"An Agile and UML-Driven Approach to Flight Delay Prediction and Notification"

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Abstract

Flight delays pose significant challenges to airline operations, passenger satisfaction, and airport efficiency. This paper presents the design and implementation of a Flight Delay Detection and Notification System, emphasizing object-oriented design principles, Unified Modeling Language (UML) diagrams, and Agile methodologies. The system aims to predict flight delays accurately and disseminate timely notifications to stakeholders, thereby enhancing operational efficiency and passenger experience. Detailed class diagrams, activity diagrams, sequence diagrams, use-case interactions, and state diagrams are discussed to illustrate the system's architecture and functionality.

The UML diagrams created in this study are a fundamental design tool that supports many software development process stakeholders. These diagrams reduce uncertainty in system structure and behavior by giving developers a clear implementation blueprint. They assist testers in comprehending interaction logic, state transitions, and processes, allowing them to create more thorough and efficient test cases. The high-level overviews also help stakeholders and project managers by making it easier to plan, communicate, and monitor system performance. This research ensures a more organized and cooperative development lifecycle by promoting improved alignment between design, development, and testing teams through the use of UML in conjunction with Agile techniques.

Keywords

Flight delays, Object-oriented design, UML diagrams, Activity diagrams, Agile methodology, Flight management system.

I. Introduction

Flight delays have become a pervasive issue in the aviation industry, leading to economic losses and diminished passenger satisfaction. The increasing complexity of air traffic and unpredictable factors such as weather conditions necessitate the development of robust systems capable of detecting and managing flight delays effectively. This paper outlines the design and implementation of a Flight Delay Detection and Notification System, leveraging object-oriented design principles and Agile methodologies to address these challenges.

II. Literature Review

Unified Modeling Language (UML) and Agile methodologies have become foundational in the modern software development lifecycle, especially for designing and deploying real-time, adaptive systems like the Flight Delay Detection and Notification System presented in this work. UML serves as a visual language that enables developers to model complex systems through standardized diagrams that capture both static structures and dynamic behaviors. As Booch, Rumbaugh, and Jacobson describe in the Unified Modeling Language User Guide [6], UML helps bridge the gap between system requirements and implementation by offering clear blueprints of software architecture, use case scenarios, object relationships, and control flows.

The application of UML in real-world systems improves maintainability, traceability, and communication between technical and non-technical stakeholders. IEEE Std 1016-2009 [1] reinforces the importance of comprehensive software design documentation, emphasizing that structured design representations—such as class, sequence, and activity diagrams—are critical for understanding and managing system complexity. These diagrams support modularity, abstraction, and reusability, all of which are particularly beneficial in the development of scalable, service-driven applications such as flight management systems.

Complementing UML, the Agile Scrum methodology supports the development of flexible and user-centric software through iterative sprints, continuous feedback, and close stakeholder collaboration. As defined in the Agile Manifesto [4], individuals and interactions, working software, customer collaboration, and responsiveness to change are prioritized over rigid processes. Scrum, a popular Agile framework, enables rapid development cycles where evolving requirements and incremental feature releases are common. Rubin [5] emphasizes that Scrum's time-boxed sprints, product backlog grooming, and daily stand-ups promote continuous alignment with user expectations and operational realities.

In contrast to traditional approaches such as the Waterfall or Spiral models, Agile methods offer a more adaptable and responsive framework, especially suitable for dynamic environments. According to Sommerville [2], while formal documentation may be minimized in Agile, essential models such as UML diagrams serve a vital role as "just enough design" to support system scalability and architectural soundness. Pressman [3] further advocates the integration of lightweight modeling practices within Agile environments, recognizing that while Agile promotes speed and adaptability, foundational system models remain crucial for long-term maintainability and effective communication among distributed teams.

Together, the use of UML and Agile Scrum offers a synergistic development approach. UML provides structured visualizations that inform sprint planning and feature refinement, while Agile ensures those models are developed and iterated upon collaboratively, delivering working software that aligns with user needs and system goals.

III. Agile Methodology Implementation (Scrum Approach)

An agile Scrum methodology was explicitly selected for the development and deployment of the Flight Delay Detection and Notification System due to its iterative nature, ability to accommodate change, and focus on stakeholder collaboration.

