan mengolah data Siswa.



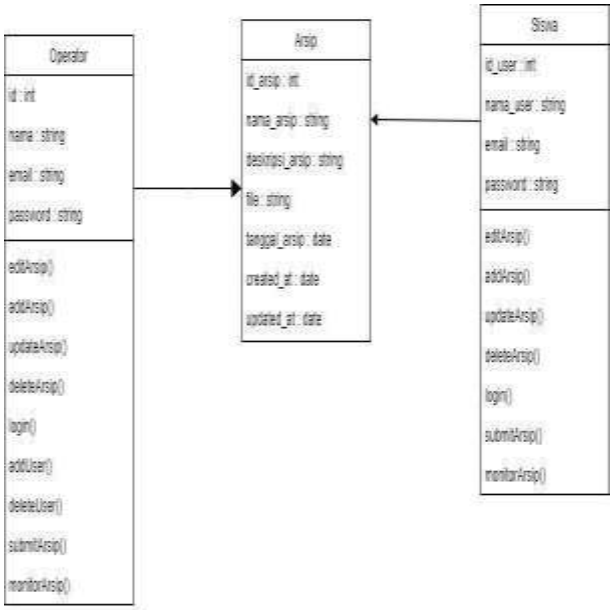
Gambar 2. Sistem Usulan

Pada sistem usulan ditambahkan beberapa kegiatan pada kolom Siswa dan Operator, yaitu Siswa melakukan Upload dokumen kedalam sistem. Kegiatan ini adalah proses digitalisasi arsip, dimana dokumen akan di- scan dan disimpan dalam bentuk softcopy. Siswa akan mendapatkan pesan email yang memberitahukan akun berupa user dan password agar dapat mengakses website registrasi. Didalam Sistem Operator akan melakukan Verifikasi Dokumen yang telah di upload kedalam sistem.

Class Diagram

Class Diagram merupakan diagram struktur statis dalam Unified Modeling Language (UML) yang digunakan untuk memodelkan struktur sistem atau program melalui menampilkan kelas, atribut, metode, serta hubungan yang terjadi antar kelas.

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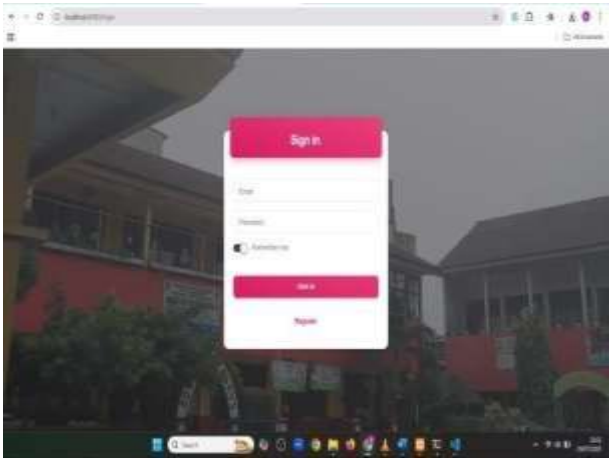


Gambar 3. Class Diagram

Implementasi Halaman Admin

Halaman Login Admin

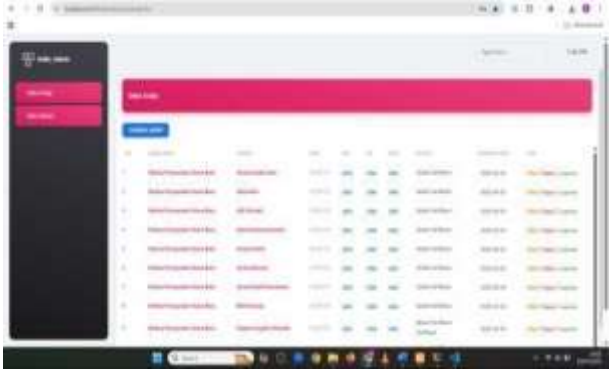
Antarmuka tersebut merupakan tampilan yang digunakan pengguna untuk masuk ke dalam sistem. Pada halaman ini terdapats sebuah form dengan dua field input, yaitu email dan password. Sementara itu, terdapat dua button, yaitu button Submit untuk masuk ke system dan button Register untuk melakukan pendaftaran.



Gambar 4. Login Admin

Halaman List Arsip

Antarmuka tersebut adalah tampilan List Arsip ketika admin yang berperan sebagai pengelola memilih menu Data Arsip yang ada pada sidebar ataupun Saat melakukan Login menggunakan ID Admin. Pada tampilan diatas terdapat tabel yang berisi Data Arsip beserta informasi dari pemilik Arsip Tersebut.

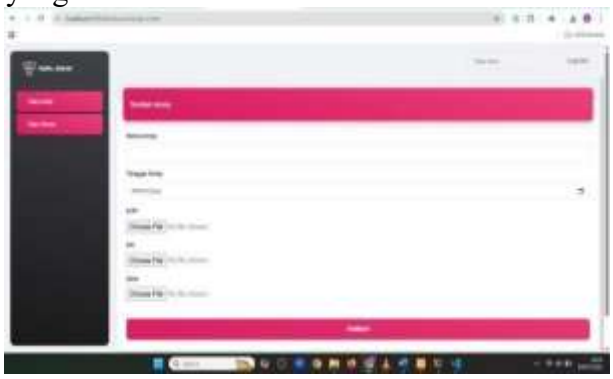


Gambar 5. Halaman List Arsip

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Halaman Tambah Arsip

Antarmuka tersebut adalah tampilan tambah data Arsip ketika admin yang bertugas sebagai pengelola memilih menu tambah arsip pada halaman Data Arsip. Pada tampilan diatas terdapat form yang digunakan untuk mengisi data dari Arsip baru yang akan di tambahkan.



Gambar 6. Halaman Tambah Arsip

Halaman Edit Arsip

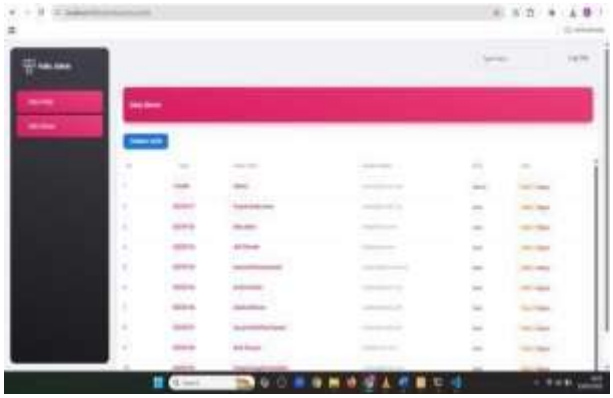
Antarmuka tersebut menunjukkan tampilan edit data Arsip ketika admin yang bertindak sebagai pengelola memilih menu edit data pada salah satu data yang ada di halaman Data Arsip. Pada tampilan di atas, Terdapat form yang diperlukan untuk mengubah data yang telah dipilih sebelumnya dari Arsip.



Gambar 7. Halaman Edit Arsip

Halaman List User

Antarmuka tersebut adalah tampilan Kelola Siswa ketika Admin yang bertugas sebagai pengelola memilih menu Data Siswa yang ada pada sidebar. Pada tampilan diatas terdapat tabel yang berisi data Siswa beserta informasi rolenya.



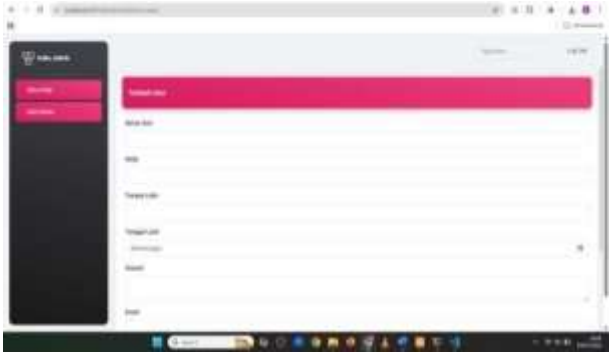
Gambar 8. Halaman List User

Halaman Tambah User

Antarmuka tersebut adalah tampilan tambah data user ketika Admin yang bertugas sebagai pengelola memilih menu tambah data pada halaman Data User. Pada tampilan diatas terdapat form yang digunakan untuk mengisi

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data dari user baru yang akan di tambahkan.



Gambar 9. Halaman Tambah User

Halaman Edit User

Antarmuka tersebut adalah tampilan edit data user ketika admin yang bertugas sebagai pengelola memilih menu edit data pada salah satu data yang ada di halaman data edit user. Pada tampilan diatas terdapat form yang digunakan untuk melakukan update data baru dari user yang di pilih sebelumnya.



Gambar 10. Halaman Edit User

Implementasi Halaman User

Halaman Login User

Antarmuka tersebut adalah halaman login yang dipakai oleh pengguna untuk mengakses sistem. Halaman ini terdapat formulir dengan dua input, yaitu email dan password. Selain itu, tersedia dua button, yaitu Submit untuk masuk dan Register untuk melakukan pendaftaran.

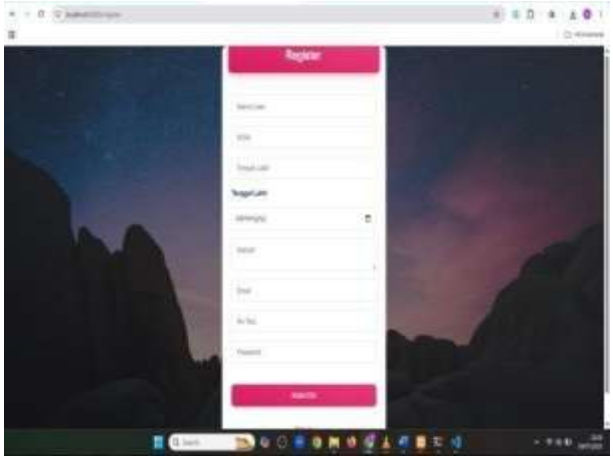


Gambar 11. Halaman Login User

Halaman Register

Antarmuka tersebut merupakan halaman yang digunakan pengguna untuk melakukan pendaftaran ke dalam sistem. Pada tampilan tersebut tersedia sebuah formulir yang berfungsi untuk mengisi data pengguna baru yang akan mendaftar. Selain itu, terdapat satu button untuk melanjutkan proses pendaftaran.

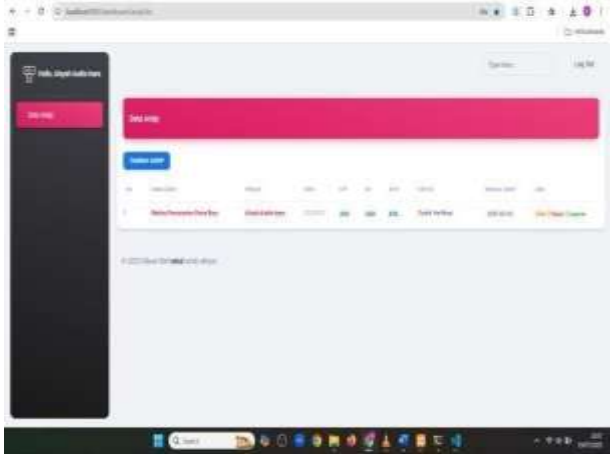
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Gambar 12. Halaman Register

Halaman List Arsip

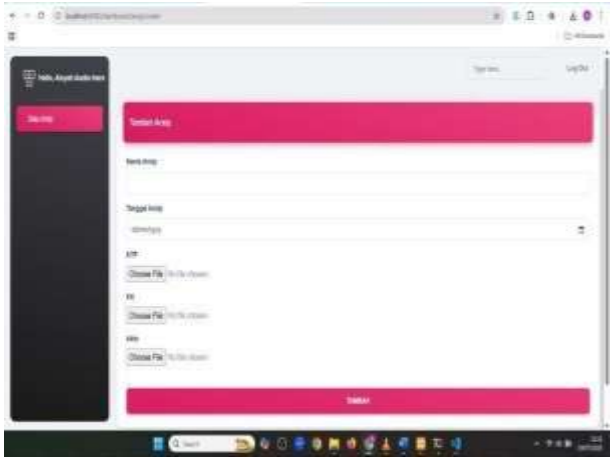
Antarmuka tersebut adalah tampilan List Arsip ketika User yang bertugas sebagai pengguna memilih menu Data Arsip yang ada pada sidebar ataupun Saat melakukan Login menggunakan ID User. Pada tampilan diatas terdapat tabel yang berisi Data Arsip beserta informasi dari pemilik Arsip Tersebut.



Gambar 13. Halaman List Arsip

Halaman Tambah Arsip

Antarmuka tersebut adalah tampilan tambah data Arsip ketika User yang berperan sebagai pengguna memilih menu tambah arsip pada halaman Data Arsip. Pada tampilan diatas terdapat form yang digunakan untuk mengisi data dari Arsip baru yang akan di tambahkan.



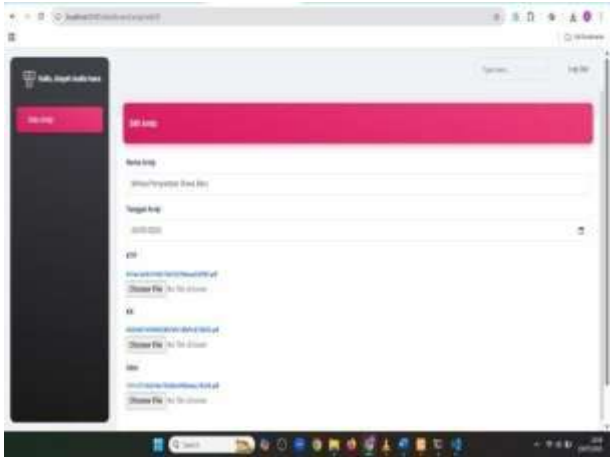
Gambar 14. Halaman Tambah Arsip

Halaman Ubah Arsip

Antarmuka tersebut adalah halaman edit data Arsip ketika User yang berperan sebagai pengguna memilih menu

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edit data pada salah satu data yang ada di halaman Data Arsip. Pada tampilan diatas terdapat form yang digunakan untuk melakukan update data baru dari Arsip yang di pilih sebelumnya.



Gambar 15. Halaman Ubah Arsip

KESIMPULAN DAN SARAN

Penelitian ini berhasil mengembangkan sistem pengelolaan arsip digital untuk pendaftaran ulang siswa baru di SDN Pasar Baru 5 Tangerang. Sistem ini terbukti mampu menyelesaikan berbagai permasalahan yang muncul pada proses pengarsipan manual, seperti kesulitan pencarian berkas, risiko kehilangan dokumen, dan lamanya proses verifikasi. Melalui penggunaan framework Laravel dan database MySQL, sistem yang dibangun memiliki kinerja stabil, aman, dan mudah digunakan oleh siswa maupun operator sekolah. Implementasi sistem ini membuat proses unggah, verifikasi, dan penyimpanan dokumen menjadi lebih cepat, terpusat, dan efisien. Secara keseluruhan, digitalisasis arsip mampu meningkatkan kualitas administrasi sekolah dan mendukung proses kerja yang lebih modern dan efektif. Untuk pengembangan selanjutnya, sistem disarankan menambahkan fitur keamanan yang lebih kuat seperti enkripsi dan cadangan data berbasis cloud agar arsip tetap aman. Pelatihan bagi operator perlu dilakukan secara berkala untuk memastikan sistem dapat digunakan secara maksimal. Fitur notifikasi otomatis juga dapat ditambahkan agar siswa mendapat informasi status verifikasi dokumen secara langsung. Selain itu, integrasi dengan sistem administrasi sekolah lain seperti Dapodik dapat mempermudah sinkronisasi data. Pengujian lebih luas di sekolah lain juga disarankan untuk memastikan sistem ini dapat diterapkan secara lebih umum dan berkelanjutan.

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Analisis Faktor Penerimaan Aplikasi Tokopedia Menggunakan Technology Acceptance Model (TAM)

(Analysis of Tokopedia Application Acceptance Factors Using Technology Acceptance Model (TAM))

Theresia Intan[1], Rini Nuraini[2],Heru Dian Setiawan[3], Warjiyono[4], Sabil[5], Rima Tamara Aldisa[6]
intantheresia520@civitas.unas,.ac.id[1], rini.nuraini@ civitas.unas.ac.id[2],herudiansetiawan@civitas.unas.ac.id[3]
warjiyono.wrj@bsi.ac.id[4], sabil.sbl@bsi.ac.id[5], rimatamaraa@civitas.unas.ac.id[6]
[1,2]Program Studi Sistem Informasi, FTKI, Universitas Nasional, Indonesia
[3]Program Studi Program Doktor Ilmu Politik, FISIP, Universitas Nasional, Indonesia
[4]Prodi Sistem Informasi Akuntansi, FTI, Universitas Bina Sarana Informatika, Indonesia
[5] Program Studi Manajemen, FEB, Universitas Bina Sarana Informatika, Indonesia
[6] Program Studi Informatika, FTKI, Universitas Nasional, Indonesia

Abstract

This study aims to utilize the Technology Acceptance Model (TAM) to examine how Perceived Ease of Use and Perceived Effectiveness influence the Behavioral Intention to Use (ITU) within the context of the Tokopedia application. A quantitative approach was employed, emphasizing causal and descriptive analysis. Behavioral Intention to Use (ITU) was designated as the dependent variable, Perceived Ease of Use (PEOU) as the independent variable, and Perceived Effectiveness (PU) as the mediating variable. Data were collected via Google Forms questionnaires completed by 43 respondents and subsequently analyzed using SPSS 23 software. The results indicate that only one of the three hypotheses was accepted and demonstrated a significant impact: the hypothesis stating that Perceived Ease of Use increases the Behavioral Intention to Use. Conversely, no significant influence was found regarding the relationship between Perceived Ease of Use and Perceived Effectiveness, nor between Perceived Effectiveness and Behavioral Intention to Use. Furthermore, reliability testing using the Cronbach's Alpha technique yielded scores of 0.924 for Perceived Usefulness, 0.933 for Perceived Ease of Use, and 0.955 for Behavioral Intention to Use. All Cronbach's Alpha values exceeded 0.70, indicating that each research instrument was reliable and suitable for further analysis.

Kata kunci: Technology Acceptance Model; Perceived Usefulness; Perceived Ease of Use; Behavioral Use; User Interest; Tokopedia.

Abstrak

Studi ini bertujuan memanfaatkan *Technology Acceptance Model* (TAM) untuk meneliti bagaimana *Perceived Ease of Use* dan *Perceived Effectiveness* memengaruhi *Behavioral Intention to Use* (ITU) dalam konteks aplikasi Tokopedia. Pendekatan kuantitatif digunakan, menekankan analisis kausal dan deskriptif. *Behavioral Intention of Use* (ITU) ditetapkan sebagai variabel dependen, *Perceived Ease of Use* (PEOU) sebagai variabel independen, dan *Perceived Effectiveness* (PU) sebagai variabel mediasi. Data dikumpulkan melalui kuesioner *Google Forms* yang diisi oleh 43 responden dan kemudian dianalisis menggunakan perangkat lunak SPSS 23. Hasilnya menunjukkan bahwa hanya satu dari tiga hipotesis yang diterima dan menunjukkan dampak signifikan: hipotesis yang menyatakan bahwa *Perceived Ease of Use* meningkatkan *Behavioral Intention to Use*. Sebaliknya, tidak ditemukan pengaruh signifikan terkait hubungan antara *Perceived Ease of Use* dan *Perceived Effectiveness*, maupun antara *Perceived Effectiveness* dan *Behavioral Intention to Use*. Selain itu, pengujian keandalan menggunakan teknik *Alpha Cronbach* menghasilkan skor 0,924 untuk Kegunaan yang Dirasakan, 0,933 untuk Kemudahan Penggunaan yang Dirasakan, dan 0,955 untuk Niat Perilaku untuk Digunakan. Semua nilai *Alpha Cronbach* melebihi 0,70, menunjukkan bahwa setiap instrumen penelitian dapat diandalkan dan cocok untuk analisis lebih lanjut.