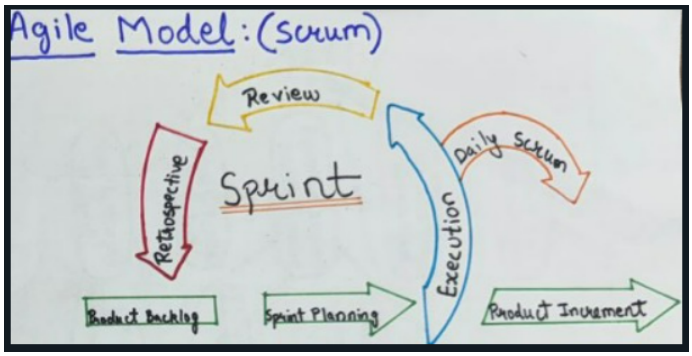

Fig1.Scrum Process of Flight delay prediction

For the development and deployment of the Flight Delay Detection and Notification System, the Agile Scrum methodology was chosen due to its iterative structure, adaptability to change, and strong emphasis on stakeholder collaboration. The Scrum framework was applied across multiple stages of the project lifecycle. Initially, a product backlog was created where stakeholder requirements were gathered, prioritized, and continuously refined. User stories were documented to describe critical features such as delay predictions, notification systems, and dashboard visualization tools.

During sprint planning, tasks were selected from the backlog and organized into short, manageable iterations. These included activities like class design, database schema development, integration of prediction algorithms, and implementation of the notification workflow. The team then proceeded with sprint execution, holding daily stand-up meetings to assess progress, address any roadblocks, and realign goals as needed. At the end of each sprint, a sprint review was conducted to demonstrate completed features to stakeholders and gather feedback. This was followed by a retrospective, which allowed the team to evaluate what worked well and identify areas for improvement, thereby enhancing future sprint performance.

The decision to adopt Agile Scrum was grounded in several benefits. Its flexibility and adaptability allowed the team to adjust quickly to evolving requirements, such as refinements in delay prediction algorithms or notification preferences. Continuous collaboration with end-users and stakeholders ensured that the development remained aligned with operational needs. Moreover, incremental delivery ensured that essential functionalities—like real-time delay detection and alert dissemination—were implemented early and refined over time.

Other development models were evaluated but deemed less suitable. The Waterfall model was rejected due to its rigid, linear structure, which lacked the flexibility needed for a dynamic system with changing requirements. The

Incremental model, though more iterative than Waterfall, fell short in accommodating rapid feedback loops. The Spiral model, while flexible and risk-aware, was considered overly complex for the relatively controlled and focused scope of this project. Ultimately, the Agile Scrum methodology provided the ideal balance between adaptability, stakeholder engagement, and iterative development required for building a responsive and reliable flight delay management system.

IV. System Design and Architecture

The system's architecture is meticulously crafted using object-oriented design principles, ensuring modularity, scalability, and maintainability. The following UML diagrams provide a comprehensive overview of the system's structure and behavior.

A. Class Diagram

The class diagram encapsulates the core components of the system, their attributes, methods, and interrelationships.

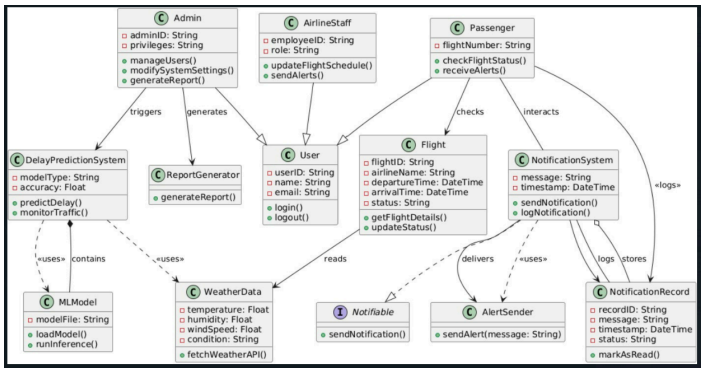

Fig 2.Class Diagram of Flight delay prediction

1. Classes tabular form

Class	Attributes
User	userID, name, email
Admin	adminID, privileges
Passenger	flightNumber
AirlineStaff	employeeID, role
Flight	flightID, airlineName, departureTime, arrivalTime, status
DelayPredictionSystem	modelType, accuracy
MLModel	modelFile
WeatherData	temperature, humidity, windSpeed, condition, fetchWeatherAPI
NotificationSystem	message, timestamp
AlertSender	—
NotificationRecord	recordID, message, timestamp, status
ReportGenerator	—