Kata kunci: Technology Acceptance Model; Perceived Usefulness; Perceived Ease of Use; Behavioral Use; Minat Pengguna; Tokopedia.

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Korespondensi Penulis:
Theresia Intan
Program Studi Sistem Informasi, Universitas Nasional
Jl. Sawo Manila, Pejaten Ps. Minggu Jakarta 12520
intantheresia520@civitas.unas,.ac.id

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PENDAHULUAN

Kemajuan internet dan teknologi informasi telah mengubah cara individu melakukan perdagangan dan transaksi. Contoh nyata dari perubahan ini adalah munculnya perdagangan elektronik, yang biasa dikenal dengan *e-commerce*, yang memungkinkan pembeli membeli barang melalui platform *online* tanpa perlu interaksi langsung. Pergeseran ini juga menyebabkan perubahan kebiasaan konsumen dan peningkatan fokus pada aspek-aspek yang mempengaruhi penerimaan teknologi dalam ranah belanja *online* (Ruiz-Herrera et al., 2023; Ryadi et al., 2021). Dalam ranah *e-commerce*, keputusan seseorang untuk berinteraksi dengan suatu platform tidak hanya dipengaruhi oleh ketersediaan layanan, tetapi juga oleh pandangan mereka terhadap teknologi yang digunakan. Dua elemen umum yang digunakan untuk menjelaskan penerimaan teknologi adalah persepsi mengenai manfaat dan persepsi mengenai kemudahan penggunaan. Studi terhadap pengguna *e-commerce* menunjukkan bahwa komponen-komponen ini dapat menjelaskan alasan konsumen memilih untuk menggunakan platform digital dan melakukan transaksi melaluinya (Andrina dkk., 2022; Harsanto dkk., 2023). Penelitian lain juga menunjukkan adanya kaitan antara persepsi manfaat dan kemudahan dengan adopsi layanan belanja daring (Ryadi dkk., 2021).

Salah satu platform belanja daring yang penting untuk dianalisis dalam konteks ini adalah Tokopedia. Penelitian terdahulu secara khusus memilih Tokopedia sebagai fokus kajian untuk mengeksplorasi elemen-elemen yang memengaruhi niat penggunaan. Sihombing dan Permana (2023) meneliti faktor-faktor penentu yang memengaruhi keinginan masyarakat Indonesia untuk menggunakan platform daring Tokopedia, dengan mempertimbangkan aspek-aspek seperti persepsi kemanfaatan dan persepsi kemudahan penggunaan. Studi lain yang dilakukan di DKI Jakarta mengkaji faktor-faktor yang memengaruhi niat pembelian di Tokopedia dengan menggabungkan *Technology Acceptance Model* (TAM) dan *e-Service Quality* (Lardo dkk., 2023). Selain itu, Jushermi dkk. (2024) menerapkan TAM untuk mempelajari penerimaan platform *e-commerce* Tokopedia di kalangan penduduk Kota Pekanbaru.

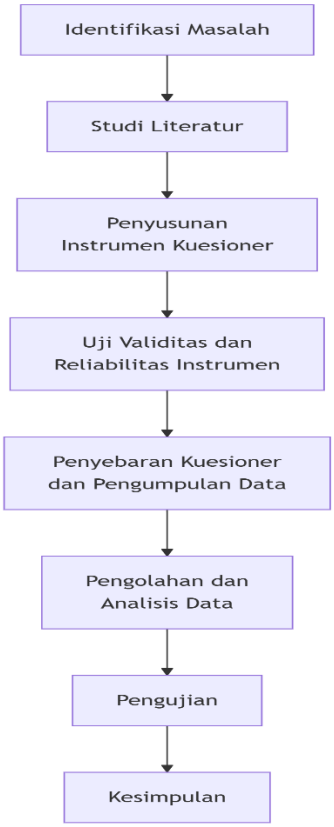
Sejalan dengan strategi ini, penelitian tersebut mencakup tiga faktor yang berkaitan dengan penerimaan teknologi: Persepsi Manfaat (*Perceived Usefulness*), Persepsi Kemudahan Penggunaan (*Perceived Ease of Use*), dan Niat Perilaku (*Behavioral Intention*). Persepsi Manfaat mencerminkan sejauh mana pengguna merasa bahwa penggunaan aplikasi memberikan keuntungan bagi tugas-tugas mereka, sementara Persepsi Kemudahan Penggunaan menunjukkan seberapa mudah aplikasi tersebut dipahami dan dioperasikan oleh pengguna. Niat Perilaku menandakan kesediaan atau niat pengguna untuk berinteraksi dengan teknologi tertentu. Ketiga elemen ini telah diterapkan dalam berbagai studi yang berfokus pada penerimaan teknologi di ranah *e-commerce* dan Tokopedia (Jushermi dkk., 2024; Sihombing & Permana, 2023; Nuralama dkk., 2024).

Meskipun telah banyak penelitian dilakukan mengenai penerimaan teknologi dalam belanja daring, penting untuk mengkaji bagaimana pandangan pengguna, niat perilaku, dan keinginan untuk menggunakan aplikasi Tokopedia saling berkaitan di berbagai kelompok demografis pengguna. Penelitian terdahulu telah menerapkan *Technology Acceptance Model* (TAM) untuk menjelaskan penerimaan dan niat penggunaan dalam *e-commerce* namun, subjek penelitian, karakteristik responden, dan variabel yang diteliti berbeda-beda (Lardo dkk., 2023; Jushermi dkk., 2024; Nuralama dkk., 2024). Oleh karena itu, penelitian ini bertujuan untuk mengevaluasi bagaimana persepsi kemanfaatan, persepsi kemudahan penggunaan, dan niat perilaku memengaruhi niat untuk menggunakan aplikasi Tokopedia. Hasil penelitian ini diharapkan dapat memberikan wawasan mengenai faktor-faktor yang terkait dengan niat untuk menggunakan aplikasi Tokopedia serta memperkaya literatur mengenai penerimaan teknologi dalam sistem *e-commerce* secara keseluruhan.

METODOLOGI PENELITIAN

Penelitian ini menggunakan strategi kuantitatif melalui survei. Data utama dikumpulkan dengan membagikan kuesioner kepada para partisipan, dan tinjauan literatur dilakukan untuk membangun landasan teoretis serta membantu perumusan instrumen penelitian. Instrumen survei yang dikenal sebagai kuesioner sering digunakan dalam penelitian untuk mengumpulkan informasi dari partisipan melalui serangkaian pertanyaan atau pernyataan yang selaras dengan tujuan penelitian. Kuesioner memungkinkan pengumpulan data secara sistematis dan dapat dilaksanakan baik secara tatap muka maupun melalui internet. Integritas data yang dikumpulkan bergantung pada seberapa baik instrumen tersebut dirancang, digunakan, dan divalidasi; oleh karena itu, instrumen tersebut harus disusun sedemikian rupa agar dapat mengukur variabel penelitian secara efektif (Ranganathan & Caduff, 2023;

Elangovan & Sundaravel, 2021). Penelitian ini menggunakan kuesioner untuk memperoleh informasi primer dari partisipan mengenai persepsi kegunaan, persepsi kemudahan penggunaan, niat perilaku, serta niat untuk menggunakan aplikasi Tokopedia. Gambar 1 berikut adalah tahapan penelitian yang dilakukan dalam penelitian:



Gambar 1. Tahapan Penelitian

Tahap penelitian ini dimulai dengan identifikasi masalah terkait penggunaan aplikasi Tokopedia, yang menjadi fokus utama studi ini. Selanjutnya, dilakukan tinjauan literatur untuk membangun landasan teoretis berdasarkan *Technology Acceptance Model* (Model Penerimaan Teknologi) serta menemukan penelitian terdahulu yang berkaitan dengan variabel-variabel yang digunakan dalam kajian ini. Sebagai contoh, penelitian oleh Sihombing dan Permana pada tahun 2023 mengkaji minat pengguna di Indonesia untuk berinteraksi dengan platform daring Tokopedia, dengan mempertimbangkan aspek-aspek seperti persepsi kemanfaatan dan persepsi kemudahan penggunaan. Senada dengan hal tersebut, studi yang dilakukan oleh Jushermi dan rekan-rekannya pada tahun 2024 menerapkan *Technology Acceptance Model* untuk mengevaluasi penerimaan terhadap *e-marketplace* Tokopedia, dengan memperhitungkan elemen-elemen seperti persepsi kemanfaatan, persepsi kemudahan penggunaan, niat penggunaan, dan penggunaan aktual. Secara paralel, Lardo dan rekan-rekannya pada tahun 2023 menelaah faktor-faktor yang memengaruhi niat pembelian di Tokopedia di wilayah DKI Jakarta dengan mengintegrasikan *Technology Acceptance Model* dan *e-Service Quality* (Kualitas Layanan Elektronik).

Berdasarkan studi dan analisis terdahulu, instrumen penelitian disusun dengan mencakup elemen-elemen berikut: persepsi efektivitas, persepsi kemudahan penggunaan, niat perilaku, serta niat pengguna untuk memanfaatkan aplikasi Tokopedia. Sebelum disebarkan kepada partisipan, instrumen tersebut menjalani uji validitas dan reliabilitas untuk memastikan kesesuaian setiap butir pertanyaan dalam pengumpulan data. Setelah instrumen dinyatakan layak, kuesioner dibuat menggunakan *Google Forms*. Kuesioner tersebut kemudian disebarkan secara daring melalui *WhatsApp* dan berbagai platform media sosial kepada individu yang memenuhi kriteria penelitian. Tautan *Google Forms* tidak disematkan di dalam aplikasi Tokopedia, melainkan disebarluaskan secara terpisah melalui saluran komunikasi yang digunakan peneliti untuk menjangkau pengguna Tokopedia.

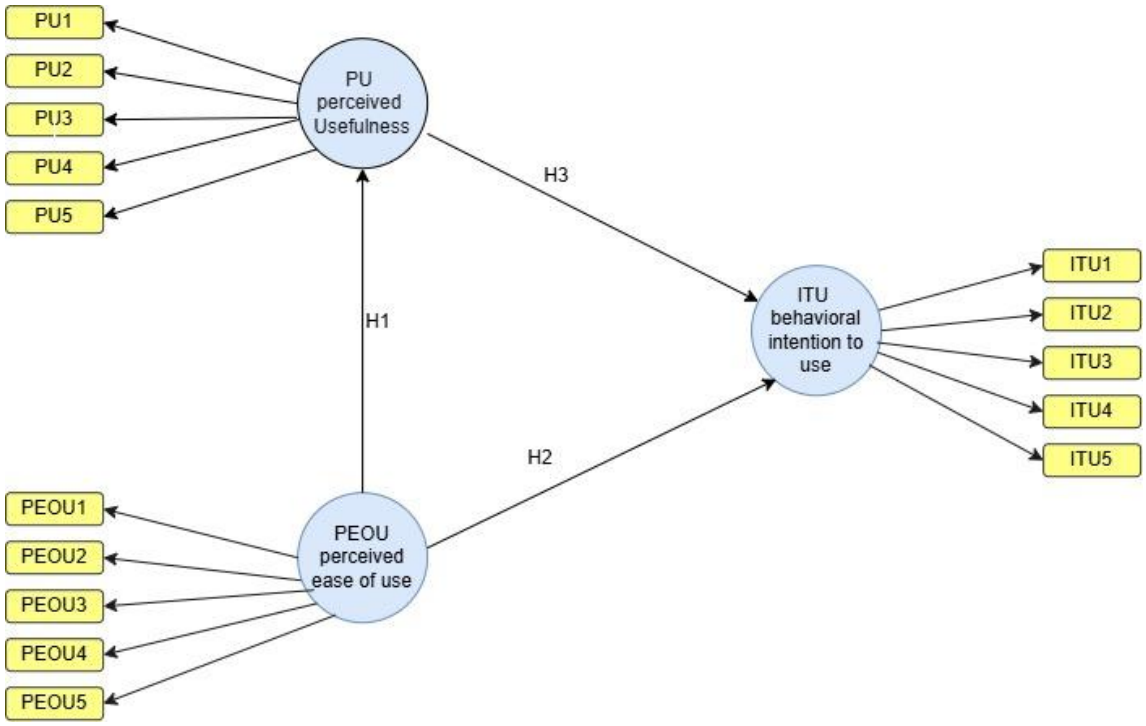
Setelah data dikumpulkan, evaluasi dan pengolahan data dilakukan menggunakan perangkat lunak *Statistical Package for the Social Sciences*. Tahap awal analisis melibatkan penggunaan statistik deskriptif untuk memerinci karakteristik data penelitian. Selanjutnya, dilakukan pengujian validitas dan reliabilitas instrumen, serta penilaian terhadap asumsi-asumsi yang diperlukan untuk analisis regresi. Untuk menguji hipotesis, digunakan uji-t guna

menilai pengaruh masing-masing variabel independen terhadap variabel dependen, sedangkan uji-F digunakan untuk mengkaji pengaruh gabungan variabel-variabel independen terhadap variabel dependen. Hasil dari pengujian-pengujian tersebut kemudian menjadi dasar dalam merumuskan kesimpulan penelitian.

Variabel dan Indikator Penelitian

Tabel 1. Variabel dan Indikator Penelitian

Variabel	Kode	Indikator
Perceived usefulness **(X1)**	PU1	Penggunaan Tokopedia meningkatkan efesiensi belanja online
	PU2	Tokopedia menyediakan fitur pembayaran online sehingga membuat proses transaksi menjadi lebih mudah
	PU3	Informasi produk tersedia saat saya membutuhkan
	PU4	Fitur pelacakan pengiriman barang membantu saya dalam memantau status pengiriman barang
	PU5	menyediakan fitur voucher dan promo sehingga dapat memberikan manfaat dalam menghemat biaya belanja
Perceived ease of use **(X2)** ***Behavioral Use*** **(X3)**	PEOU1	Ulasan dan rating produk Tokopedia membantu saya dalam mengambil keputusan
	PEOU2	Aplikasi Tokopedia mudah dipelajari oleh pengguna baru
	PEOU3	Fitur-fitur yang tersedia pada Tokopedia mudah dipahami
	PEOU4	Proses transaksi pada Tokopedia mudah dilakukan
	PEOU5	Tidak mengalami kesulitan dalam penggunaan Tokopedia
Behavioral Use **(X3)**	ITU1	Saya tertarik untuk menggunakan Tokopedia
	ITU2	Tokopedia menjadi pilihan utama saya untuk belanja online
	ITU3	Saya menggunakan Tokopedia setiap kali membutuhkan produk atau layanan tertentu
	ITU4	Saya lebih sering menggunakan Tokopedia dibandingkan toko online lainnya
	ITU5	Saya sering mendapatkan voucher dan promo saat menggunakan Tokopedia



Gambar 2. Model Penelitian

Hipotesis Penelitian

Hipotesis penelitian merupakan dugaan sementara mengenai hubungan antara variabel independen dan variabel dependen yang akan diuji melalui analisis statistik. Berdasarkan kerangka konseptual yang telah ditetapkan, hipotesis dalam penelitian ini adalah sebagai berikut.

Hubungan antara Niat Menggunakan Aplikasi Tokopedia dan Persepsi Kegunaan

Persepsi kegunaan merupakan penilaian pengguna mengenai manfaat yang diperoleh dari penggunaan aplikasi Tokopedia. Semakin besar manfaat yang dirasakan pengguna, semakin besar pula kecenderungan pengguna untuk menggunakan aplikasi Tokopedia. Persepsi kegunaan berpengaruh positif terhadap niat menggunakan aplikasi Tokopedia.

Hubungan antara Niat Menggunakan Aplikasi Tokopedia dan Persepsi Kemudahan Penggunaan

Persepsi kemudahan penggunaan merupakan penilaian pengguna terhadap tingkat kemudahan dalam mengoperasikan aplikasi Tokopedia. Kemudahan penggunaan yang dirasakan pengguna dapat mendorong peningkatan niat untuk menggunakan aplikasi tersebut. Persepsi kemudahan penggunaan berpengaruh positif terhadap niat menggunakan aplikasi Tokopedia.

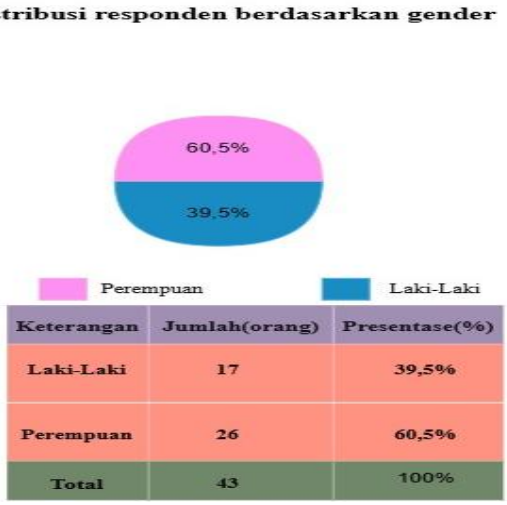
Hubungan antara Niat Perilaku dan Niat Menggunakan Aplikasi Tokopedia

Niat perilaku mencerminkan keinginan pengguna untuk menggunakan aplikasi Tokopedia. Semakin kuat niat perilaku pengguna, semakin besar kecenderungan pengguna untuk menggunakan aplikasi tersebut. Niat perilaku berpengaruh positif terhadap niat menggunakan aplikasi Tokopedia.

HASIL DAN PEMBAHASAN

Profil Responden

Tautan *Google Form* digunakan untuk menyebarkan kuesioner kepada 43 pengguna program Tokopedia, sehingga menghasilkan kelompok responden dengan beragam latar belakang, termasuk variasi jenis kelamin. Jumlah responden dalam penelitian ini masih terbatas, sehingga hasil penelitian perlu diinterpretasikan sesuai dengan jumlah responden dan belum dapat digeneralisasikan secara luas kepada seluruh pengguna aplikasi Tokopedia.



Gambar 3. Gender

Gambar 3 menunjukkan bahwa di antara 43 titik data responden yang disertakan dalam analisis ini, sebagian besar adalah perempuan (26 orang atau 60,5%), sedangkan sisanya adalah laki-laki (39,5%).

Tabel 2. Usia

USIA	JUMLAH ORANG	PRESENTASE (%)
<17	2	4,70%
17-20 Tahun	36	83,70%
21-25 Tahun	3	7,00%
26-30 Tahun	0	0%
30 Tahun	2	4,70%
Total	43	100%

Tabel 2 menunjukkan bahwa di antara 43 partisipan yang dianalisis, kategori terbesar terdiri dari individu berusia 17 hingga 20 tahun yang berjumlah 36 orang, atau mencakup 83,7% dari kelompok tersebut. Sebaliknya, kategori dengan jumlah terkecil mencakup individu berusia 30 tahun, yang terdiri dari 2 partisipan atau 4,7%.