2. Description of classes

The User class serves as a foundational entity for all system users, providing common attributes such as user ID, name, and email, along with basic operations like login and logout. The Admin class extends the functionality of User, allowing administrative privileges to manage users, configure system settings, and generate analytical reports. The Passenger class represents the end-user of the system who can check flight status and receive notifications about flight delays or confirmations. AirlineStaff handles scheduling and operational communication by updating flight details and dispatching relevant alerts.

The Flight class encapsulates key flight-related attributes including identifiers, airline information, and scheduling details, while providing methods to retrieve and update flight status. DelayPredictionSystem is a core functional unit that leverages traffic and environmental data to anticipate delays using machine learning models. The MLModel class supports the prediction system by loading and executing trained models for delay analysis.

WeatherData supplies current weather metrics like temperature and wind speed, which are crucial for determining flight viability and delay forecasting. The NotificationSystem manages the creation and dispatching of messages to users and logs these events for reference. AlertSender is responsible solely for delivering the generated notifications across communication channels. NotificationRecord logs the content, timing, and delivery status of every notification sent, supporting system transparency and user accountability. Lastly, the ReportGenerator is a utility class primarily used by administrators to compile and export system usage or performance reports.

Class	Methods
User	login(), logout()
Admin	manageUsers(), modifySystemSettings(), generateReport()
Passenger	checkFlightStatus(), receiveAlerts()
AirlineStaff	updateFlightSchedule(), sendAlerts()
Flight	getFlightDetails(), updateStatus()
DelayPredictionSystem	predictDelay(), monitorTraffic()
MLModel	loadModel(), runInference()
WeatherData	—
NotificationSystem	sendNotification(), logNotification()
AlertSender	sendAlert(message)
NotificationRecord	markAsRead()
ReportGenerator	generateReport()

3. Relationship Descriptions

Generalization: The Passenger, Admin, and AirlineStaff classes inherit from the base User class, gaining common attributes and behaviors like authentication and profile management.

Passenger → Flight: There is a direct association where passengers interact with the flight module to check availability and status.

Admin → ReportGenerator: Admin users directly use the report generation component to compile system reports.

Flight → WeatherData: The flight class directly accesses weather information to assist in scheduling and delay prediction.

NotificationSystem → AlertSender: The notification system relies on a dedicated alert sender to deliver messages.

Aggregation: The NotificationSystem aggregates NotificationRecord instances, meaning it manages and stores logs of notifications, but these logs can exist independently.

Composition: The DelayPredictionSystem comprises the ALLModel, implying the model is an essential part of the system and cannot exist separately.

Passenger → NotificationSystem: Passengers are associated with the system to receive flight updates, confirmations, and delay alerts.

NotificationSystem → NotificationRecord: This association maintains a persistent record of all notifications that have been sent.

DelayPredictionSystem → WeatherData, ALLModel: The system depends on weather inputs and machine learning models to function accurately.

NotificationSystem → AlertSender: A dependency exists as the alert sender must be available for the system to notify users.

Association Class: NotificationRecord functions as an association class between Passenger and NotificationSystem, storing metadata like message content, timestamp, and delivery status.

Relationship Type	Source Class(es)	Target Class
Generalization (Inheritance)	Passenger, Admin, AirlineStaff	User
Direct Association	Passenger	Flight
Direct Association	Admin	ReportGenerator
Direct Association	Flight	WeatherData
Direct Association	NotificationSystem	AlertSender
Aggregation	NotificationSystem	NotificationRecord
Composition	DelayPredictionSystem	MLModel
Association	Passenger	NotificationSystem
Association	NotificationSystem	NotificationRecord
Dependency	DelayPredictionSystem	WeatherData, MLModel
Dependency	NotificationSystem	AlertSender
Association Class	Passenger, NotificationSystem	NotificationRecord

B. Activity Diagrams

Activity diagrams illustrate the dynamic aspects of the system, detailing workflows for critical processes.

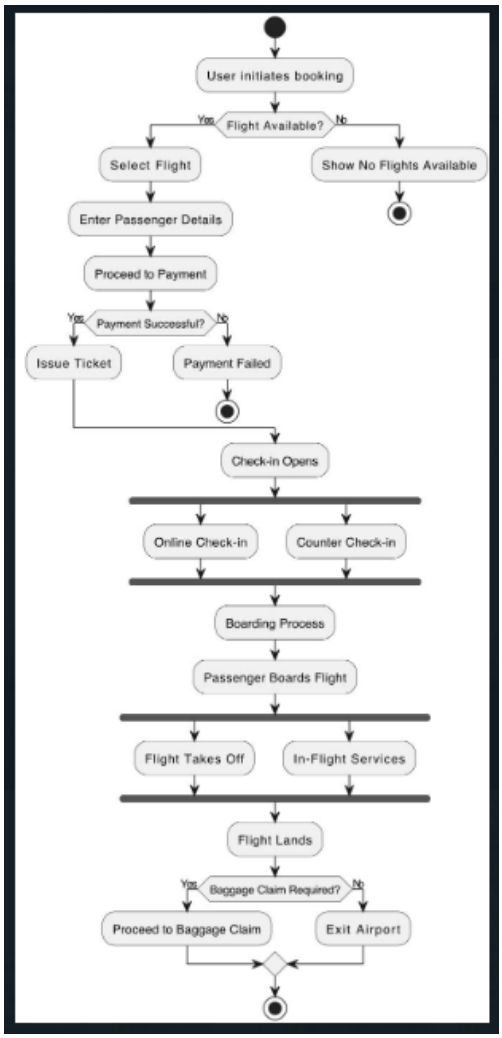

Fig 3.Activity Diagram of Flight delay prediction

Activity	Type	Condition / Notes
User initiates booking	Action	Start of the process
Check if flight is available	Decision	Branches into Yes or No path
Select flight	Action	If flight is available
Enter passenger details	Action	Follows flight selection
Proceed to payment	Action	After entering details
Check if payment is successful	Decision	Branches into success or failure
Issue ticket	Action	If payment is successful
Payment failed	Action (End)	If payment fails → ends process
Show no flights available	Action (End)	If no flight is available → ends process
Check-in opens	Action	Continues if booking was successful
Online check-in	Parallel Action	Forked parallel activity
Counter check-in	Parallel Action	Runs simultaneously with online check-in
Boarding process	Action	After check-in
Passenger boards flight	Action	Before takeoff
Flight takes off	Parallel Action	Forked parallel activity
In-flight services	Parallel Action	Runs during flight
Flight lands	Action	After takeoff is complete
Check if baggage claim is needed	Decision	Based on passenger's travel
Proceed to baggage claim	Action	If baggage claim required
Exit airport	Action	If no baggage claim or after baggage collection
End	Terminal State	Process completes

The activity diagram models the sequential and parallel flow of activities involved in a passenger's journey, from flight booking to arrival. It begins with user login and proceeds through key steps such as flight selection, payment, check-in, boarding, and in-flight services. Conditional branches handle payment failures, flight delays, or baggage claims, while parallel flows represent

simultaneous processes like online and counter check-ins. This diagram effectively captures the system's operational workflow, decision points, and concurrent actions, offering a comprehensive view of user interactions and system behavior.

C. Sequence Diagrams

Sequence diagrams provide a temporal view of interactions between system components during specific processes.