Tabel Statistics dan Uji Reliabilitas

Tabel 3. Statistik Deskriptif Variabel Penelitian

Indikator	Mean	Std.Devietion	N
PU1	3,65	.949	43
PU2	3,84	1.167	43
PU3	3,76	.796	43
PU4	3,70	1.051	43
PU5	3,86	1.032	43
PE1	3.72	1.031	43
PE2	3.77	0.972	43
PE3	3.65	0.923	43
PE4	3.93	0.961	43
PE5	3.84	0.949	43
ITU1	3.56	0.908	43
ITU2	3.35	1.021	43
ITU3	3.47	1.032	43
ITU4	3.40	1.050	43
ITU5	3.58	0.932	43

Tabel 4. Hasil Uji Reliabilitas

Variabel	*Cronbach Alpha*	Standar Reliabilitas	Keterangan
Perceived Usefulness	0,924	0,70	Reliabel
Perceived Ease Of Use	0,933	0,70	Reliabel
Behavioral Intention to Use	0,955	0,70	Reliabel

Berdasarkan penilaian reliabilitas yang dilakukan dengan metode *Cronbach's Alpha*, ukuran *Perceived Effectiveness* memperoleh skor sebesar 0,924, sedangkan variabel *Perceived Ease of Use* memperoleh skor sebesar 0,933, dan variabel *Behavioral Intention to Use* memperoleh skor sebesar 0,955. Masing-masing skor *Cronbach's Alpha* melampaui 0,70, menunjukkan bahwa alat penelitian tersebut menunjukkan keandalan yang memadai (Kyriazos & Stalikas, 2023).

Pembahasan

Setiap variabel yang dianalisis dalam penelitian ini dinilai reliabel berdasarkan evaluasi reliabilitas menggunakan *Cronbach's Alpha*, karena semuanya melampaui kriteria 0,70. Nilai *Cronbach's Alpha* untuk variabel *Perceived Usefulness* (PU), *Perceived Ease of Use* (PEOU), dan *Behavioral Intention to Use* (BI) masing-masing adalah 0,924, 0,933, dan 0,955. Angka-angka ini menunjukkan bahwa setiap pengukuran dalam variabel masing-masing menunjukkan tingkat konsistensi internal yang tinggi dalam evaluasi konsep yang sedang diteliti. Akibatnya, instrumen penelitian mampu menghasilkan data yang dapat diandalkan dan konsisten untuk mengevaluasi elemen-elemen yang memengaruhi minat pengguna terhadap aplikasi Tokopedia, menurut TAM (*Technology Acceptance Model*). Temuan reliabilitas yang kuat juga menyiratkan bahwa kuesioner memenuhi kriteria sebagai alat penelitian, sehingga layak untuk diteliti lebih lanjut guna mengeksplorasi hubungan antara Kemudahan Penggunaan yang Dirasakan, Kegunaan yang Dirasakan, dan Niat Perilaku untuk Menggunakan serta minat dalam menggunakan aplikasi Tokopedia.

KESIMPULAN DAN SARAN

Simpulan

Berdasarkan penelitian yang telah dilakukan, dapat disimpulkan bahwa instrumen pengukuran yang digunakan memenuhi standar reliabilitas. Hal ini didukung oleh nilai *Cronbach's Alpha* yang diperoleh: 0,924 untuk *Perceived Usefulness* (PU), 0,933 untuk *Perceived Ease of Use* (PEOU), dan 0,955 untuk *Behavioral Intention* (BI) yang semuanya melampaui ambang batas minimal 0,70. Dengan demikian, setiap instrumen pengukuran dalam penelitian ini dinilai reliabel dan tepat untuk mengukur faktor-faktor yang memengaruhi minat pengguna

terhadap aplikasi Tokopedia dalam kerangka *Technology Acceptance Model* (TAM). Hasil pengujian hipotesis menunjukkan bahwa *Perceived Ease of Use* berpengaruh positif dan signifikan terhadap niat untuk menggunakan aplikasi Tokopedia. Sebaliknya, *Perceived Usefulness* dan *Behavioral Intention* tidak memiliki pengaruh yang signifikan terhadap minat pengguna terhadap aplikasi tersebut. Selain itu, analisis secara simultan menunjukkan bahwa ketiga variabel independen tersebut secara bersama-sama memengaruhi minat pengguna terhadap aplikasi Tokopedia.

Saran

Para penulis merekomendasikan agar penelitian selanjutnya melibatkan lebih banyak lagi responden untuk menghasilkan analisis yang lebih representatif. Lebih lanjut, diharapkan penelitian selanjutnya dapat memperkenalkan variabel tambahan di luar Model Penerimaan Teknologi (TAM), seperti Kepercayaan, Risiko yang Dirasakan, atau Kualitas Layanan, sehingga faktor-faktor yang memengaruhi minat dalam menggunakan aplikasi Tokopedia dapat dianalisis lebih mendalam. Bagi Tokopedia, hasil studi ini diharapkan dapat memberikan masukan untuk meningkatkan kemudahan penggunaan, manfaat, dan kualitas layanan aplikasinya, sehingga meningkatkan minat masyarakat dalam menggunakan Tokopedia.

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Strategic Information Systems and Digital Capability as Enablers of Digital Transformation in Indonesian Higher Education University

Ahmad Subadri[1]✉, Ikra Muhibban Ananta[2], Mega Fitri Yani[3]
ahmadsubadri953@gmail.com[1], muhib.ikra@gmail.com[2], megafitriyani02@gmail.com[3]
[12] Informatics, Faculty of Science and Technology, UIN Sunan Kalijaga, Yogyakarta, Indonesia
[3] Center of Excellence Digital Intelligent Enterprise, Telkom University, Indonesia
ORCID ID[1]: https://orcid.org/0000-0002-2564-0499 ORCID ID[2]: https://orcid.org/0009-0008-2079-7703
ORCID ID[3]: https://orcid.org/0009-0006-4551-447X

Abstract

Digital transformation has become an essential strategic initiative for higher education institutions seeking to improve service quality, enhance operational efficiency, and strengthen data-driven governance. Despite the increasing adoption of digital technologies, limited empirical research has examined how Strategic Information Systems (SIS) contribute to Digital Transformation through the development of Digital Capability. This study investigates the relationship between Strategic Information Systems, Digital Capability, and Digital Transformation in the higher education context. An exploratory qualitative case study was conducted at University PGRI Yogyakarta (UPY), Indonesia. Data were collected through semi-structured interviews, observations, organizational documents, and insider inquiry, and analyzed using thematic analysis. The findings reveal that Strategic Information Systems serve as key enablers by providing integrated digital infrastructure, facilitating information sharing, and supporting organizational decision-making. These capabilities strengthen Digital Capability, which subsequently drives Digital Transformation across the institution. The study also shows that Digital Capability supports process integration, continuous system enhancement, service innovation, and data-driven governance practices. Informants also reported value creation in academic and administrative services. This research contributes to the Information Systems literature by providing exploratory evidence on the role of Digital Capability in linking Strategic Information Systems with Digital Transformation. The findings offer practical guidance for university leaders and information system managers in developing integrated digital ecosystems that support long-term institutional development.

Keywords: Strategic Information Systems; Digital Capability; Digital Transformation; Higher Education; Case Study

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Corresponding Author:
Ahmad Subadri
ahmadsubadri953@gmail.com
Informatics, Faculty of Science and Technology, UIN Sunan Kalijaga, Yogyakarta, Indonesia
Jl. Marsda Adisucipto Yogyakarta 55281

INTRODUCTION

Digital transformation has become a strategic priority for organizations in adapting to rapid technological advancements and an increasingly digital environment. Technologies such as AI, Big Data Analytics, Cloud Computing, IoT, and digital platforms have reshaped how organizations create and deliver value. In higher education, digital transformation extends beyond administrative digitalization and encompasses broader changes in governance, academic activities, research, student services, and data-driven decision-making (Esteve-Mon et al., 2023; Mohamed Hashim et al., 2022). Higher education institutions are increasingly required to provide services that are more flexible, integrated, and responsive to an increasingly competitive and digitalized educational environment (Alenezi, 2021).

In supporting this transformation, Strategic Information Systems (SIS) play an important role as a strategic enabler that facilitates business process integration, cross-functional coordination, and effective information management. Strategic information systems enable organizations to establish interconnected digital ecosystems in real time, thereby improving operational efficiency, service quality, and data-driven decision-making capabilities (Nerbel & Kreutzer, 2023). In higher education institutions, SIS can be realized through the integration of academic, financial, human resource, research, and stakeholder service systems into a unified

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digital architecture. The implementation of Enterprise Resource Planning (ERP), Customer Relationship Management (CRM), and Single Sign-On (SSO) has become increasingly important in supporting such integration through the concepts of a single source of truth, system interoperability, and consistent user experiences (Fernández et al., 2023; Herold et al., 2023; Siuta-Tokarska et al., 2022).

Despite increasing investments in information technology in the higher education sector, many Higher Education Institutions (HEIs) continue to face various challenges in achieving effective digital transformation. Previous studies have identified problems such as information system fragmentation, low data interoperability, limited digital infrastructure, gaps in the digital competencies of human resources, resistance to organizational change, and insufficient alignment between digital initiatives and institutional strategic objectives (Mohamed Hashim et al., 2022; Nerbel & Kreutzer, 2023; Pashkov & Pashkova, 2022). These conditions indicate that the success of digital transformation is determined not only by technology adoption but also by an organization's ability to develop and utilize digital resources sustainably. Digital capability refers to an organization's ability to develop, integrate, and strategically utilize digital technologies to support innovation, organizational adaptation, and value creation (Wang et al., 2022). The literature indicates that SIS serves as a foundation for developing digital capability by providing technological infrastructure, data integration, and support for information-based decision-making processes (Esteve-Mon et al., 2023; Franco et al., 2021; Herold et al., 2023). From the perspective of Dynamic Capability, digital capability is viewed as an organizational ability to sense, seize, and transform in response to environmental changes driven by digital technologies (Ellström et al., 2022; Leso et al., 2024; Liboni et al., 2023; Miguel et al., 2022). Organizations with strong digital capabilities tend to be better positioned to utilize strategic information systems to improve operational effectiveness, accelerate decision-making, and support organizational change on a sustainable basis (Franco et al., 2021; Liboni et al., 2023). Thus, digital capability can be regarded as a mechanism that bridges the relationship between Strategic Information Systems and successful digital transformation, consistent with the view that successful digital transformation in higher education depends on an institution's ability to sustainably integrate digital technologies into academic and administrative processes (Laufer et al., 2021; Romero et al., 2021).

Although the literature on digital transformation in higher education has developed rapidly, significant research gaps remain. Most studies focus on the adoption of specific technologies or the digitalization of learning processes without providing a comprehensive understanding of how Strategic Information Systems contribute to the development of digital capability and how such capability supports digital transformation at the organizational level (Esteve-Mon et al., 2023; Pashkov & Pashkova, 2022; Ragazou et al., 2022). Furthermore, empirical evidence explaining the relationship between Strategic Information Systems, Digital Capability, and Digital Transformation in the context of higher education, particularly in developing countries, remains relatively limited (Lustosa Rosario et al., 2021; Mohamed Hashim et al., 2022; Yu et al., 2022; Yu & Moon, 2021). This gap highlights the need for research that can explain the mechanisms through which strategic information systems build organizational digital capabilities and drive comprehensive digital transformation.

Table 1 compares this study with prior studies from Malaysia, India, and Brazil. None explains, within a single institution, how an internally developed and integrated information systems ecosystem is associated with sensing, seizing, and transforming activities; this is the novelty addressed here.

Table 1. Research Gap Matrix

Study	Context and method	Key findings	Limitation	Gap addressed here
Esteve-Mon et al. (2023); Fernández et al. (2023); Mohamed Hashim et al. (2022)	Higher education; literature reviews and a conceptual model	Strategic elements, digital transformation initiatives, and a sustainable transformation model	No institution-level evidence on how systems build capability	Case-based capability mechanism through an integrated SIS ecosystem
Wildan Zulfikar et al. (2018)	Malaysia; single case study of a born-digital university	Changes to the learning value proposition	Centered on the learning offer, not on information systems	SIS integration and in-house capability
Goarty & Gupta (2025)	India; 23 administrators, thematic analysis	Six barriers to digital transformation	Barrier-oriented; administrators only	Enabling capability; developers and users as informants
Moraes et al. (2026)	Brazil; single case, documents and 8 interviews	Advanced digital maturity; staff, budget, and infrastructure challenges	Maturity assessment; no account of capability development	How in-house development builds capability
This study	Indonesia; exploratory single case (UPY)	See Results and Discussion	See Limitations	-

To address this research gap, this study explores the relationship between Strategic Information Systems, Digital Capability, and Digital Transformation through a case study of Universitas PGRI Yogyakarta (UPY). UPY was selected because it has an internally developed and managed information system ecosystem, integrated through Single Sign-On (SSO). In addition, system development is carried out using the Scrumban approach, which enables digital development and transformation processes to be implemented iteratively and adaptively.

Based on this background, this study seeks to answer the following research questions: (1) How do Strategic Information Systems contribute to the development of Digital Capability at Universitas PGRI Yogyakarta? (2) How does Digital Capability support the Digital Transformation process in the context of higher education? and (3) How does the integration of information systems within a higher education digital ecosystem facilitate organizational transformation and improve service quality?

In line with these research questions, the objective of this study is to analyze the role of Strategic Information Systems in developing Digital Capability and to explore how such capability supports Digital Transformation in higher education institutions. This study provides several contributions. From a theoretical perspective, it applies the Dynamic Capability lens to show how an internally developed and integrated information systems ecosystem is associated with sensing, seizing, and transforming activities in a university, and it offers exploratory propositions (P1-P4) that link Strategic Information Systems, Digital Capability, and Digital Transformation and can be tested in future research. From a practical perspective, this study provides insights for higher education leaders, information system managers, and policymakers in designing integrated digital ecosystems.

Theoretical Framework

This study adopts the Dynamic Capability perspective (Teece, 2007), preferred to the Resource-Based View and to absorptive capacity and institutional theory, because it explains how capabilities are built and renewed over time rather than how valuable resources are possessed, how external knowledge is assimilated, or how institutional pressures are met (Ellström et al., 2022). Sensing (identifying needs), seizing (mobilizing resources), and transforming (renewing work practices) are mapped to the findings in Table 7. Strategic Information Systems (SIS) are systems that support and help shape organizational strategy rather than merely automating operations (Peppard & Ward, 2016). Digital Capability is the ability to develop, integrate, and strategically use digital technologies (Wang et al., 2022), and Digital Transformation is a process of significant change in an organization's properties through combinations of information, computing, communication, and connectivity technologies (Vial, 2019). Value Chain Reconfiguration adapts Porter's (1985) value chain, with Bharadwaj et al. (2013), to academic services, research, finance, human resources, and stakeholder services. Institutional Outcomes (efficiency, service quality, and data-driven decisions) are kept separate from Digital Transformation, which is the change itself, and are treated as perceived outcomes. Customer Relationship Management (Payne & Frow, 2005; Buttle & Maklan, 2019) is not a construct in Figure 1; stakeholder services such as the tracer study are treated as one dimension of Value Chain Reconfiguration.

The arrows in Figure 1 follow an enabling logic: integrated systems supply the foundations for capability (Werder & Richter, 2022), capability turns technology into changed processes and services (Wang et al., 2022), and changed processes reconnect value chain activities through shared data. Digital Capability is treated as a mediating mechanism rather than a moderator or antecedent, because in the case it is described as developed through SIS and as the means through which transformation occurs; this role is interpreted analytically and not tested statistically. Four exploratory propositions guide the analysis. P1: Integrated SIS provide the foundation for digital capability. P2: Digital capability enables digital transformation through sensing, seizing, and transforming. P3: Digital transformation is reflected in value chain reconfiguration. P4: Reconfigured activities are associated with perceived outcomes that feed back into SIS development. Scrumban is a development methodology, not a construct; it is analyzed as an emergent practice through which seizing is exercised.

RESEARCH METHODS

Research Design

This study employs a qualitative approach using a case study method to explore the relationship between Strategic Information Systems (SIS), Digital Capability, and Digital Transformation in the context of higher education. The case study approach was selected because it enables an in-depth understanding of contemporary phenomena within real-world organizational settings, particularly when the boundaries between the phenomenon under investigation and its organizational context cannot be clearly separated (Yin, 2018). The exploratory analytical framework underlying this study, whose constructs are defined in the Theoretical Framework subsection, is presented in Figure 1. It is used to structure the analysis rather than to test causal relationships.

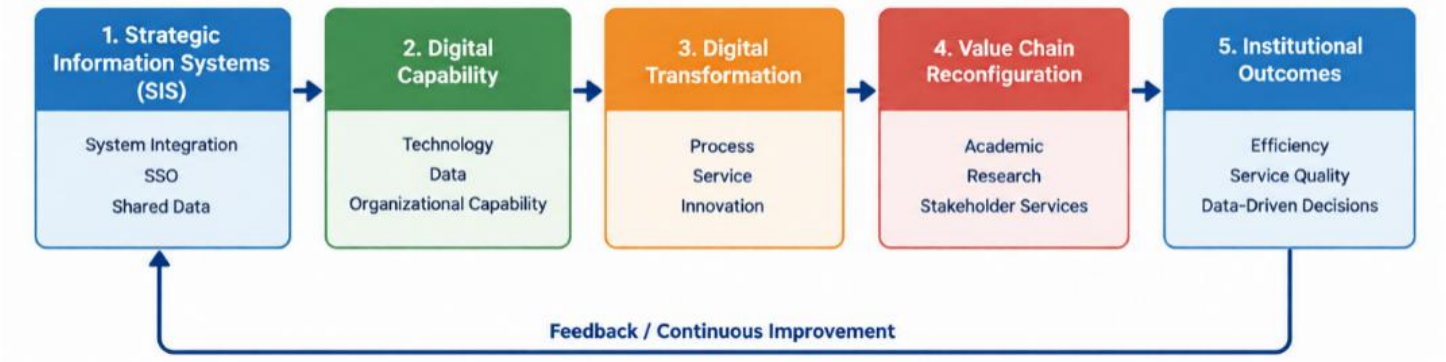


Figure 1. Exploratory Research Framework

Research Context and Case Selection

The study was conducted at Universitas PGRI Yogyakarta (UPY), a higher education institution that has developed and managed its information system ecosystem internally for more than a decade. UPY was selected because it has an integrated information system ecosystem connected through Single Sign-On (SSO), as described in the Results. The study was conducted from May to June 2026.

Data Collection

This study employed a combination of primary and secondary data. Primary data were collected through observations, semi-structured interviews, and insider inquiry. Six informants were selected using purposive sampling to represent the perspectives of system developers, academic staff, administrative staff, and end users. The selection criterion was direct involvement in developing, operating, or using at least one system of UPY's ecosystem: three developers (DEV1-DEV3), one academic staff member (AC1), one administrative staff member (AD1), and one student (EU1) (Table 2). Institutional leaders were not interviewed (see Limitations). Each interview lasted approximately 30 minutes and focused on the informants' experiences related to information system integration, digital capability development, and organizational digital transformation. In addition to interviews, the study employed an insider research approach, in which one of the researchers was a member of UPY's internal information system development team. This position provided access to system development processes, technology integration, and organizational dynamics. Data interpretations were triangulated across interviews, observations, and organizational documents and compared with relevant literature; potential insider bias is addressed in the Researcher Reflexivity subsection.

Secondary data were obtained from more than 30 organizational documents and artifacts, including system architecture documentation, SSO integration documents, system development reports, business process documentation, IT governance policies, Scrumban implementation documentation, tracer study reports, and academic and administrative documents. Data collection continued until thematic saturation was reached, indicated by the absence of significant new themes emerging from the final interview; given the small, role-based sample, saturation is understood here as saturation within the perspectives represented rather than across the whole institution.