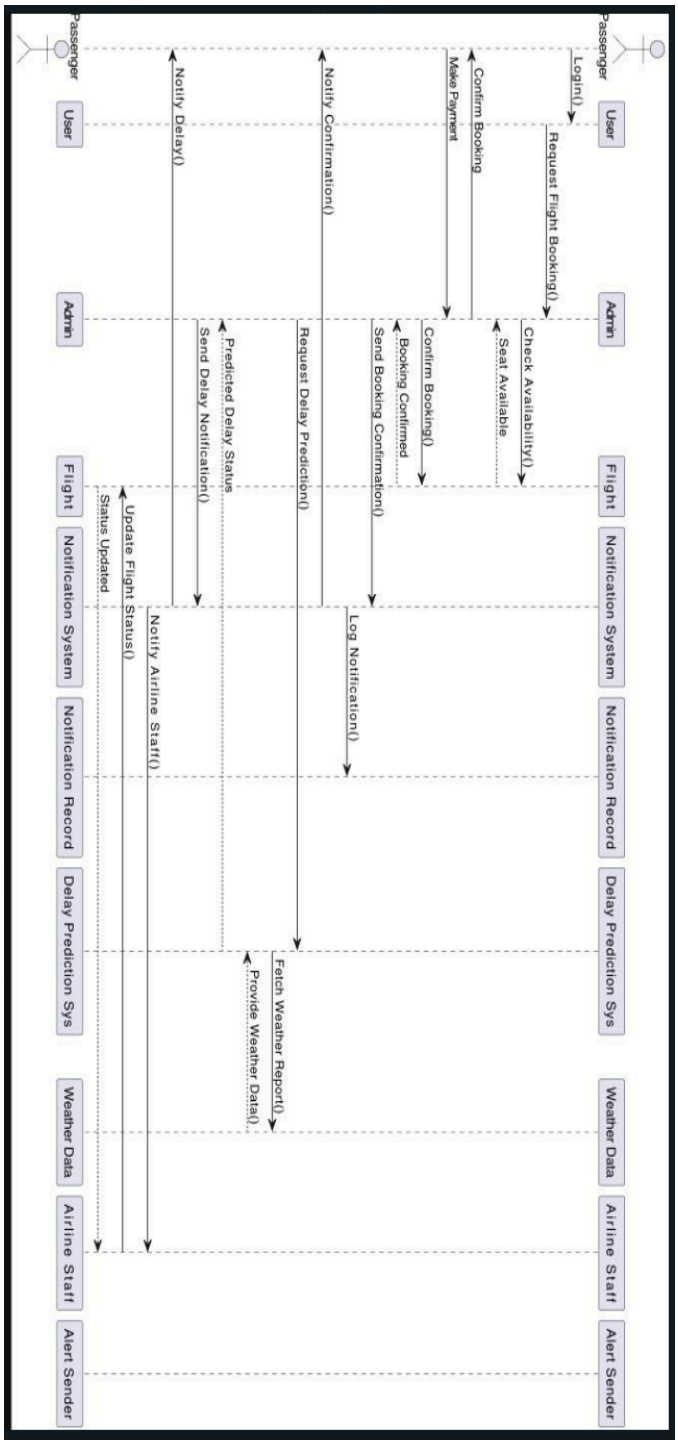

Fig 4.Sequence Diagram of Flight delay prediction

1. Flight Booking Flow

Sender	Receiver	Action / Message	Remarks
Passenger	User (U)	Login()	Passenger logs into the system
User (U)	Admin (A)	Request Flight Booking()	User requests to book a flight
Admin (A)	Flight (F)	Check Availability()	Admin checks seat availability
Flight (F)	Admin (A)	Seat Available	Flight confirms availability
Admin (A)	Passenger	Confirm Booking	Confirms availability to user
Passenger	Admin (A)	Make Payment	Passenger initiates payment
Admin (A)	Flight (F)	Confirm Booking()	Booking is confirmed in system
Flight (F)	Admin (A)	Booking Confirmed	Acknowledgement of successful booking
Admin (A)	Notification System (NS)	Send Booking Confirmation()	Sends notification to system
Notification System (NS)	Notification Record (NR)	Log Notification()	Booking confirmation is logged
Notification System (NS)	Passenger	Notify Confirmation()	Passenger receives booking alert

The process begins when the Passenger logs into the system, interacting with the User interface (U). After successful authentication, the User sends a Request Flight Booking message to the Admin (A). The Admin then contacts the Flight system (F) to Check Availability for the selected route. Once the Flight confirms that seats are available, the Admin sends a Booking Confirmation to the Passenger. The Passenger then proceeds to Make Payment, which is handled by the Admin. Upon successful payment, the Admin sends a Confirm Booking request to the Flight system, which replies with Booking Confirmed. The Admin then notifies the Notification System (NS) to send a Booking Confirmation to the user. The Notification System logs this communication in the Notification Record (NR) and finally sends a Confirmation Notification to the Passenger.