Table 2. Interview Participants

Code	Role
DEV1	Information System Developer
DEV2	Database and Integration Developer
DEV3	System Architect and SSO Developer
AC1	Academic Staff
AD1	Administrative Staff
EU1	Student (End User)

Source: Primary data, processed (2026)

Table 3. Data Sources

Data Source	Type	Purpose
Interviews	Primary	Understanding stakeholder perspectives
Observation Notes	Primary	Understanding system usage
Insider Inquiry Records	Primary	Understanding system development processes
System Documents	Secondary	Understanding system architecture
Business Process Documents	Secondary	Understanding digital transformation
Academic Literature	Secondary	Supporting theoretical interpretation

Source: Primary and secondary data, processed (2026)

Data Analysis

The data were analyzed using thematic analysis, combining inductive and theory-driven coding. The analysis was conducted in stages through open coding, axial coding, and selective coding. In the initial stage, interview transcripts, observation notes, and organizational documents were analyzed to identify initial themes, including system integration, SSO implementation, user feedback, service efficiency, and organizational collaboration. The identified codes were subsequently grouped into broader categories corresponding to the research constructs, namely Strategic Information Systems, Digital Capability, Digital Transformation, Value Chain Reconfiguration, and Institutional Outcomes. In addition, Scrumban practice was identified as an emergent theme, and stakeholder engagement was coded as part of Value Chain Reconfiguration (stakeholder services). In the final stage, these categories were integrated into the exploratory framework to explain the relationships among the five constructs. The analysis was conducted manually using a documented coding protocol (no computer-assisted qualitative data analysis software, such as NVivo or ATLAS.ti, was used) and was iteratively verified through triangulation of interview data, observations, and organizational documents. Table 4 presents the coding structure and the source of each code. Theme frequencies are not reported because, with six role-based informants, counts would imply a statistical weight that an exploratory qualitative design cannot support; instead, every code in Table 4 is attributed to its informant or document source so that readers can trace how each theme was derived. Informant statements are reported as paraphrases attributed to informant codes rather than verbatim quotations, to protect the anonymity of a small sample whose roles are identifiable.

Table 4. Coding Structure and Audit Trail

Construct / Category	Open codes (source: informant code or documents)
Strategic Information Systems	SSO (DEV3; documents); cross-unit data consistency and reduced duplication (DEV1); data accuracy and accessibility (DEV2); API integration, shared database, and system interoperability (documents)
Digital Capability	Internal system development (DEV1, DEV2; documents); continuous system evaluation (DEV1); user feedback collection (DEV1, DEV2); development prioritized by institutional needs (DEV1); cross-unit collaboration and shared data access (AC1, AD1)
Digital Transformation	Faster and more transparent academic processes (AC1); automation of manual administrative processes (AD1); service efficiency (AC1, AD1); mobile services and notifications as suggested improvements (EU1)
Value Chain Reconfiguration	Integrated data flows replacing manual documentation (AD1); student data accessed through the integrated system (AC1); automatic payment validation, LPPM research management, and tracer study feedback (documents); stakeholder services: daily use and easier access (EU1)
Institutional Outcomes	Process efficiency (AC1, AD1); faster access to information (AC1); data-driven decision support (documents)
Emergent theme: Scrumban practice	Changing user requirements as a development challenge (DEV1); phased development oriented to user feedback (DEV1); priority setting through periodic evaluation and communication with work units (DEV2)

Note: 28 open codes; "documents" refers to system, SSO, development, and business process documents.
Source: Research data analysis (2026)

Research Trustworthiness

To enhance the quality of the research, four trustworthiness criteria proposed by Lincoln and Guba (1985) were applied.

Table 5. Trustworthiness Procedures

Criterion	Strategy
Credibility	Triangulation of interviews, observations, and documents
Dependability	Systematic coding procedures and documentation
Confirmability	Evidence-based interpretation and reflective notes
Transferability	Rich description of the organizational context

Source: Lincoln & Guba (1985), adapted

Triangulation was conducted by comparing data obtained from interviews, observations, insider inquiry, and organizational documents. This approach was intended to mitigate, but cannot eliminate, potential bias arising from the researcher's position as an insider researcher. The measures taken to manage that position are described below.

Researcher Reflexivity

One researcher (the first author) belongs to UPY's internal development team that builds the systems examined; he has served as head of information system development in the PPTIK unit for 3.5 years. This position provided access but risks favorable interpretation and socially desirable responses, particularly because three of the six informants (DEV1-DEV3) are on the same team and may have felt obliged to answer favorably to a senior colleague. To manage this, interpretations were triangulated across interviews, observations, and documents, three informants came from outside the team (AC1, AD1, EU1), and reflective notes were kept (Table 5). Residual bias is acknowledged in the Limitations.

RESULTS AND DISCUSSION

The results follow the five constructs of Figure 1, Scrumban practice and stakeholder services are reported as emergent themes, and risk management as an implication for practice.

Strategic Information Systems as a Strategic Foundation and Enabler of Digital Capability

The research findings show that Universitas PGRI Yogyakarta (UPY) has developed an integrated information systems ecosystem as the foundation for institutional digital transformation. The ecosystem consists of the Academic Information System (SIAKAD), financial system, personnel management system, research and community service system (LPPM), tracer study system, and mobile applications connected through a Single Sign-On (SSO) mechanism. DEV1 explained that system integration enables data to be used consistently across different units, reducing data duplication and improving work efficiency. Similarly, DEV2 stated that integrated systems make data more accurate and accessible to the units that need it. Meanwhile, DEV3 emphasized that SSO is an important foundation for building an integrated digital ecosystem because it allows users to access multiple services through a single account.

Table 6. Integrated Information Systems Ecosystem at UPY

System	Main Function	Strategic Role
SIAKAD	Academic administration	Integration of academic services
Financial System	Financial management	Transaction automation
Personnel Management System	Human resource management	Standardization of employee data
LPPM System	Research management	Research governance
Tracer Study	Alumni management	Stakeholder relations
SSO	Authentication integration	System interoperability

Source: Primary data, processed (2026)

From the perspective of Strategic Information Systems (SIS), the implementation of SSO functions as strategic infrastructure that supports system interoperability, data consistency, and business process integration. This is consistent with Werder & Richter (2022), who argue that information technology capabilities aligned with organizational strategy are important for developing digital capabilities. The ability of the internal team to independently develop and integrate systems demonstrates that the strategic benefits of information systems are derived not only from the technologies employed but also from the organization's ability to manage and utilize them.

Developing Digital Capability and the Emergent Role of Scrumban Practice

The implementation of integrated SIS has contributed to the development of Digital Capability at UPY. This capability is reflected in the organization's ability to independently develop, manage, and integrate various information systems through an internal development team. DEV1 explained that the team regularly evaluates the systems, collects user feedback, and develops systems based on institutional priorities. DEV2 added that user feedback is collected through user reports, discussions with work units, and periodic system evaluations.

In addition to technical capabilities, Digital Capability is also reflected in cross-unit collaboration. AC1 stated that integrated systems enable faster and more transparent access to academic data, while AD1 explained that coordination among units has improved because data can be accessed collectively. These findings indicate that Digital Capability at UPY is not solely technological but also encompasses managerial and organizational dimensions. Table 7 maps these findings to the sensing, seizing, and transforming dimensions of Dynamic Capability (Teece, 2007).

Table 7. Evidence of Digital Capability Mapped to Dynamic Capability Dimensions

Dimension	Manifestation at UPY	Supporting evidence
Sensing	Collecting user feedback through user reports, discussions with work units, and periodic evaluations; feedback through the tracer study	DEV1, DEV2; EU1
Seizing	Prioritizing and developing systems in phased, feedback-oriented cycles (Scrumban) by the internal team; integrating them through SSO and shared data	DEV1, DEV2, DEV3
Transforming	Renewing work practices through automation of manual administrative processes and integrated data flows (Table 8)	AC1, AD1

Source: Primary data, processed (2026)

Digital Transformation Practices at UPY

Digital transformation at UPY is not only realized through technology implementation but also through changes in how the organization develops and manages its information systems. The development team has adopted the Scrumban approach, which combines Scrum and Kanban principles to support iterative and adaptive system development. The interview findings indicate that changing user requirements are one of the main challenges in system development (DEV1). To address this challenge, the team applies a phased development approach oriented toward user feedback. DEV2 explained that periodic evaluations and communication with work units serve as the primary mechanisms for determining system development priorities. These findings suggest that the Digital Capability developed through SIS is reflected in digital transformation practices, one of which is the Scrumban approach.

This study shows that the Digital Capability developed through the implementation of SIS enables UPY to carry out digital transformation sustainably. This capability is reflected in the organization's ability to develop new digital services, integrate business processes, and respond more quickly to user needs through the Scrumban approach. This finding is consistent with the Dynamic Capability perspective, which emphasizes an organization's ability to sense, seize, and transform in response to changes in the digital environment (de Miguel et al., 2022). Scrumban is therefore treated in this study as an empirical practice through which the seizing dimension of Digital Capability is exercised at UPY. It is a software development methodology rather than a theoretical construct, and it is not part of the framework in Figure 1.

Value Chain Reconfiguration and Value Creation

The integration of information systems at UPY has changed the way various organizational activities are carried out. Processes that were previously separated and dependent on manual documentation are now connected through integrated data flows. The integration between SIAKAD and the financial system enables student payment validation to be performed automatically, while the LPPM system supports more structured research management. Interview findings support these changes. AD1 explained that document processing time has become faster and administrative errors have decreased following the implementation of digitalization. AC1 also stated that academic services have become more efficient because student data can be accessed through an integrated system.

Table 8. Value Chain Reconfiguration at UPY

Activity	Supporting System	Transformation Impact
Academic Services	SIAKAD + SSO	Faster academic services
Research	LPPM System	Improved research governance
Alumni	Tracer Study	Increased institutional feedback
Finance	Financial System	Transaction automation
Human Resources	Personnel Management System	Standardized personnel management

Source: Primary data, processed (2026)

One important implication of digital transformation at UPY is the reconfiguration of the value chain, as shown in Table 8. Value chain reconfiguration is thus a consequence of the organization's increased ability to utilize information in an integrated manner. Therefore, value chain reconfiguration can be viewed as one of the outcomes of the relationship between SIS, Digital Capability, and Digital Transformation.

Institutional Outcomes and Institutional Value Creation

This study did not measure competitive advantage or competitive performance, and no comparative or benchmark data were collected. The findings are therefore interpreted as institutional value creation as reported by informants, not as evidence of competitiveness. Informants reported that the integration of digital services

improves process efficiency, accelerates access to information, and supports data-driven decision-making. This finding supports the view that the strategic benefits of technology do not arise directly from information system implementation but through the development of Digital Capability that enables organizations to create value sustainably. Thus, Digital Capability can be viewed as a mechanism linking technology investments to perceived improvements in institutional outcomes, a relationship that should be tested with performance indicators in future research.

Stakeholder Services and User Experience

Stakeholder services, including the tracer study and the digital services through which the institution interacts with students and alumni, are treated here as one dimension of Value Chain Reconfiguration rather than as a separate construct (Payne & Frow, 2005); the evidence comes mainly from one informant (EU1) and is tentative. The Customer Relationship Management (CRM) function at UPY is realized through the tracer study system and digital services that support interactions with students and alumni. From the end-user perspective, EU1 stated that information systems are used almost every day for various academic activities, such as course registration, viewing class schedules, and accessing grades. In addition, EU1 suggested developing notification features and mobile services as improvements to the user experience.

The integration of digital services through SSO and mobile applications strengthens the engagement of students and alumni as key stakeholders. These findings suggest that information systems not only support internal organizational processes but also improve service quality, user experience, and the institution's relationships with its stakeholders.

Implications for Practice: Risk Management and Sustainability of Digital Transformation

This subsection reflects the authors' interpretation rather than interview data. Digital transformation also introduces challenges that need to be managed continuously. In the context of UPY, the use of integrated systems requires risk management covering data security, system reliability, and the continuity of digital services, which can be guided by IT governance frameworks such as COBIT 2019 (ISACA, 2018) and ISO/IEC 38500 (ISO/IEC, 2015). This suggests that the success of digital transformation depends not only on technology implementation but also on the organization's ability to manage risks and ensure the sustainability of the digital ecosystem that has been established.

Theoretical Implications

The findings are consistent with, and reinforce, the Dynamic Capability framework (Teece, 2007) in a higher education setting: sensing, seizing, and transforming are each identifiable (Table 7). Sensing and seizing are carried out largely through an in-house ecosystem, so capability resides in the team's routines rather than in acquired technology. As a single exploratory case, the findings illustrate rather than test or challenge the framework. Unlike the barriers reported in India (Goarty & Gupta, 2025) or the staff and budget shortages in a Brazilian federal institution that partly contracts companies to build systems (Moraes et al., 2026), UPY informants described an in-house team that develops and integrates the systems. This suggests, without generalizing, that in-house development may build capability and reduce vendor dependence.

CONCLUSIONS AND SUGGESTIONS

Conclusions

The implementation of Strategic Information Systems (SIS) at Universitas PGRI Yogyakarta demonstrates that an integrated information systems ecosystem consisting of SIAKAD, the financial system, personnel management system, LPPM system, Tracer Study, and Single Sign-On (SSO) architecture can serve as a strategic foundation for developing organizational digital capabilities. These capabilities subsequently support sustainable digital transformation (with Scrumban as the agile practice observed in the case), facilitate business process integration, and enable value chain reconfiguration that is reported by informants to improve operational efficiency and service quality and to contribute to institutional value creation. The empirical findings provide exploratory support for the analytical framework linking Strategic Information Systems, Digital Capability, Digital Transformation, value chain reconfiguration, and institutional outcomes. The results suggest that the contribution of information systems to institutional outcomes does not occur directly, but rather through the development of digital capabilities and organizational transformation processes that enable sustainable value creation. One important finding is the role of internal capabilities in determining the success of digital transformation. In-house system development enables the organization to build contextual technical competencies and institutional knowledge, increase flexibility in responding to change, and reduce dependence on external vendors.

Limitations

This study has limitations. It is a single case with six informants, three of them developers; institutional leaders (rector, ICT head, deans) were not interviewed, so the strategic perspective is captured only through documents, and the findings and framework are exploratory. The researcher's insider position and overlap with three informants may have shaped interpretation despite the measures described. Evidence on stakeholder services rests mainly on one informant, and risk management is an implication rather than a finding. No competitive performance or comparative data (rankings, accreditation, enrollment, satisfaction surveys) were collected, so competitiveness claims are outside the scope of this study. Data were collected over a short period (May to June 2026).

Suggestion

From a theoretical perspective, these findings contribute to the literature on Strategic Information Systems and digital transformation by illustrating, through the Dynamic Capability lens (Teece, 2007), how an internally developed and integrated information systems ecosystem is associated with sensing, seizing, and transforming activities, and by offering exploratory propositions (P1-P4) for future testing. From a practical perspective, higher education institutions seeking to develop an integrated digital ecosystem are encouraged to strengthen internal capabilities, continuously develop their information systems, and implement adaptive digital governance. Future research is recommended to expand the research context through comparative studies across higher education institutions or to examine the relationships among the constructs in the proposed exploratory framework using quantitative approaches to obtain broader validation. Future studies should include institutional leaders and performance indicators before testing any claim regarding competitiveness.

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Integrasi IoT, GIS, dan AI untuk Pemantauan Hutan Cerdas Perhutani

(Integration of IoT, GIS, and AI for Perhutani's Smart Forest Monitoring)

Muhamad Sabri Ahmad[1], Moh. Syadad Mahiri[2]
[1] msabri@unkhair.ac.id; [2] sadadalmahiri@gmail.com
[1] informatika, Fakultas Teknik, Universitas Khairun, Indonesia
[2] Sekretaris Dewan Eksekutif Daerah (DED) Jaringan Pemantau Independen Kehutanan (JPIK) Jawa Timur
[1] ORCID ID[1]: 000-0003-4125-2792

Abstract

Perhutani's digital transformation has been supported by the use of geospatial information systems for collecting, centralizing, and presenting forest management information. However, geospatial systems do not yet automatically provide continuous microclimate monitoring, multimodal risk analysis, and early warning directly connected to field personnel follow-up. This study aims to design a smart forestry technology framework that integrates *Internet of Things* (IoT) sensors, *Long Range* (LoRa) communication, Geographic Information Systems (GIS), satellite imagery and Unmanned Aerial Vehicles (UAVs), as well as Artificial Intelligence (AI) for forest health monitoring and early detection of fire risks in areas managed by Perhutani. The study employs a *design science research* approach through requirements analysis, architectural design, risk score modeling, simulation based on the data range of the *UCI Forest Fires* dataset, and the development of evaluation indicators. The novelty of this study lies in integrating Perhutani's GIS with low-power environmental monitoring, multimodal risk assessment, and field personnel validation within a closed-loop operational cycle. The simulation results show that the average risk score increases from 0.148 for the low-risk category to 0.870 for the critical-risk category. The proposed framework provides a measurable foundation for pilot testing and calibration using local Perhutani data.

Keywords: smart forestry; Internet of Things; Geographic Information System; artificial intelligence; Perhutani.

Abstrak

Transformasi digital Perhutani telah ditopang oleh pemanfaatan sistem informasi geospasial untuk pengumpulan, pemusatan, dan penyajian informasi pengelolaan hutan. Namun, sistem geospasial belum secara otomatis menyediakan pemantauan mikroklimat secara kontinu, analisis risiko multimodal, dan peringatan dini yang terhubung langsung dengan tindak lanjut petugas. Penelitian ini bertujuan merancang kerangka teknologi hutan cerdas yang mengintegrasikan sensor *Internet of Things* (IoT), komunikasi *Long Range* (LoRa), Sistem Informasi Geografis (GIS), citra satelit dan wahana udara nirawak (UAV), serta kecerdasan buatan (AI) untuk pemantauan kesehatan hutan dan deteksi dini risiko kebakaran pada kawasan yang dikelola Perhutani. Penelitian menggunakan pendekatan *design science research* melalui analisis kebutuhan, perancangan arsitektur, pemodelan skor risiko, simulasi berbasis rentang data *UCI Forest Fires*, dan penyusunan indikator evaluasi. Kebaruan penelitian terletak pada integrasi GIS Perhutani dengan pemantauan lingkungan berdaya rendah, penilaian risiko multimodal, dan validasi petugas dalam satu siklus operasional tertutup. Hasil simulasi menunjukkan skor rata-rata meningkat dari 0,148 pada kategori rendah menjadi 0,870 pada kategori kritis. Kerangka yang diusulkan memberikan dasar terukur untuk uji percontohan dan kalibrasi menggunakan data lokal Perhutani.

Kata kunci: kehutanan cerdas; Internet of Things; sistem informasi geografis; kecerdasan buatan; Perhutani.

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Corresponding Author/Korespondensi Penulis:
Author's Full Name
Study Programs, Faculties, Universities
University Address
Email: ----------@-----.---

PENDAHULUAN

Transformasi digital di bidang kehutanan tidak lagi berhenti pada pemetaan dan penyimpanan data. Perkembangannya bergerak menuju kehutanan cerdas (*smart forestry*), yaitu pengelolaan yang memadukan

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sensor, konektivitas, komputasi, kecerdasan buatan, dan sistem pendukung keputusan. Sensor lapangan dan jaringan *Internet of Things* (IoT) memungkinkan kondisi hutan diamati secara berkala atau kontinu, sedangkan AI membantu menyaring data menjadi informasi yang lebih mudah digunakan dalam pengambilan keputusan (Ehrlich-Sommer et al., 2024; Damaševičius et al., 2024; Wang et al., 2025; Zhao et al., 2023).

Dalam konteks Perhutani, pengembangan tersebut tidak dimulai dari nol. Perum Perhutani telah memanfaatkan Perhutani *Digital Forest* berbasis ArcGIS untuk mendukung pengumpulan data lapangan, pemusatan informasi, dan penyajian data melalui *dashboard*. Pemanfaatan drone di lingkungan Perhutani juga menunjukkan bahwa teknologi spasial telah digunakan untuk inventarisasi, pemantauan kawasan, dan pengawasan areal kerja. Karena fondasi GIS sudah tersedia, persoalan yang lebih penting bukan lagi sekadar digitalisasi peta, melainkan bagaimana data spasial tersebut dapat dipadukan dengan pemantauan lapangan dan analitik risiko secara lebih cepat dan operasional (Perum Perhutani, 2022; Esri Indonesia, 2022; Perum Perhutani, 2025).

Pemantauan hutan memerlukan data yang berbeda dari sisi cakupan ruang dan frekuensi waktu. Penginderaan jauh dan LiDAR efektif untuk menggambarkan struktur tegakan, perubahan tutupan, dan karakteristik vegetasi pada wilayah yang luas, tetapi hasilnya tetap dipengaruhi oleh resolusi sensor, waktu perekaman, kondisi atmosfer, dan kebutuhan verifikasi lapangan. Deret waktu Sentinel-1/2 menunjukkan potensi untuk memperkuat pemetaan vegetasi, sedangkan data VIIRS telah digunakan di Indonesia untuk mendukung pemantauan titik panas dan verifikasi kejadian kebakaran (Tan et al., 2025; Indradjad et al., 2024).

Pada skala tapak, sensor IoT dapat melengkapi penginderaan jauh dengan menyediakan data mikroklimat berfrekuensi tinggi. Jaringan berdaya rendah seperti LoRa/LoRaWAN dan LPWAN relevan untuk kawasan hutan yang tidak seluruhnya memiliki infrastruktur komunikasi stabil. Parameter yang dapat diamati mencakup suhu, kelembapan, kondisi bahan bakar permukaan, gas, partikulat, dan indikator lingkungan lain yang berkaitan dengan risiko kebakaran. Sejumlah penelitian telah menunjukkan bahwa sensor, IoT, dan *model machine learning* dapat digunakan bersama untuk membangun indikasi awal terhadap perubahan kondisi lingkungan (Sendra et al., 2020; Zhao et al., 2023; Mahaveerakannan et al., 2023; Üremek et al., 2024).

Peran AI kemudian memperluas fungsi pemantauan dari pencatatan kondisi menuju deteksi dan prediksi. *Model machine learning* telah digunakan untuk diagnosis risiko kebakaran, sementara *deep learning* banyak diterapkan pada citra untuk mendeteksi asap atau api dan memperkirakan tingkat bahaya. Pemrosesan pada perangkat *edge* dapat mengurangi kebutuhan pengiriman data mentah dan menekan latensi, sedangkan UAV dapat digunakan untuk memeriksa lokasi yang sulit dijangkau atau memerlukan konfirmasi visual (Roh et al., 2024; Huang et al., 2024; Yang et al., 2024; Ramadan et al., 2024).

Meskipun teknologi tersebut berkembang cepat, penerapan di lapangan masih menghadapi persoalan yang tidak selalu terlihat dari nilai akurasi *model*. Sumber data yang beragam perlu disatukan, jaringan harus tetap andal, keluaran AI harus dapat dipahami, dan *model* yang baik di satu lokasi belum tentu memberikan hasil yang sama di wilayah lain. Selain itu, sistem perlu mengikuti cara kerja organisasi agar informasi yang dihasilkan benar-benar berujung pada tindakan. Tinjauan terbaru di bidang kehutanan menempatkan interoperabilitas, kualitas data, generalisasi *model*, kapasitas komputasi, interpretabilitas, dan validasi lapangan sebagai persoalan penting dalam penerapan AI dan IoT (Giannakidou et al., 2024; Amoah-Nuamah et al., 2025; Forkuo et al., 2026; FAO, 2026).

Dari kondisi tersebut terlihat celah penelitian yang lebih spesifik. Belum banyak kajian yang menempatkan GIS Perhutani yang telah berjalan sebagai pusat integrasi data sensor mikroklimat, komunikasi LoRa/LPWAN, citra UAV atau satelit, analitik AI, dan verifikasi petugas dalam satu alur kerja yang utuh. Penelitian terdahulu umumnya kuat pada satu bagian, misalnya komunikasi sensor, deteksi asap, prediksi bahaya, pemetaan citra, atau UAV. Kebutuhan operasional Perhutani justru berada pada hubungan antarbagian tersebut: data harus diterima, dianalisis, dipetakan, diterjemahkan menjadi prioritas, kemudian diperiksa di lapangan. Dengan demikian, gap penelitian terletak pada keterputusan antara *sensing*, analitik, konteks spasial, dan tindakan operasional (Sendra et al., 2020; Huang et al., 2024; Tan et al., 2025; Forkuo et al., 2026).

Kebaruan penelitian ini berupa Perhutani Smart Forest Early-Warning Framework, yaitu rancangan arsitektur *closed-loop* yang menghubungkan data GIS dan inventarisasi yang sudah tersedia dengan sensor IoT berdaya rendah, citra satelit dan UAV, analitik risiko multimodal, *dashboard* GIS, serta verifikasi petugas lapangan. Hasil verifikasi tidak berhenti sebagai laporan, tetapi dikembalikan ke basis data untuk memperbaiki ambang dan *model* pada tahap berikutnya. Karena itu, kebaruan penelitian bukan terletak pada penciptaan sensor atau algoritma baru, melainkan pada rancangan integrasi yang disesuaikan dengan fondasi digital dan kebutuhan kerja Perhutani.

Penelitian ini menjawab tiga pertanyaan: bagaimana integrasi IoT, GIS, penginderaan jauh, dan AI dapat dirancang untuk konteks pengelolaan hutan Perhutani; bagaimana data dari beberapa sumber dapat diubah

menjadi prioritas risiko spasial yang tetap dapat diverifikasi; dan indikator apa yang perlu digunakan dalam uji percontohan. Tujuannya adalah menghasilkan arsitektur sistem, alur data, *model* penilaian risiko, dan kerangka evaluasi yang dapat digunakan sebagai dasar pengembangan prototipe. Manfaat yang diharapkan ialah meningkatnya ketepatan pemantauan, kecepatan deteksi anomali, prioritas patroli atau inspeksi, dan ketertelusuran tindak lanjut tanpa mengurangi peran pertimbangan profesional petugas kehutanan.

METODOLOGI PENELITIAN

Penelitian ini menggunakan pendekatan *design science research* karena keluaran utama yang dibangun berupa artefak konseptual: arsitektur sistem, alur data, mekanisme penilaian risiko, dan rancangan evaluasi untuk pemantauan hutan cerdas Perhutani. Proses penelitian dilakukan melalui tujuh tahap yang saling berurutan, yaitu identifikasi masalah, penetapan kebutuhan, perancangan arsitektur, pemilihan parameter dan sumber data, penyusunan model skoring, simulasi menggunakan data publik, serta penyusunan indikator uji percontohan. Pendekatan ini sengaja dipilih agar penelitian tetap membedakan antara hasil perancangan dan bukti efektivitas lapangan yang baru dapat diperoleh setelah implementasi pada wilayah Perhutani.

Perumusan kebutuhan dimulai dari kondisi eksisting Perhutani yang telah memiliki fondasi *GIS* dan praktik pengumpulan data lapangan. Kebutuhan teknologi kemudian dipetakan dari literatur *smart forestry*, *IoT* kehutanan, *remote sensing*, *LiDAR*, *UAV*, kesehatan hutan, serta deteksi dan prediksi kebakaran. Hasil pemetaan digunakan untuk menentukan fungsi yang benar-benar diperlukan oleh sistem, keterkaitan antarlapisan, kebutuhan interoperabilitas, serta data minimum yang harus tersedia. Literatur dipakai sebagai dasar penetapan kebutuhan, bukan sebagai pengganti data lapangan Perhutani.

Kebutuhan fungsional dibagi menjadi enam kelompok: penginderaan lingkungan, komunikasi data, integrasi geospasial, analitik risiko, dukungan keputusan, dan validasi lapangan. Kebutuhan nonfungsional meliputi efisiensi energi, ketahanan terhadap gangguan jaringan, ketertelusuran data, keamanan akses, interoperabilitas, kemudahan penggunaan, serta kemampuan bekerja mendekati waktu nyata. Arsitektur dirancang modular agar setiap lapisan dapat diuji secara bertahap pada satu petak atau satu Kesatuan Pemangkuan Hutan sebelum diterapkan pada cakupan yang lebih luas.

Pada lapisan penginderaan, variabel utama yang dipertimbangkan adalah suhu udara, kelembapan relatif, kelembapan tanah atau bahan bakar permukaan, tekanan udara, serta gas atau partikulat yang berkaitan dengan indikasi pembakaran. Penempatan sensor dirancang berbasis prioritas, bukan seragam, dengan mempertimbangkan vegetasi, topografi, akses manusia, dan riwayat gangguan. Pada lokasi yang memiliki nilai risiko lebih tinggi, node dapat dilengkapi kamera *edge* atau sensor optik. Data titik tersebut selanjutnya dipadukan dengan data cuaca, riwayat kejadian, *hotspot*, serta citra satelit dan *UAV* untuk memperkuat konteks spasial.

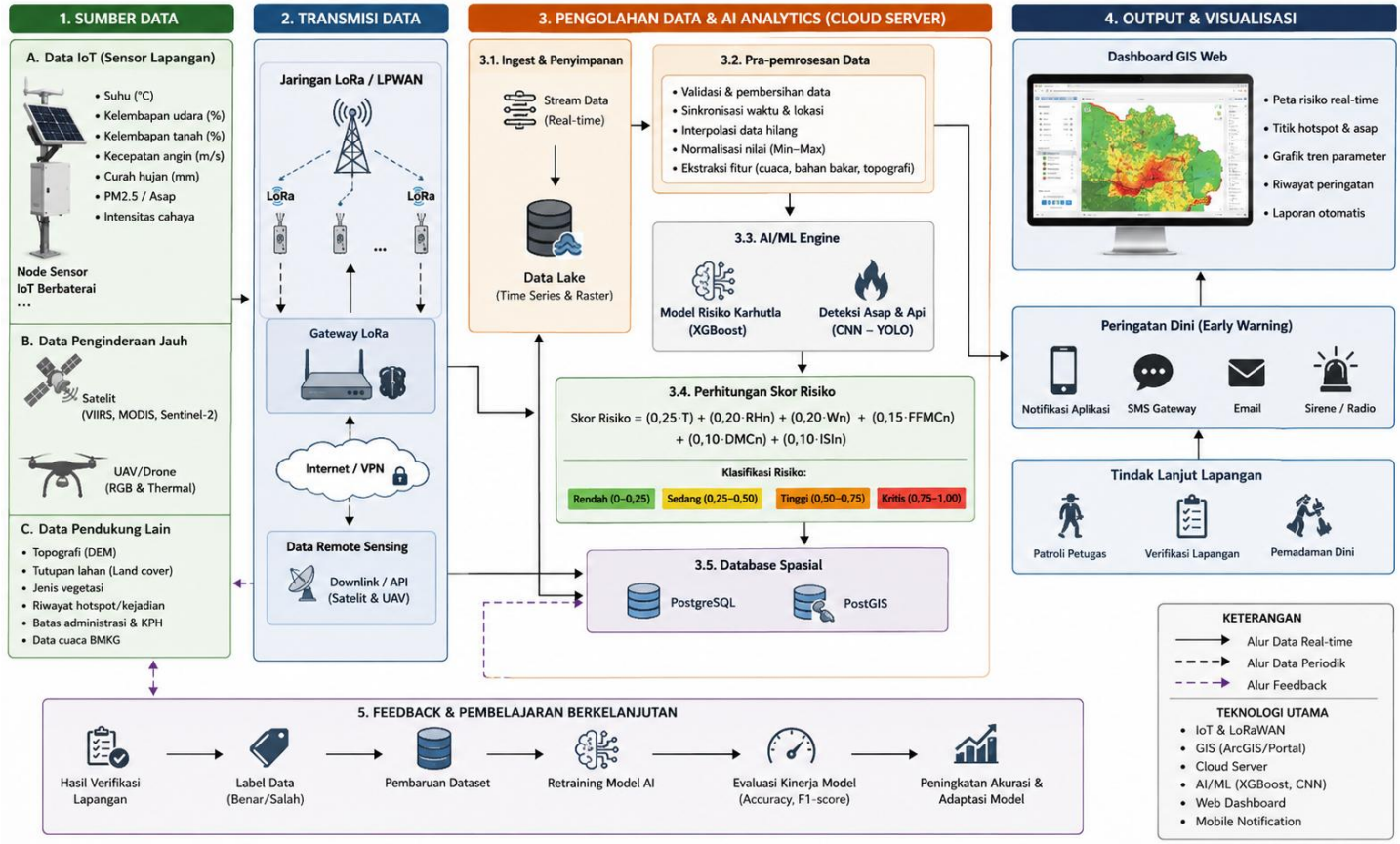
Komunikasi antarnode dirancang menggunakan *LoRa/LoRaWAN* atau *LPWAN* setara karena kebutuhan dayanya rendah dan sesuai untuk pengiriman paket data berukuran kecil. Gateway meneruskan data ke *server* melalui jaringan yang tersedia. Untuk lokasi dengan konektivitas tidak stabil, mekanisme *store-and-forward* digunakan agar data tidak hilang ketika jaringan terputus. Setiap rekaman membawa waktu, koordinat, identitas perangkat, status baterai, dan indikator kualitas sinyal sehingga sistem dapat membedakan perubahan lingkungan dari gangguan perangkat.

Analitik risiko dibangun melalui fusi data *multimodal*. Tahap pertama melakukan *screening* terhadap perubahan temporal, misalnya kenaikan suhu, penurunan kelembapan, atau anomali sensor. Tahap kedua menggabungkan informasi tersebut dengan variabel spasial seperti topografi, tutupan lahan, indeks vegetasi, *hotspot*, jarak dari akses, dan hasil interpretasi *UAV*. Pada tahap awal, model yang relatif mudah dijelaskan seperti *Random Forest* atau *gradient boosting* lebih sesuai dibanding model yang sangat kompleks. Keluaran sistem tidak hanya berupa kelas risiko, tetapi juga skor, lokasi, faktor dominan, tingkat keyakinan, dan rekomendasi verifikasi agar *AI* tetap berfungsi sebagai *decision support*.

Untuk menguji perilaku model sebelum tersedia data lapangan Perhutani, simulasi menggunakan rentang variabel UCI Forest Fires. Enam variabel yang digunakan ialah suhu, kelembapan relatif, kecepatan angin, FFMC, DMC, dan ISI. Setiap variabel dinormalisasi ke rentang 0-1. Suhu, angin, FFMC, DMC, dan ISI menggunakan normalisasi positif, sedangkan kelembapan relatif menggunakan normalisasi terbalik. Skor risiko dihitung dengan R = 0,20N_suhu + 0,15N_RH(inv) + 0,15N_angin + 0,20N_FFMC + 0,15N_DMC + 0,15N_ISI. Bobot tersebut digunakan sebagai konfigurasi awal untuk menguji konsistensi mekanisme skoring, bukan sebagai bobot operasional Perhutani. Skor kemudian dikelompokkan menjadi rendah (R < 0,25), sedang (0,25 <= R < 0,50), tinggi (0,50 <= R < 0,75), dan kritis (R >= 0,75).

Evaluasi uji percontohan dirancang pada dua tingkat. Evaluasi teknis mencakup ketersediaan node, *packet delivery ratio*, *latency* sensor-ke-*dashboard*, akurasi koordinat, kelengkapan data, serta *precision*, *recall*, F1, dan *false-positive rate* sesuai tugas model. Evaluasi operasional mencakup waktu dari *alert* hingga verifikasi, proporsi *alert* yang ditindaklanjuti, konsistensi pencatatan hasil pemeriksaan, dan perubahan kinerja setelah *feedback* petugas dimasukkan ke sistem. Untuk keluaran probabilistik, *calibration* juga perlu diperiksa agar skor probabilitas mencerminkan frekuensi kejadian aktual.

Alur metodologi penelitian yang digunakan dalam artikel ini disajikan pada Gambar 1.



Gambar 1. Metodologi Penelitian

HASIL DAN PEMBAHASAN

Arsitektur Perhutani Smart Forest Early-Warning Framework

Hasil perancangan menghasilkan arsitektur enam lapis yang menempatkan *GIS* Perhutani sebagai pusat integrasi. Lapisan penginderaan menangkap perubahan mikroklimat dan indikasi gangguan; lapisan komunikasi mengirimkan data dari node menuju *gateway* dan *server*; lapisan integrasi menyatukan sensor dengan basis data spasial, inventaris, cuaca, citra satelit, dan *UAV*; lapisan analitik menghasilkan deteksi anomali dan skor risiko; lapisan *decision support* menerjemahkan hasil analitik menjadi prioritas lokasi; sedangkan lapisan validasi mencatat hasil pemeriksaan petugas sebagai umpan balik. Susunan ini penting karena nilai sistem tidak berasal dari satu teknologi, melainkan dari kesinambungan aliran data sampai menjadi tindakan yang dapat ditelusuri.

Setiap teknologi mengisi kekosongan yang tidak dapat ditangani oleh teknologi lain. *IoT* memberikan resolusi waktu yang tinggi pada titik pengamatan, sementara satelit menyediakan cakupan luas tetapi dengan interval akuisisi tertentu. *UAV* memberikan detail pada area prioritas, *GIS* menyatukan posisi dan aset, dan *AI* membantu menyaring volume data menjadi urutan pemeriksaan. Dengan rancangan modular, penggantian sensor, metode komunikasi, atau model analitik tidak harus mengubah seluruh arsitektur. Karakter ini membuat kerangka lebih realistis untuk diuji pada kondisi KPH yang berbeda.

Tabel 1. Komponen arsitektur dan fungsi utama kerangka yang diusulkan

Lapisan	Teknologi/komponen	Fungsi utama
Sensing	Sensor suhu, RH, kelembapan tanah/bahan bakar, gas/partikulat, kamera opsional	Merekam kondisi lokal dan anomali secara kontinu
Komunikasi	LoRa/LoRaWAN, *gateway*, seluler/*backhaul*	Mengirim data dengan konsumsi daya rendah dan mekanisme *store-and-forward*
Integrasi geospasial	GIS, basis data spasial, API/ETL	Menyatukan sensor, inventaris, cuaca, topografi, satelit, UAV
Analitik AI	*Anomaly detection*, *Random Forest*/*XGBoost*, *model* citra	Menghasilkan probabilitas atau kelas risiko dan faktor dominan
Decision support	*Dashboard* GIS, peta prioritas, notifikasi	Mengubah keluaran analitik menjadi lokasi dan tugas yang dapat ditindaklanjuti
Validasi lapangan	Aplikasi petugas, foto/geotag, status tindak lanjut	Memastikan kejadian, menutup *alert*, dan menyediakan label untuk pembelajaran ulang

Gap Riset dan Posisi Kontribusi

Perbandingan dengan penelitian terdahulu menunjukkan bahwa kontribusi utama artikel ini berada pada tingkat integrasi operasional. Sebagian penelitian menghasilkan model deteksi, jaringan sensor, atau metode pemetaan yang baik, tetapi belum selalu menjelaskan bagaimana hasil model masuk ke alur pemeriksaan lapangan. Kajian terbaru juga menempatkan generalisasi model, interpretabilitas, kualitas data, interoperabilitas, dan validasi lapangan sebagai hambatan penting dalam penerapan *AI* kehutanan (Forkuo et al., 2026; Amoah-Nuamah et al., 2025; Food and Agriculture Organization of the United Nations, 2026). Karena itu, posisi kontribusi penelitian ini bukan menggantikan teknologi yang telah ada, melainkan menghubungkannya dalam satu proses yang dapat diuji dan diaudit.