2. Flight Delay Prediction Flow

Sender	Receiver	Action / Message	Remarks
Admin (A)	Delay Prediction System (DPS)	Request Delay Prediction()	Admin requests delay estimation
DPS	Weather Data (WD)	Fetch Weather Report()	Retrieves weather for analysis
Weather Data	DPS	Provide Weather Data()	Supplies weather info
DPS	Admin (A)	Predicted Delay Status	Sends back delay prediction

This phase is initiated by the Admin, who sends a Request Delay Prediction to the Delay Prediction System (DPS). The DPS then contacts the Weather Data service (WD) to Fetch Weather Report. Once the weather data is retrieved, the Weather Data system sends it back to the DPS, which analyzes the information and sends the Predicted Delay Status back to the Admin for further action.

3. Delay Notification Flow

Sender	Receiver	Action / Message	Remarks
Admin (A)	Notification System (NS)	Send Delay Notification()	Triggers delay notification
Notification System (NS)	Passenger	Notify Delay()	Sends delay alert to passenger
Notification System (NS)	Airline Staff (AS)	Notify Airline Staff()	Notifies airline staff
Airline Staff (AS)	Flight (F)	Update Flight Status()	Updates flight status accordingly
Flight (F)	Airline Staff (AS)	Status Updated	Confirms flight status change

Following a delay prediction, the Admin prompts the Notification System to Send Delay Notification. The Notification System sends a Delay Alert to the Passenger and also Notifies the Airline Staff (AS). Once notified, the Airline Staff contacts the Flight system to Update the Flight Status. The Flight system confirms this with a Status Updated message, completing the notification and coordination workflow.

D. Use Case Diagram

The use case diagram delineates the functional requirements of the system by illustrating interactions between actors and use cases.