Tabel 2. Perbandingan fokus penelitian terdahulu dan kontribusi artikel

Aspek	Kecenderungan penelitian terdahulu	Kontribusi artikel ini
GIS	Pemetaan, inventaris, *dashboard* dan analisis spasial	GIS Perhutani diposisikan sebagai *backbone* integrasi dan orkestrasi *alert*
IoT	Monitoring parameter lokal atau deteksi kebakaran	IoT dihubungkan dengan konteks spasial, *remote sensing*, dan tindak lanjut lapangan
AI	Klasifikasi/prediksi pada *dataset* tertentu	AI sebagai *risk scoring* multimodal yang disertai faktor dominan dan human validation
UAV/satelit	Deteksi/pemetaan skala luas atau detail lokal	Digunakan adaptif: satelit untuk *screening*, UAV untuk verifikasi area prioritas
Operasional	Sering berhenti pada performa algoritma/prototipe	*Closed-loop* dari *sensing* → analitik → tugas lapangan → label balik ke sistem
Evaluasi	Akurasi *model* dominan	Ditambah *latency*, reliabilitas *node*, *false alarm*, respons petugas, dan *traceability*

Skema Penilaian Risiko Multimodal

Penilaian risiko dua tahap digunakan untuk menjaga keseimbangan antara kecepatan dan kedalaman analisis. Screening awal berfungsi menangkap perubahan yang memerlukan perhatian, sedangkan pemodelan tahap kedua menambahkan konteks spasial dan historis. Pendekatan ini menghindari penggunaan model kompleks pada seluruh aliran data sekaligus, sekaligus memberi jejak penjelasan mengenai faktor yang menyebabkan suatu lokasi memperoleh skor lebih tinggi. Dalam praktiknya, keluaran tersebut lebih berguna bagi petugas dibanding satu label risiko tanpa alasan yang dapat ditelusuri.

Penggunaan *UAV* atau kamera *edge* ditempatkan sebagai pemeriksaan lanjutan, bukan sebagai sumber data yang harus aktif terus-menerus. Aktivasi berdasarkan skor risiko dapat menghemat energi, bandwidth, dan waktu inspeksi. Strategi ini juga mengurangi ketergantungan pada satu modalitas: sensor numerik dapat memberi sinyal awal, citra memberi bukti visual, sedangkan petugas memastikan kondisi sebenarnya. Kombinasi tersebut penting karena asap, suhu tinggi, atau anomali sensor masing-masing dapat menghasilkan false alarm apabila dipakai secara terpisah.

Empat tingkat risiko digunakan untuk menerjemahkan skor menjadi tindakan. Kategori rendah tidak memerlukan intervensi selain pemantauan rutin; kategori sedang memerlukan pengamatan lebih dekat; kategori tinggi memerlukan verifikasi berbasis citra atau pemeriksaan jarak jauh; dan kategori kritis menjadi prioritas pemeriksaan lapangan sesuai SOP. Ambang 0,25, 0,50, dan 0,75 pada simulasi hanya berfungsi sebagai batas demonstratif. Pada implementasi nyata, ambang harus diturunkan dari data lokal dan mempertimbangkan biaya false alarm serta konsekuensi keterlambatan deteksi.

Simulasi Berbasis Dataset Publik dan Hasil Perhitungan

Simulasi menggunakan UCI Forest Fires dipakai untuk memeriksa konsistensi model matematis, bukan untuk menilai akurasi sistem pada kawasan Perhutani. Dataset tersebut berisi 517 observasi dengan variabel meteorologi dan Indeks Cuaca Kebakaran, termasuk suhu, kelembaban relatif, kecepatan angin, FFMC, DMC, dan ISI (Cortez & Morais, 2007). Karena sumber data berasal dari Montesinho, Portugal, dataset hanya digunakan sebagai acuan rentang numerik. Pemisahan fungsi ini penting agar hasil simulasi tidak disimpan sebagai bukti kinerja lapangan pada ekosistem yang berbeda.

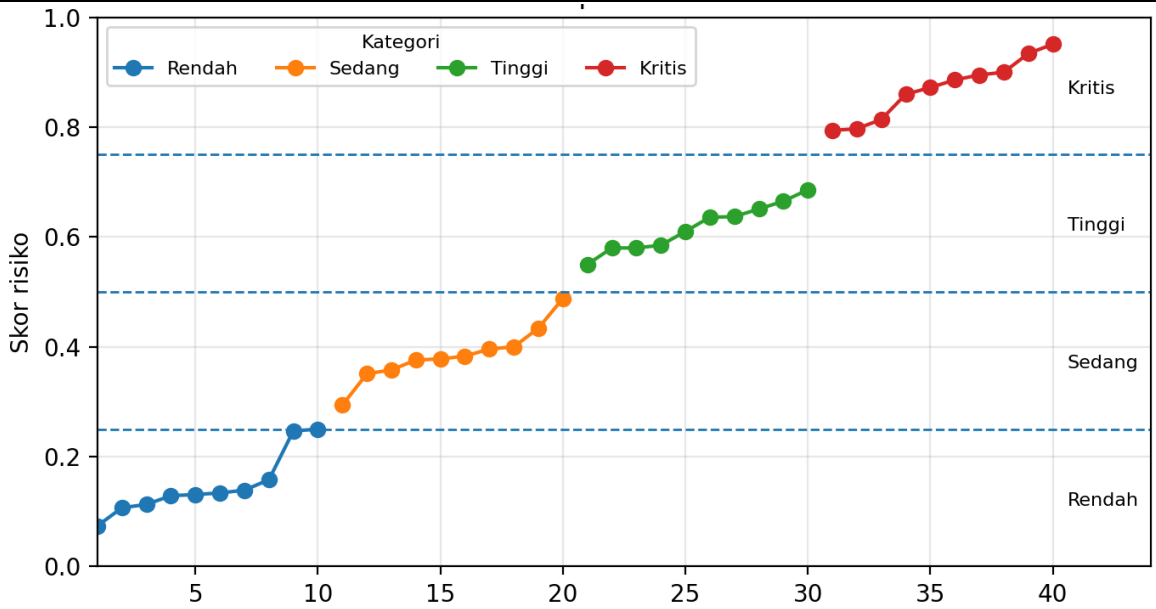
Dari rentang tersebut terbentuk 40 skenario sintetis yang dibagi merata ke dalam empat kategori risiko. Penyusunan skenario dilakukan terkontrol agar perubahan skor dapat diamati ketika suhu, angin, FFMC, DMC, dan ISI meningkat sementara kelembaban relatif menurun. Dengan rencana ini, simulasi digunakan sebagai uji logika internal: apabila kombinasi kondisi yang secara konseptual lebih kering dan lebih mendukung penyebaran api tidak menghasilkan skor lebih tinggi, maka formulasi bobot perlu ditinjau ulang sebelum digunakan pada uji percontohan.

Hasil normalisasi dan pembobotan menghasilkan klasifikasi kategori yang konsisten. Rata-rata skor bergerak dari 0,148 pada kategori rendah, 0,386 pada kategori sedang, 0,618 pada kategori tinggi, hingga 0,870 pada kategori kritis. Pola tersebut tidak membuktikan kemampuan prediksi terhadap kejadian kebakaran, tetapi menunjukkan bahwa formula merespons perubahan variabel sesuai arah yang dirancang. Dengan kata lain, simulasi memvalidasi perilaku pemeliharaan, bukan validitas ekologis atau akurasi model operasional.

Tabel 3. Ringkasan hasil olahan 40 skenario berbasis rentang UCI Forest Fires

Kategori	n	Suhu (°C)	RH (%)	Angin (km/jam)	FFMC	DMC	ISI	Skor R
Rendah	10	6,65	88,40	1,84	30,79	41,50	8,59	0,148
Sedang	10	13,60	67,45	4,03	48,18	116,65	22,00	0,386
Tinggi	10	21,24	46,74	5,84	65,52	186,30	35,34	0,618
Kritis	10	29,54	28,13	8,19	85,65	260,42	49,01	0,870

Sumber: simulasi penulis berdasarkan struktur dan rentang variabel UCI Forest Fires (Cortez & Morais, 2007).

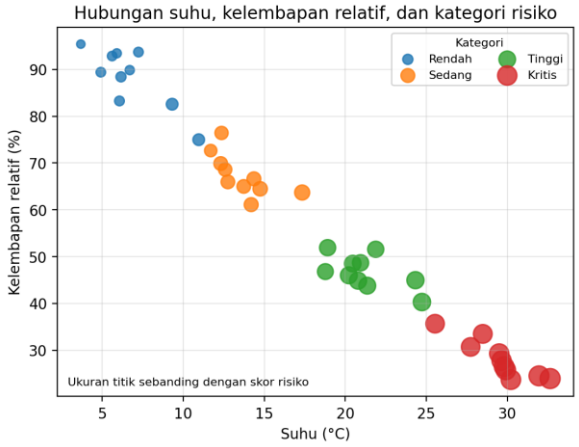


Gambar 2. Sebaran skor risiko pada 40 skenario simulasi

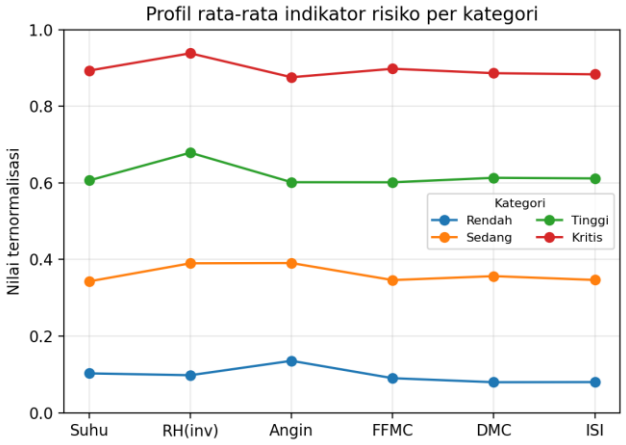
Tabel 4. Contoh rincian 8 skenario simulasi berbasis rentang UCI Forest Fires

Sken	Kat	Suhu	RH	Angin	FFMC	DMC	ISI	Skor
1	R	3.7	95.4	0.7	25.8	32.5	6.4	0.070
5	R	5.6	92.9	1.8	31.5	20.5	10.3	0.130
10	R	5.9	93.5	1.1	30.1	19.9	8.2	0.110
12	S	12.6	68.6	3.7	48.9	102.5	19.3	0.360
16	S	11.7	72.7	2.1	45.6	81.8	17.1	0.290
22	T	18.9	51.9	5.4	60.9	198.6	34.9	0.580
30	T	18.8	46.8	5.6	56.0	186.4	26.7	0.550
40	K	31.9	24.5	9.2	90.1	279.8	50.0	0.930

Sumber: olahan penulis; Kat = kategori (R = rendah, S = sedang, T = tinggi, K = kritis).



Gambar 3. Suhu, RH, dan kategori risiko



Gambar 4. Profil indikator per kategori

Tabel 3 dan Tabel 4 memperlihatkan konsistensi perubahan skor pada tingkat agregat maupun pada contoh skenario individual. Visualisasi pada Gambar 2-4 memperkuat pola tersebut: kelompok dengan risiko lebih tinggi cenderung berada pada suhu yang lebih tinggi, kelembapan relatif yang lebih rendah, serta nilai FFMC, DMC, dan ISI yang lebih besar. Hal penting dari hasil ini bukan sekadar perbedaan antarwarna atau kategori, tetapi keterbacaan hubungan antara perubahan masukan dan keluaran skor. Keterbacaan tersebut menjadi syarat penting apabila sistem akan digunakan sebagai dasar prioritas kerja petugas.

Dalam penerapan operasional, skor tinggi atau kritis harus diperlakukan sebagai sinyal untuk memeriksa lokasi, bukan sebagai keputusan bahwa kebakaran telah terjadi. Konfirmasi dapat dilakukan menggunakan *hotspot* VIIRS/MODIS, citra *UAV* atau Sentinel-2, serta pemeriksaan petugas. Mekanisme ini menempatkan model sebagai penyaring awal yang mempersempit area perhatian. Manfaat yang diharapkan adalah waktu dan sumber daya patroli dapat diarahkan ke lokasi yang lebih prioritas tanpa menghilangkan verifikasi manusia.

Keterbatasan utama simulasi terletak pada perbedaan domain data. Kondisi iklim, bahan bakar, jenis tegakan, topografi, dan aktivitas manusia di kawasan Perhutani tidak identik dengan lokasi asal UCI Forest Fires. Oleh karena itu, nilai minimum-maksimum, bobot, dan ambang yang digunakan dalam artikel ini tidak dapat langsung dijadikan standar operasional. Uji percontohan perlu mengumpulkan data lokal yang cukup untuk menilai ulang distribusi variabel, hubungan antarfitur, dan ambang yang menghasilkan keseimbangan terbaik antara sensitivitas deteksi dan jumlah false alarm.

Human-in-the-Loop dan Tata Kelola Data

Mekanisme *human-in-the-loop* menjadi penghubung antara analitik dan keputusan lapangan. Setiap *alert* yang diperiksa petugas diberi status, misalnya kejadian kebakaran, pembakaran terkendali, aktivitas masyarakat, gangguan sensor, atau kondisi lain. Label tersebut kemudian disimpan sebagai data validasi. Jika proses ini dilakukan konsisten, sistem akan memiliki sumber data lokal untuk mengkalibrasi ambang, mengevaluasi false alarm, dan melakukan *retraining* model. Dengan demikian, kualitas sistem berkembang dari pengalaman operasi nyata, bukan hanya dari *dataset* publik.

Ketertelusuran data diperlukan karena satu *alert* dapat terbentuk dari beberapa sumber yang berbeda. Rekaman sensor perlu menyimpan identitas perangkat, koordinat, waktu, status kalibrasi, kualitas sinyal, dan daya; citra memerlukan metadata lokasi dan waktu; sementara perubahan model perlu dicatat melalui *model versioning*. Hak akses *dashboard* juga perlu dibedakan berdasarkan peran. Struktur ini memungkinkan penyebab suatu *alert* ditelusuri ketika hasil model berbeda dengan kondisi yang ditemukan petugas.

Interoperabilitas menentukan apakah kerangka dapat berkembang tanpa terikat pada satu perangkat atau aplikasi. Penggunaan format terbuka seperti *GeoJSON*, layanan web *GIS*, dan *API* yang terdokumentasi memungkinkan integrasi sumber baru dengan perubahan minimal pada arsitektur. Sebelum *scale-up*, data induk seperti kode petak, unit kerja, kategori kejadian, dan status tindak lanjut perlu distandardisasi. Tanpa keseragaman tersebut, penambahan sensor dan model justru berisiko memperbesar inkonsistensi data.

Rancangan Uji *Pilot* dan Indikator Keberhasilan

Uji percontohan sebaiknya dimulai pada wilayah terbatas yang memiliki variasi kondisi lingkungan dan akses komunikasi. Tahap awal berfungsi membangun *baseline*, menguji konektivitas, dan memastikan kualitas sensor. Setelah aliran data stabil, *risk scoring* sederhana dapat diaktifkan dan dibandingkan dengan hasil verifikasi lapangan. Citra dan model *AI* yang lebih kompleks baru ditambahkan ketika data lokal telah memadai. Urutan ini membuat evaluasi lebih terkontrol karena kegagalan pada satu tahap dapat diketahui sebelum investasi diperluas.

Tabel 5. Indikator evaluasi uji pilot

Dimensi	Indikator	Tujuan
Perangkat	*Availability node*; *drift*; umur baterai	Menilai keandalan *sensing* jangka panjang
Jaringan	*Packet delivery ratio*; *latency*; *downtime gateway*	Menilai kemampuan komunikasi di kondisi lapangan
Data	*Completeness*; *timestamp consistency*; *spatial accuracy*	Menilai kualitas data untuk analitik
AI	*Precision*; *recall*; F1; AUROC/PR-AUC; *calibration*	Menilai kemampuan diskriminasi dan probabilitas risiko
Operasional	*Alert-to-acknowledge time*; *alert-to-verification time*	Menilai manfaat sistem terhadap kecepatan respons
Kualitas *alert*	*False-positive rate*; *duplicate alert rate*	Mengendalikan alarm fatigue
Pembelajaran	Perubahan performa setelah feedback lapangan	Menilai nilai *closed-loop human-in-the-loop*
Governance	Persentase data memiliki *provenance* dan log tindakan	Menjamin ketertelusuran dan auditabilitas

Implikasi untuk Perhutani

Bagi Perhutani, nilai praktis kerangka ini adalah memperkuat fungsi *digital forest* yang telah ada. *GIS* tidak perlu diganti, tetapi digunakan sebagai ruang integrasi untuk menerima data sensor, menampilkan prioritas, dan merekam tindak lanjut. Dengan cara ini, digitalisasi tidak berhenti pada penyajian informasi, tetapi bergerak menuju siklus pemantauan, analisis, verifikasi, dan pembelajaran. Nilai tambah tersebut akan terlihat apabila sistem mampu mengurangi waktu pencarian lokasi bermasalah dan meningkatkan ketertelusuran tindakan petugas.

Manfaat tersebut masih bersifat potensial karena penelitian belum melakukan uji lapangan pada kawasan Perhutani. Artikel ini karena itu tidak menyatakan peningkatan efisiensi, penurunan kejadian kebakaran, atau akurasi tertentu. Hasil yang dapat dipertanggungjawabkan pada tahap ini adalah kelayakan konseptual arsitektur, konsistensi mekanisme skoring pada simulasi, serta tersusunnya indikator untuk menguji sistem secara objektif pada tahap berikutnya.

Roadmap Implementasi Bertahap

Implementasi dapat dilakukan dalam empat tahap. Tahap pertama menyiapkan data induk, perangkat, dan konektivitas; tahap kedua menghubungkan sensor dengan *GIS* dan memastikan kualitas aliran data; tahap ketiga mengaktifkan analitik risiko, notifikasi, dan verifikasi; sedangkan tahap keempat melakukan *scale-up* setelah indikator teknis dan operasional memenuhi target. Setiap tahap sebaiknya memiliki keluaran yang terukur agar keputusan untuk melanjutkan tidak hanya didasarkan pada tersedianya perangkat.

Setiap tahap membutuhkan kriteria lanjut atau berhenti. Model *AI* tidak layak diperluas jika data sensor masih sering hilang, georeferensi tidak konsisten, atau jumlah *alert* tidak dapat ditangani oleh petugas. Demikian pula, model yang bekerja baik pada satu KPH tidak boleh langsung diterapkan pada KPH lain tanpa validasi karena komposisi tegakan, mikroklimat, topografi, dan pola aktivitas manusia dapat berbeda. Validasi lokal dan *recalibration* menjadi bagian dari proses *scale-up*, bukan pekerjaan tambahan setelah sistem berjalan.

Keamanan Siber, Keandalan, dan Keberlanjutan Sistem

Penerapan *IoT* di kawasan hutan menambah kebutuhan pengamanan perangkat, komunikasi, dan akses data. Setiap node perlu memiliki identitas perangkat dan autentikasi, komunikasi *gateway-server* perlu dienkripsi, dan hak akses *dashboard* dibedakan menurut fungsi pengguna. Setiap perubahan konfigurasi serta *alert* penting juga perlu tercatat dalam *audit trail*. Pengamanan ini diperlukan tidak hanya untuk mencegah akses tidak sah, tetapi juga untuk menjaga keandalan bukti ketika keputusan operasional ditinjau kembali.