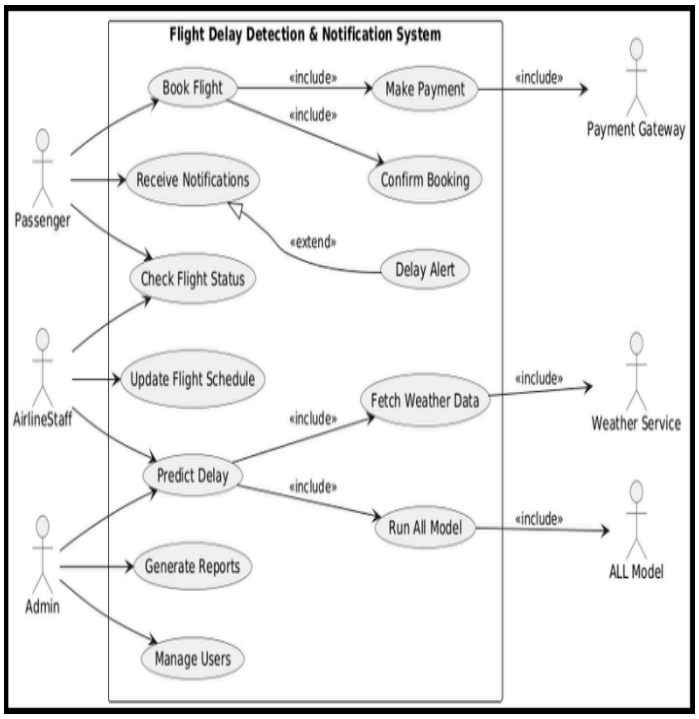

Fig 5.Use Case Diagram of Flight delay prediction

Actor	Use Case	Description
Passenger	Book Flight	Allows passengers to search and book available flights.
	Make Payment	Processes flight payment through an integrated payment gateway.
	Confirm Booking	Confirms booking details and updates the system post-payment.
	Receive Notifications	Sends flight updates and alerts to passengers.
	Delay Alert	Sends specific alerts when a delay is predicted (extends Receive Notifications).
	Check Flight Status	Enables users to view current status of flights.
AirlineStaff	Check Flight Status	Checks the status of flights in real-time.
	Update Flight Schedule	Allows airline staff to update flight timings and availability.
	Predict Delay	Analyzes flight and weather data to forecast delays.
	Delay Alert	Receives delay notifications relevant to flight operations.
Admin	Predict Delay	Triggers delay prediction based on data.
	Delay Alert	Sends alerts to stakeholders based on delay prediction.
	Generate Reports	Enables admins to produce system and operational reports.
	Manage Users	Lets admins manage user roles and access.
Payment Gateway	Make Payment	Handles secure transaction processing during flight booking.
Weather Service	Fetch Weather Data	Supplies real-time weather conditions.
AllModel (ML Model)	Run ML Inference	Uses machine learning models to predict delay likelihood.

The use case diagram represents the interactions between various actors and the flight delay management system. Passengers, as the primary users, can book flights, make payments through an integrated Payment Gateway, confirm bookings, check flight statuses, and receive notifications—including specific delay alerts if applicable. Airline Staff interact with the system to check flight statuses, update flight schedules, and utilize delay

prediction features. Admins have broader access, enabling them to manage users, generate operational reports, and initiate delay prediction processes. These delay predictions are supported by real-time data from a Weather Service and processed using an AllModel (ML Model) component that runs machine learning inference. The system ensures a smooth end-to-end experience from booking to flight arrival by automating notifications and enhancing operational decision-making.

E. State Diagram

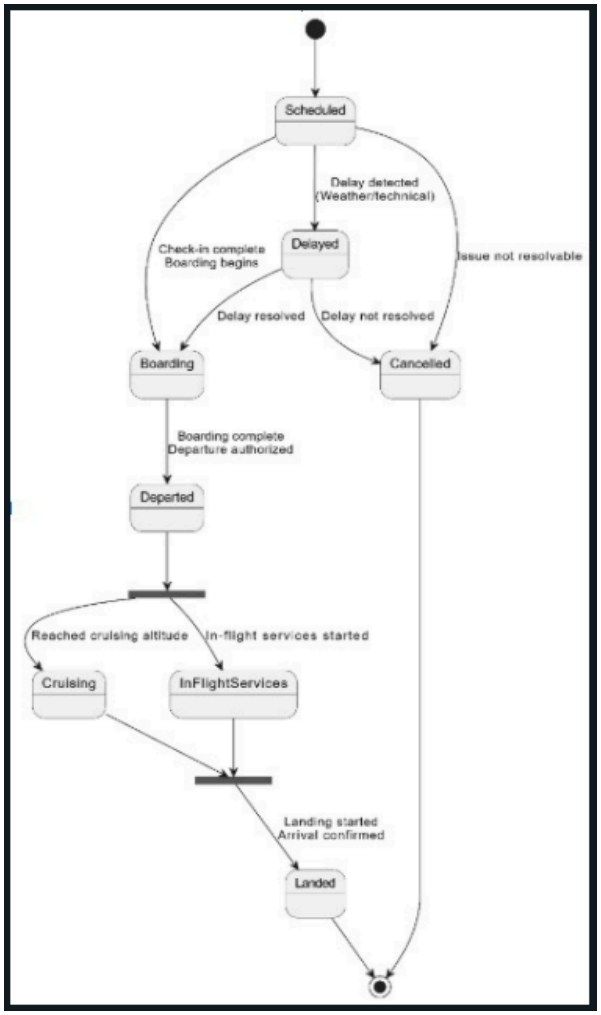

Fig 6.State Diagram of Flight delay prediction

State Diagram Tabular form

From State	To State	Trigger / Condition
Scheduled	Boarding	Initiated when the check-in process concludes and boarding begins.
Boarding	Departed	Triggered by aircraft departure confirmation from ground control.
Departed	In-Flight	Automatically transitions once the aircraft is airborne.
In-Flight	Landed	Occurs after successful landing at the destination airport.
Scheduled	Delayed	Triggered by detected anomalies like severe weather or technical issues.
Delayed	Boarding	Resumes normal operations when delay conditions are resolved.
Scheduled / Delayed	Cancelled	Occurs when issues cannot be resolved within acceptable time frames.