Keandalan fisik sama pentingnya dengan akurasi model. Sensor lapangan menghadapi kelembapan tinggi, perubahan suhu, gangguan satwa, petir, dan kerusakan mekanis, sehingga pelindung perangkat, sumber daya, kalibrasi, dan redundansi harus diuji sejak *pilot*. Selain itu, *total cost of ownership* perlu memasukkan biaya perangkat, energi, konektivitas, *server*, inspeksi, penggantian komponen, pemeliharaan model, dan pelatihan petugas. Sistem hanya layak diperluas apabila manfaat operasionalnya sebanding dengan beban pemeliharaan jangka panjang.

KESIMPULAN DAN SARAN

Simpulan

Penelitian ini menghasilkan rancangan Perhutani Smart Forest Early-Warning Framework sebagai model teknologi terapan yang mengintegrasikan *Internet of Things* (IoT), LoRa/LPWAN, Sistem Informasi Geografis (GIS), *remote sensing*, UAV, kecerdasan buatan, serta verifikasi petugas lapangan dalam satu alur pemantauan terpadu. Kerangka tersebut dirancang untuk menjawab kesenjangan antara sistem informasi geospasial yang telah tersedia di lingkungan Perhutani dengan kebutuhan pemantauan mikroklimat, analisis risiko, dan tindak lanjut

lapangan secara lebih terstruktur. Hasil simulasi terhadap 40 skenario yang dibentuk berdasarkan struktur dan rentang variabel UCI Forest Fires menunjukkan pola peningkatan skor risiko yang konsisten. Nilai rata-rata skor risiko diperoleh sebesar 0,148 pada kategori rendah, 0,386 pada kategori sedang, 0,618 pada kategori tinggi, dan 0,870 pada kategori kritis. Pola tersebut menunjukkan bahwa kombinasi kenaikan suhu, kecepatan angin, FFMC, DMC, dan ISI serta penurunan kelembapan relatif dapat dibedakan oleh mekanisme pembobotan yang digunakan dalam model.

Hasil tersebut menunjukkan bahwa metode penilaian risiko yang dirancang mampu menghasilkan klasifikasi awal yang dapat digunakan sebagai dasar prioritas pemantauan dan verifikasi lapangan. Meskipun demikian, nilai skor yang diperoleh belum dapat diartikan sebagai tingkat akurasi operasional pada kawasan Perhutani karena data yang digunakan masih berupa simulasi dan bukan hasil pengamatan langsung di wilayah kerja Perhutani. Oleh karena itu, kontribusi utama penelitian ini terletak pada tersedianya arsitektur sistem, mekanisme integrasi data, model perhitungan risiko, visualisasi hasil, serta indikator evaluasi yang dapat digunakan sebagai dasar pengembangan prototipe dan uji percontohan. Pendekatan *human-in-the-loop* yang ditempatkan pada tahap akhir juga memastikan bahwa keluaran AI berfungsi sebagai sistem pendukung keputusan, sedangkan keputusan operasional tetap mempertimbangkan hasil verifikasi dan pengetahuan petugas kehutanan.

Saran

Penelitian selanjutnya perlu melakukan uji percontohan pada satu wilayah Kesatuan Pemangkuan Hutan (KPH) dengan menggunakan data lapangan aktual agar bobot, nilai normalisasi, dan batas klasifikasi risiko dapat dikalibrasi berdasarkan karakteristik lokal. Pengumpulan data disarankan mencakup suhu, kelembapan relatif, kelembapan bahan bakar atau tanah, kecepatan angin, kondisi vegetasi, riwayat hotspot, serta hasil verifikasi kejadian di lapangan. Data sebaiknya dikumpulkan sekurang-kurangnya selama satu siklus musim agar variasi kondisi basah dan kering dapat terwakili. Hasil uji lapangan kemudian perlu dibandingkan dengan keluaran model menggunakan indikator seperti *precision*, *recall*, F1-score, *false-positive rate*, latensi peringatan, waktu verifikasi petugas, dan tingkat keberhasilan tindak lanjut. Dengan cara tersebut, skor 0,148–0,870 yang dihasilkan pada simulasi saat ini dapat dibandingkan dengan distribusi risiko berdasarkan kondisi aktual dan selanjutnya digunakan untuk memperoleh ambang yang lebih sesuai bagi Perhutani.

Pengembangan berikutnya juga disarankan tidak hanya berfokus pada peningkatan akurasi algoritma, tetapi pada keberhasilan sistem dalam mendukung proses kerja Perhutani. Integrasi sensor IoT dengan GIS yang telah tersedia perlu diuji terhadap kestabilan jaringan LoRa/LPWAN, ketersediaan daya sensor, kualitas data, interoperabilitas antarsistem, keamanan akses, dan kemampuan petugas dalam menindaklanjuti peringatan. Setelah sistem terbukti stabil pada skala uji percontohan, penerapan dapat diperluas secara bertahap ke beberapa KPH dengan tetap melakukan kalibrasi pada setiap wilayah karena karakter tegakan, topografi, mikroklimat, dan aktivitas manusia dapat berbeda. Pengembangan lanjutan dapat mencakup deteksi kesehatan tegakan, identifikasi perubahan tutupan lahan, pemantauan gangguan atau penebangan ilegal berbasis citra dan suara, serta integrasi *digital twin*, tetapi pengembangan tersebut sebaiknya dilakukan setelah fondasi data, jaringan, dan prosedur verifikasi lapangan telah terbukti berjalan dengan baik.

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Depression Detection Using a Hybrid Convolutional Neural Network and Recurrent Neural Network Approach

Khadijat Jibrin[1]✉, Mustapha Ismail[2], Maimuna Salisu Tabra[3]
[1] Department of Computer Science, Federal Polytechnic Kaltungo, Nigeria
[23] Department of Computer Science, Faculty of Science, Gombe State University, Nigeria
Email: khadijaj1032@gmail.com[1]; mismail@gsu.edu.ng[2]; munattabra@gsu.edu.ng[3]
ORCID ID [1]: 0000-0000-0000-0000; ORCID ID[2]: 0000-0002-6207-092; ORCID ID[3]: 0000-0002-6148-5182

Abstract
Depression is a widespread psychological condition that disrupts how people feel, think, and function, and recognising it early allows support to begin before symptoms worsen. Most automated approaches rely either on conventional machine learning, which struggles with interacting risk factors, or on single deep learning models that capture only one type of pattern. Here we propose a hybrid network that joins one-dimensional convolutional layers (CNN) to a bidirectional long short-term memory layer (BiLSTM) in order to separate depressed from non-depressed students. The novelty lies in treating structured demographic, academic, and lifestyle attributes as an ordered sequence so that convolutional and bidirectional recurrent layers can learn their interactions jointly. An open Kaggle dataset of 27,901 student records with 16 attributes was used. Missing values were imputed, categorical attributes were encoded, numerical features were standardised, and class weighting was applied; 80% of the records were used for training, while a stratified 20% was kept aside for testing. Evaluation relied on six measures: accuracy, precision, recall, F1-score, area under the ROC curve, and Matthews correlation. On the unseen test records the network reached 84% accuracy, with F1 = 0.84, ROC-AUC = 0.91, and MCC = 0.67, outperforming the classical models reported in comparable studies. The framework offers a reliable and scalable basis for automated mental-health screening in educational settings.
Keywords: Bidirectional LSTM[1]; Convolutional Neural Network[2]; Depression Detection[3]; Hybrid Deep Learning[4]; Mental Health Screening[5].

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Corresponding Author:
Khadijat Jibrin
Department of Computer Science, Federal Polytechnic Kaltungo
Gombe Yola Road, Kaltungo, Gombe State, Nigeria.
Email: Khadijaj1032@gmail.com

INTRODUCTION
Depression is a condition that affects a very large number of people across the globe and can harm both mental and physical health; its severity is usually judged from the overall state of a person's mental health (Ahmed et al., 2017). According to World Health Organization (2023) figures, close to 280 million people worldwide are living with depression, making it one of the commonest and most serious psychiatric disorders (Rehmani et al., 2024). Because the condition tends to persist, it alters how people think, feel, and cope, causing considerable personal suffering and placing a financial burden on health services. When depression co-exists with other illnesses, it complicates therapy, delays recovery, and raises the cost of care, so recognising it early improves outcomes and lowers long-term expenditure (Ali et al., 2022; Bhadra & Kumar, 2023; Torous et al., 2020).
Clinicians usually diagnose depression with standardised self-report scales, notably the nine-item Patient Health Questionnaire (PHQ-9) and the Beck Depression Inventory (BDI), alongside structured interviews conducted by trained staff (Ali et al., 2022; Levis et al., 2020). Among 587 primary care patients in rural Ethiopia, Ali et al. (2022) observed AUCs of 0.84 for the PHQ-9 and 0.81 for the WHO-5, although low literacy, interviewer bias, and cultural differences limited the findings. A meta-analysis of 81 studies from 22 countries reported pooled sensitivity and specificity above 80% for the PHQ-9 (Torous et al., 2020), and a review of 55 screening tools confirmed it as the most frequently validated instrument while stressing the need for setting-specific validation (Manea et al., 2017). However, diagnoses also depend on the instrument used: in a synthesis of 69,405 participants from 212 studies, the MINI interview labelled participants as depressed more often than the SCID (aOR = 1.46)

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(Levis et al., 2020). These instruments are therefore affected by assessor bias, are time-consuming to administer, and depend on how accurately patients describe their own symptoms. Digital approaches are also gaining ground; for example, digitally delivered lifestyle programmes produced small-to-moderate reductions in depressive symptoms across 61 randomised trials (Brinsley et al., 2025). The growing volume of patient data calls for objective, automated screening methods that can handle large datasets efficiently (Bhadra & Kumar, 2023).

Progress in machine learning (ML) now makes it possible to screen for depression automatically using electronic health records, clinical notes, and behavioural information (Saha et al., 2024; Bader et al., 2024; Vu et al., 2025). Deep learning has attracted particular interest because it can uncover intricate structure that human reviewers might overlook (Deng et al., 2023). Bertl et al. (2024) used gated recurrent units with self-attention on nationwide medical claims data and reached an AUC of 98% in flagging new depression diagnoses six months in advance, although transfer to other health systems remains untested. Voice and mixed-modality inputs have been studied as well: Sahu and Singh (2024) fused acoustic and textual cues in a CNN–Bi-LSTM that scored 98% on interview benchmarks, although its precision dropped in noisy recordings; an attention-based acoustic fusion network reached 94.3% accuracy (Xu et al., 2024); a bimodal transformer obtained an F1-score of 0.897 (Deng et al., 2023); and a facial and audio model estimated PHQ-8 scores to within 3.51 points on average (Jin et al., 2025). Further studies combined audio, video, and text sensing (Zhang et al., 2024a) or compared traditional ML and deep learning on EEG signals (Lin et al., 2024).

Social media text has been another major source. Nadeem et al. (2022) stacked CNN and Bi-LSTM layers with self-attention and reached 97.4% accuracy on Twitter data, while dynamic graph models reached 91.4% accuracy and an AUC of 0.945 (Kuo et al., 2023). Among transformer models, RoBERTa reached 98.1% accuracy on 632,000 tweets (Bokolo & Liu, 2023) and 95.6% accuracy in grading depression severity (Qasim et al., 2025), BERT combined with LIME and SHAP explanations reached 94.3% accuracy on Reddit posts (Masud et al., 2025), and natural language processing has been applied to Sina Weibo posts (Zhang et al., 2024b). For bilingual Roman Urdu and English text, a linear SVM achieved 84% accuracy, ahead of BERT, although class imbalance remained a problem (Rehmani et al., 2024).

Despite this progress, several gaps remain. Much of the work on structured data still relies on conventional ML, which has difficulty learning interactions among many demographic, academic, and lifestyle variables, and models frequently miss subtle patterns, which leads to misclassification (Rehmani et al., 2024). Many studies report high accuracy while giving little attention to class imbalance, and few report measures that stay reliable under imbalance, such as the Matthews correlation coefficient (MCC) or the area under the ROC curve (ROC-AUC). Where deep learning is used, CNNs and recurrent networks are usually applied on their own, so local feature interactions and dependencies between features are not captured together (Deng et al., 2023; Zhang et al., 2024a). Transformer models perform very well on text but suit tabular data less well and need considerable computing power (Bertl et al., 2024; Bokolo & Liu, 2023), and weak validation designs make it uncertain whether reported models would generalise (Saha et al., 2024).

Hence, we ask whether a hybrid network able to learn local feature interactions as well as dependencies across features can identify depression in structured student data more reliably than classical approaches. To answer this, the study builds a hybrid CNN–BiLSTM classifier for two-class depression detection on an open student dataset, trains it with class weights on a stratified train–test split, and judges it with six complementary performance measures

RESEARCH METHODS

Research design and data

We adopted a quantitative experimental design, training and testing a hybrid deep learning classifier on secondary data (workflow in Figure 1). Our data source was the Student Depression Dataset, an openly accessible Kaggle collection (Jurado, 2025) of 27,901 anonymised student records described by 18 columns. Once the identifier column had been dropped, 16 predictors remained, grouped as demographic (gender, age, city, profession, degree), academic (CGPA, academic pressure, work/study hours, and study satisfaction), lifestyle and well-being (financial stress, sleep duration, dietary habits, job satisfaction, and work pressure), and mental-health history (a family history of mental illness and past suicidal thoughts). The target is binary: 16,336 records (58.5%) are labelled depressed and 11,565 (41.5%) not depressed. As the data are public and contain no identifying information, this secondary analysis did not need ethical approval or participant consent.

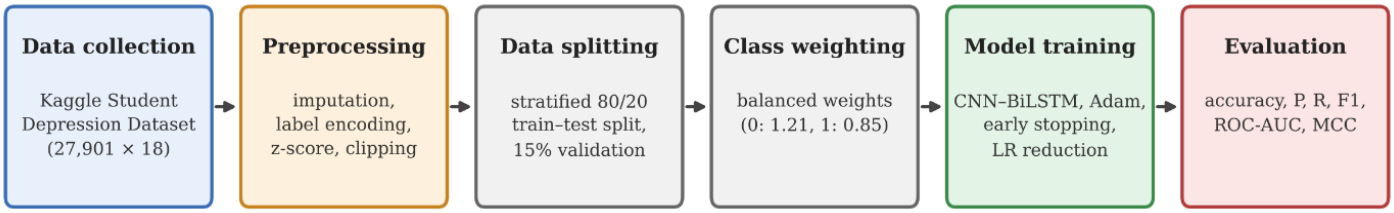


Figure 1. Workflow followed in this study

Data preprocessing

Infinite values were treated as missing, and columns or rows that were entirely empty were removed. Missing numerical values were filled with the column median, and missing categorical values were assigned a separate "missing" category. Categorical attributes were converted to integer codes with label encoding, numerical attributes were standardised with z-score normalisation, and all feature values were clipped to the range [−5, 5] to prevent extreme values from destabilising training. A stratified split (random seed 42) then allocated 22,320 records (80%) to training and set 5,581 (20%) aside for testing, preserving the original class ratio in each; while the model was being fitted, 15% of the training portion served as a validation set. To compensate for the unequal class sizes, balanced class weights were computed from the training labels (1.21 for the not-depressed class and 0.85 for the depressed class) and applied to the loss function.

Model architecture

Figure 2 illustrates the architecture. Every record is reshaped into a sequence of 16 steps with a single channel, so each attribute occupies one position in the sequence. The convolutional block stacks two Conv1D layers (64 filters of width 3, same padding, ReLU), each followed by batch normalisation and dropout (0.25 after the first and 0.20 after the second); together they learn local combinations of neighbouring attributes. Their output feeds a BiLSTM with 64 units per direction, which scans the attribute sequence both ways so that relations between distant attributes can be captured, and is followed by dropout of 0.30. Next come a 64-unit ReLU dense layer with dropout of 0.25 and, finally, one sigmoid unit whose output is read as the probability that the student is depressed; outputs of 0.5 or above are labelled depressed. In total, the network contains 87,489 parameters, 87,233 of them trainable.

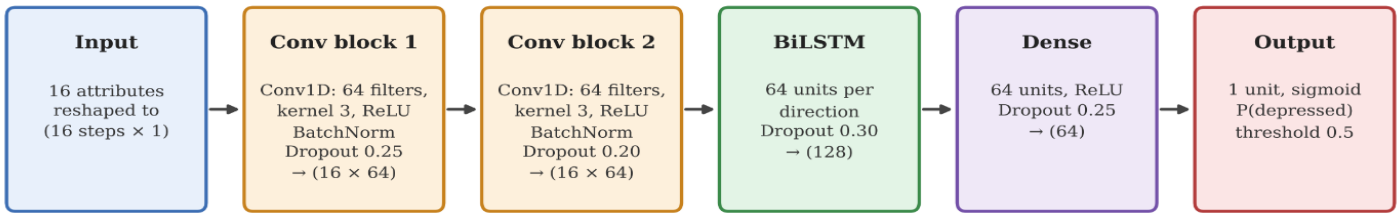


Figure 2. Layer structure of the hybrid CNN–BiLSTM network

Training and evaluation

All experiments ran on Google Colab with Python 3.13, TensorFlow 2.21.0 (Keras 3.13.2), scikit-learn 1.6.1, NumPy 2.1.3, and pandas 2.2.3. Weights were optimised with Adam (starting learning rate 1×10^{-4}, gradient norm clipped at 1.0) against binary cross-entropy, in mini-batches of 64 and for at most 60 epochs. Training halted once validation loss had failed to improve for six consecutive epochs, and the best weights were then restored; in addition, the learning rate was cut by half after every three epochs without improvement, down to a floor of 1×10^{-7}. For the held-out test set we report the confusion matrix together with accuracy, recall, precision, F1-score, ROC-AUC, and MCC; MCC draws on every cell of the confusion matrix and therefore stays informative when the classes are unequal in size.

RESULTS AND DISCUSSION

Training behaviour

Training stopped after 23 epochs, when early stopping restored the weights from epoch 17, which had the lowest validation loss (0.391). In Figure 3, the training and validation losses drop steeply over the opening epochs before easing into a smooth decline, with validation loss tracking training loss closely, which indicates good convergence without overfitting. The accuracy curves in Figure 4 show the same pattern: training accuracy passes 0.80 within the first few epochs, validation accuracy follows an almost identical path, and both level off at about 0.83. The

narrow gap between the curves shows that the network learned transferable patterns instead of memorising individual training examples.

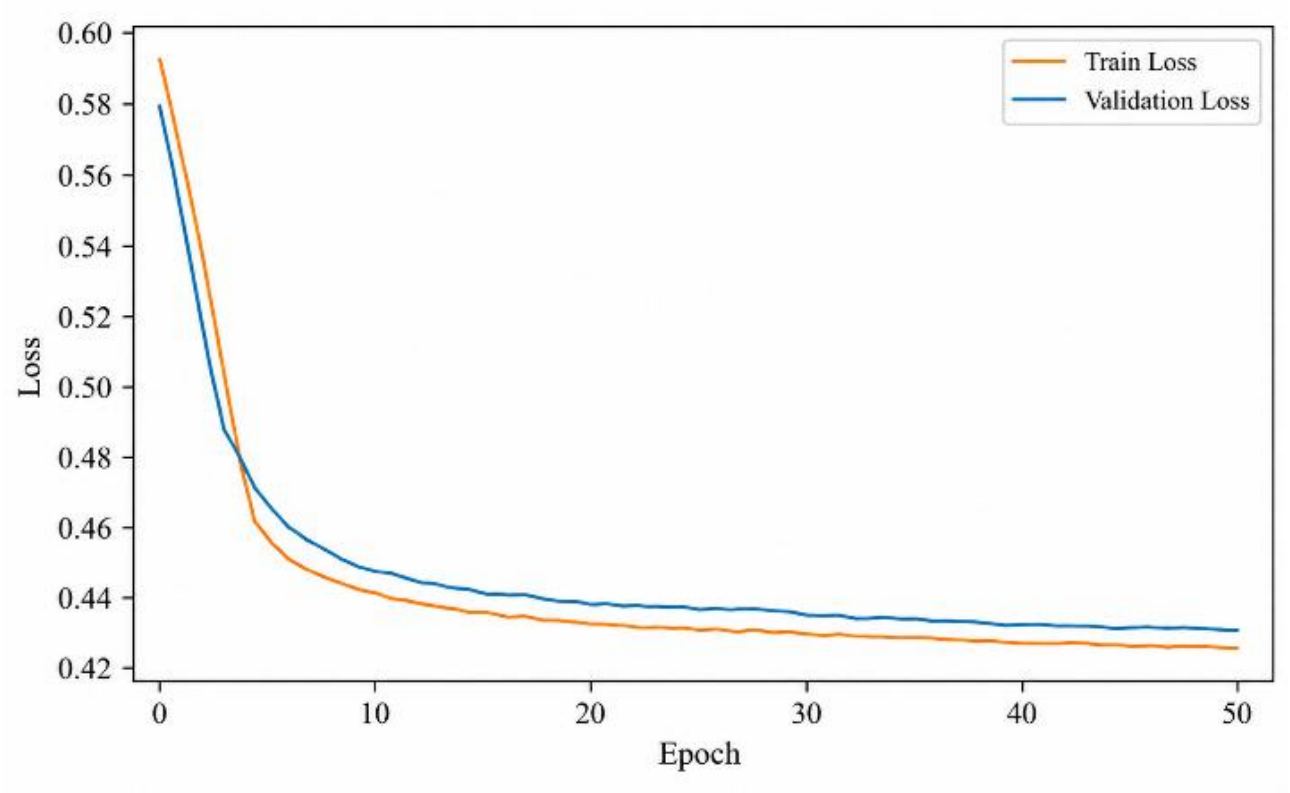


Figure 3. Loss on training and validation data per epoch

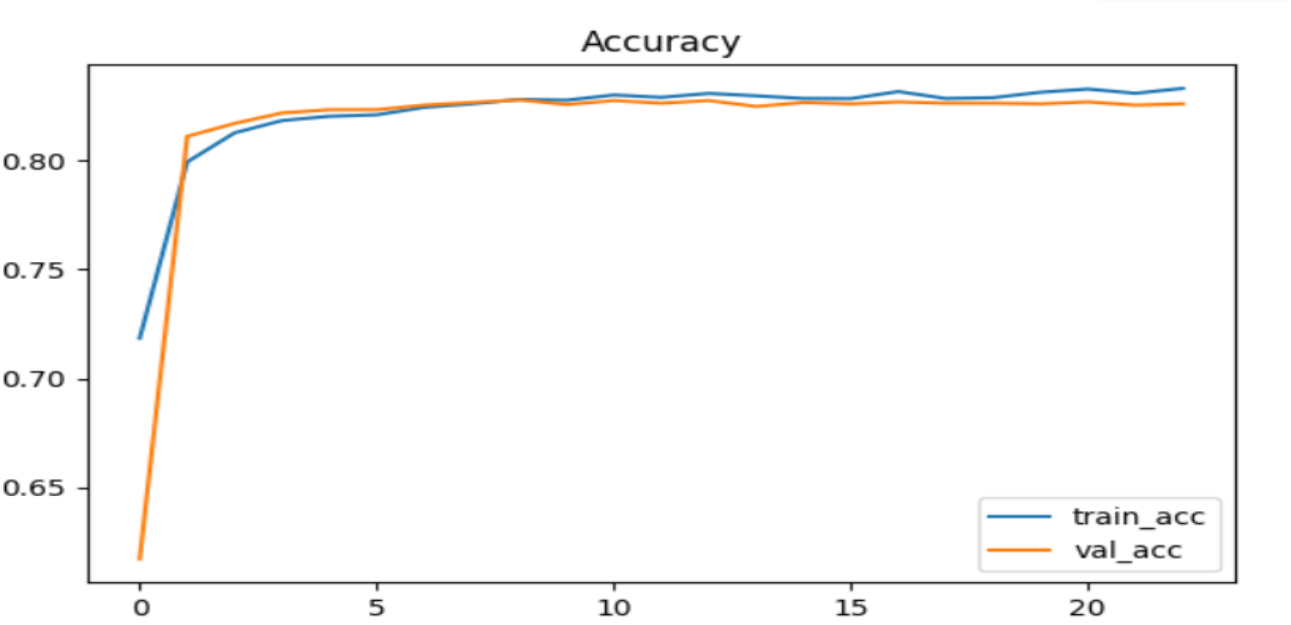


Figure 4. Accuracy on training and validation data per epoch

Classification performance

Of the 5,581 test records, Figure 5 shows that 1,837 non-depressed students were classified correctly (true negatives) and 2,861 depressed students were detected correctly (true positives). There were 476 false positives and 407 false negatives, giving an overall accuracy of 0.84. Per class, the depressed group obtained 0.86 precision, 0.88 recall, and an F1 of 0.87, while the not-depressed group obtained 0.82 precision, 0.79 recall (specificity), and an F1 of 0.81; the weighted averages were 0.84 for all three. False positives may cause needless worry or extra assessment, but false negatives matter more in mental-health screening because they correspond to students who may need support but are missed. These errors reflect the difficulty of the task, since self-reported answers and overlapping behavioural signs make exact detection hard.

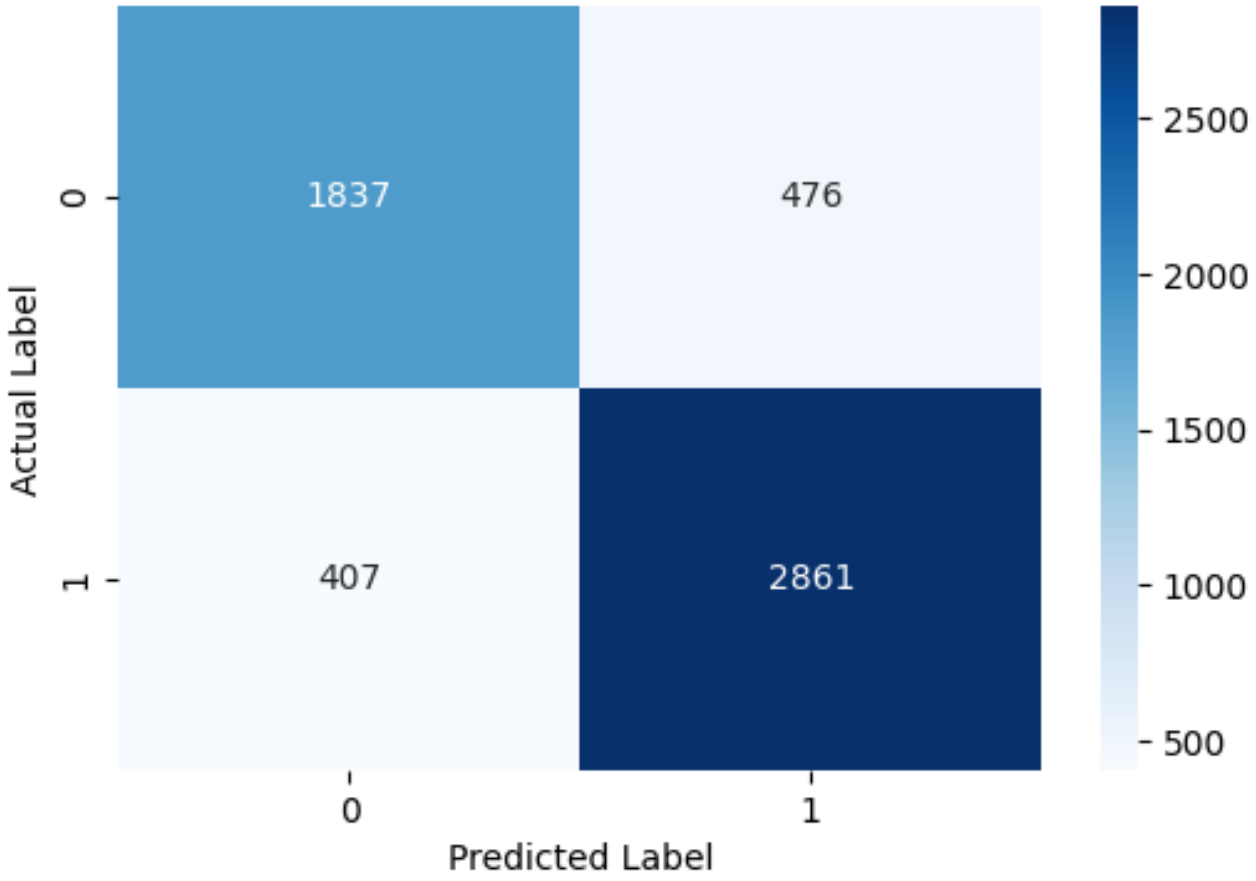


Figure 5. Test-set confusion matrix for the CNN–BiLSTM model

Figure 6 reports an MCC of 0.6728, which indicates strong agreement between predicted and true classes despite unequal class sizes. The ROC curve in Figure 7 gives an AUC of 0.91, which is conventionally regarded as *excellent* discrimination: for a randomly chosen pair of depressed and non-depressed students, the model ranks the depressed student higher 91% of the time. The high AUC also shows that performance remains robust as the decision threshold changes, which matters when screening programmes set different sensitivity and specificity targets.

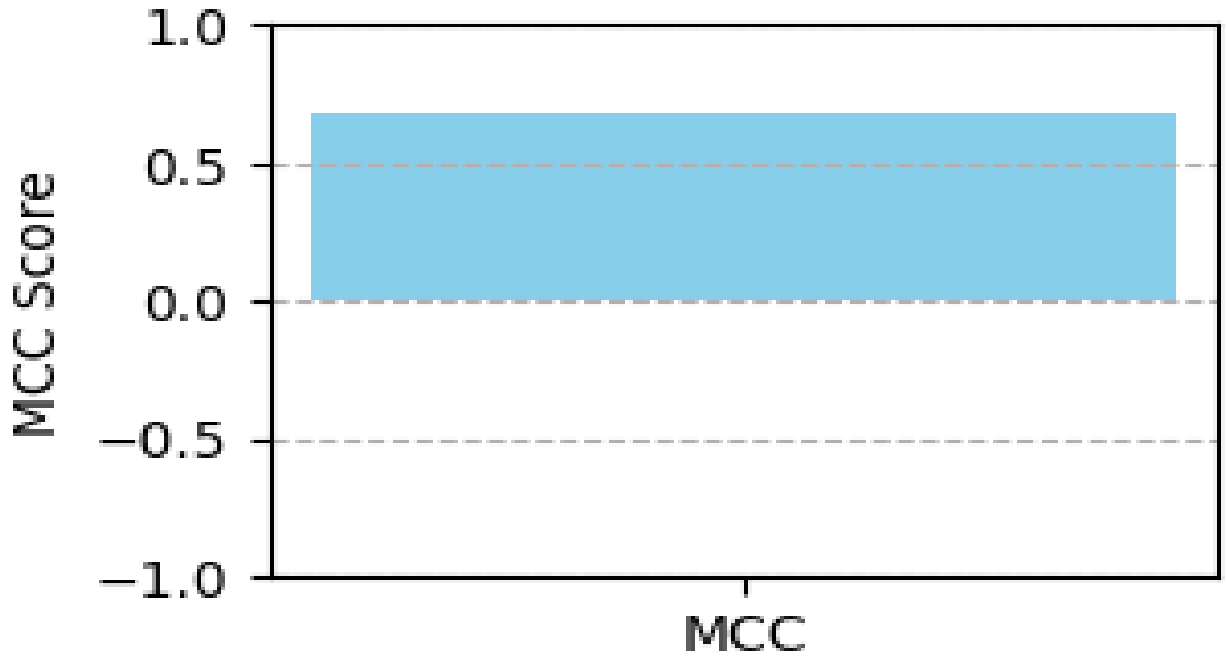


Figure 6. MCC achieved by the CNN–BiLSTM model

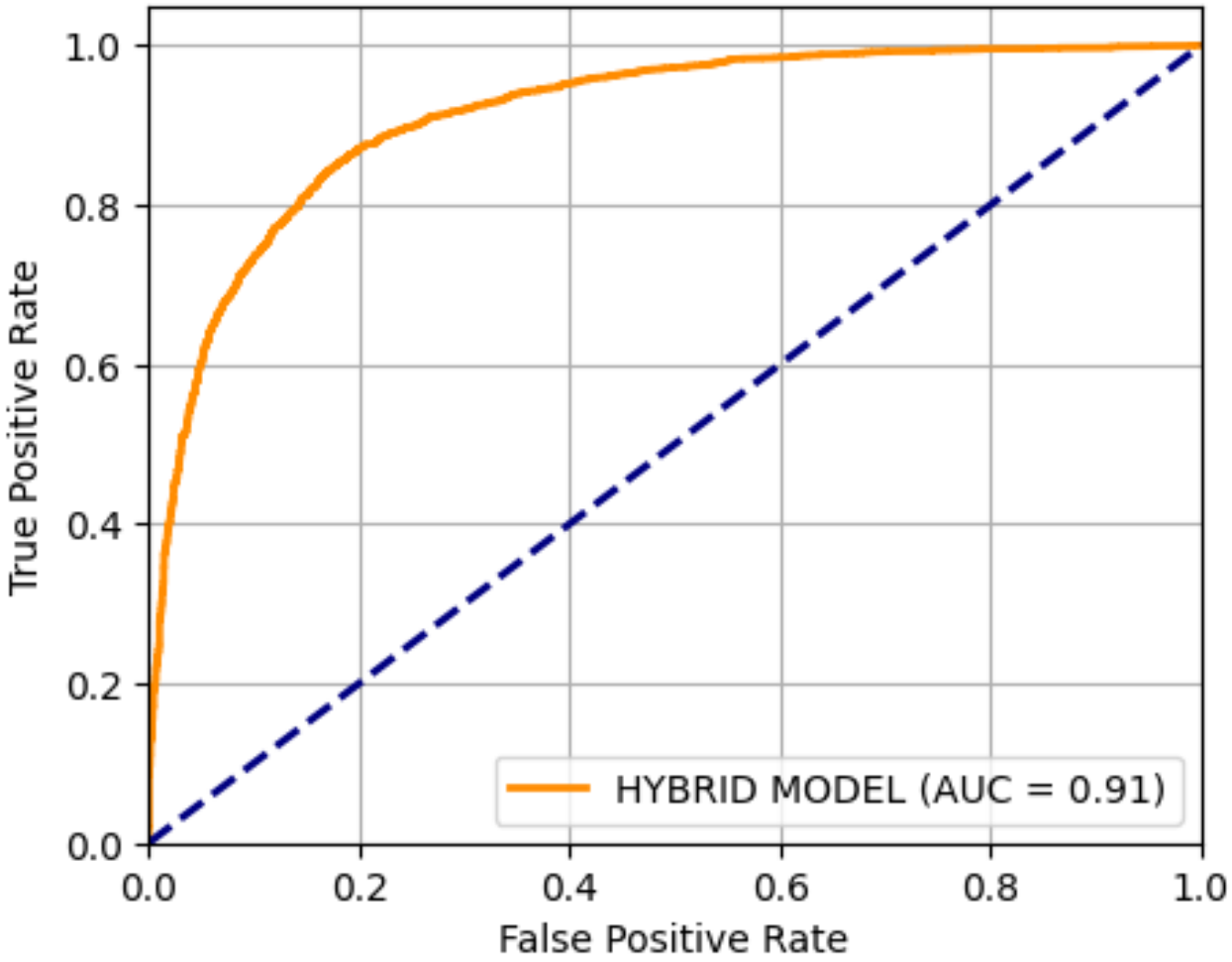


Figure 7. ROC curve for the binary CNN–BiLSTM classifier

Comparison with previous studies

Table 1 sets the proposed model beside recent studies. Using an SVM on bilingual Roman Urdu–English posts, Rehmani et al. (2024) obtained 0.84 accuracy and an F1-score of 0.88 but gave no ROC-AUC. Torres Cruz et al. (2023) trained a Naive Bayes classifier on survey responses and reported only accuracy (0.78). Sonjaya et al. (2025) worked with the same Kaggle data as the present study and, again with Naive Bayes, reached 0.78 accuracy and 0.68 sensitivity. Das et al. (2025) compared classical learners for probable depression in Bangladeshi patients with chronic diseases; the strongest, CatBoost, achieved 0.71 accuracy and a ROC-AUC of 0.76. Our network scored 0.84 for accuracy as well as for weighted precision, recall, and F1, and its ROC-AUC of 0.91 indicates a more even error profile and markedly better discrimination than any of the classical models listed.

Table 1. Performance of the CNN–BiLSTM model against previously published studies

Author(s) & Year	Model and data	Accuracy	Precision	Recall	F1-score	ROC-AUC
Rehmani et al. (2024)	SVM (Roman Urdu and English text)	0.84	0.86	0.85	0.88	—
Sonjaya et al. (2025)	Naive Bayes (Kaggle student depression data)	0.78	—	0.68	—	—
Torres Cruz et al. (2023)	Naive Bayes (survey data)	0.78	—	—	—	—
Das et al. (2025)	CatBoost (chronic-disease patients)	0.71	0.71	—	0.71	0.76
Proposed model	Hybrid CNN–BiLSTM (Kaggle student data, binary)	0.84	0.84	0.84	0.84	0.91

Discussion

These results address the research question. Because precision, recall, and F1 are similar for the two classes, the model clearly serves both groups well, and the stable learning curves suggest that batch normalisation, dropout, and early stopping together prevented overfitting. Class weighting also helped: although depressed students made up 58.5% of the data, the not-depressed class still reached a recall of 0.79, and the MCC of 0.67 confirms that performance was not driven by the majority class, which addresses the concern raised by Rehmani et al. (2024) that imbalance weakens depression classifiers. In terms of design, the convolutional layers learn how neighbouring attributes interact locally, while the BiLSTM layer models broader dependencies across all attributes; this combination explains the advantage over Naive Bayes and SVM models (Torres Cruz et al., 2023; Rehmani et al., 2024), which cannot represent such non-linear interactions. This agrees with earlier hybrid CNN–LSTM studies on text and speech (Nadeem et al., 2022; Sahu & Singh, 2024) and shows that the same benefit extends to structured tabular data. Our accuracy falls short of what transformers achieve on tweets and other social media posts (Bokolo & Liu, 2023; Qasim et al., 2025), but those models handle a different kind of data and demand far greater computing resources. The remaining false negatives suggest that future work should favour higher sensitivity, for example by lowering the decision threshold, even at the cost of a small rise in false positives.

CONCLUSIONS AND SUGGESTIONS

Conclusion

We built a hybrid CNN–BiLSTM network to detect depression in students from structured survey data. Tested on 5,581 unseen records, it reached 84% accuracy, a weighted F1 of 0.84, an AUC of 0.91, and an MCC of 0.67, confirming that combining convolutional feature extraction with bidirectional sequence modelling captures the relationships between demographic, academic, and lifestyle factors and depression more effectively than the classical approaches compared. The findings imply that such hybrid models could support low-cost, large-scale screening in schools, universities, and digital-health services, where timely identification of at-risk students enables early support. The main limitations are that the data were self-reported and non-clinical, so the predictions should be interpreted cautiously in clinical settings, and that the model was evaluated on a single stratified train–test split of one dataset.

Suggestion

Future research should confirm the results with k-fold cross-validation and comparisons against stand-alone CNN, BiLSTM, and classical baselines, validate the model on larger, more diverse, and clinically assessed datasets, use longitudinal data to examine how depression-related patterns change over time, and evaluate the usability and reliability of the approach when integrated into intelligent decision-support systems for real-world screening.

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