V. Results and Discussion

The implementation of the Flight Delay Detection and Notification System demonstrated robust technical performance and operational viability across multiple components. The system's primary achievement lies in its ability to perform real-time delay detection through the integration of machine learning algorithms trained on multi-dimensional datasets, including meteorological inputs, airport traffic patterns, and historical flight data. The use of predictive modeling—potentially employing ensemble techniques or supervised learning methods such as random forests or gradient boosting—enabled accurate estimation of flight delay probabilities. This reduced uncertainty in operational timelines and facilitated data-driven decision-making for both airline staff and administrators.

Another significant system capability was the deployment of a comprehensive, event-driven notification mechanism. Upon detection of a potential delay, the system automatically triggered customized alerts to relevant stakeholders—including passengers, ground crew, and airline operators—via integrated communication channels. This not only enhanced situational awareness but also mitigated passenger frustration by providing transparent, timely updates. The system further incorporated interactive dashboards developed using data visualization frameworks, which presented key performance metrics and real-time flight information in a user-friendly interface. These dashboards facilitated proactive monitoring and streamlined collaboration between operational teams.

In terms of observed benefits, the system notably enhanced the end-user experience by providing timely and context-aware alerts, enabling passengers to make informed travel decisions. On the operational front, early detection of potential delays allowed for improved gate management, resource allocation, and contingency planning—leading to greater efficiency in airline operations. Additionally, cost reductions were indirectly realized by minimizing last-minute scheduling disruptions and enhancing passenger communication.

Despite its effectiveness, the system presents several areas for potential enhancement. Integration scalability remains a key consideration; while effective in a controlled environment, the current architecture may require optimization—such as containerization and load balancing—to support high-throughput, multi-airline deployments across larger airport infrastructures. Model performance could also be improved through continuous learning mechanisms, expanded data inputs (e.g., air traffic

control feeds, maintenance logs), and adaptive thresholding techniques. Finally, the user interface could benefit from extended platform support and enhanced personalization features, including dynamic alert preferences and multilingual support.

VI. Conclusion

This research presented a comprehensive design and development of a Flight Delay Detection and Notification System, emphasizing robust object-oriented principles, clearly defined UML-based diagrams, agile Scrum methodology, and iterative development practices. The proposed system demonstrates substantial potential for improving flight operational efficiency, minimizing delay impacts, and significantly enhancing passenger satisfaction. Continuous improvements, scalability enhancements, and user-centric developments represent promising directions for future research and implementation.

Model / Diagram	Purpose	Alternate Not Used	Why Not Used
Use Case Diagram	Maps user interaction with the system	Context Diagram	Too abstract; lacks feature-level functional clarity
Class Diagram	Defines system structure and relationships	ER Diagram	Doesn't show methods or behavior; only data relationships
Sequence Diagram	Shows interaction flow over time	Collaboration Diagram	Doesn't indicate message order or timing clearly
Activity Diagram	Represents process workflows	Flowchart	Informal; lacks object-awareness and parallel logic
State Diagram	Captures state transitions of objects	Sequence Diagram	Not focused on lifecycle states
Agile (Scrum)	Enables iterative, feedback-driven	Waterfall, Spiral, Incremental	Lacks flexibility; not suited for evolving requirements

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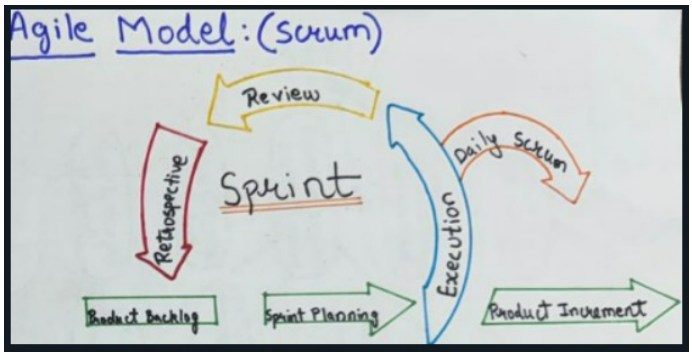
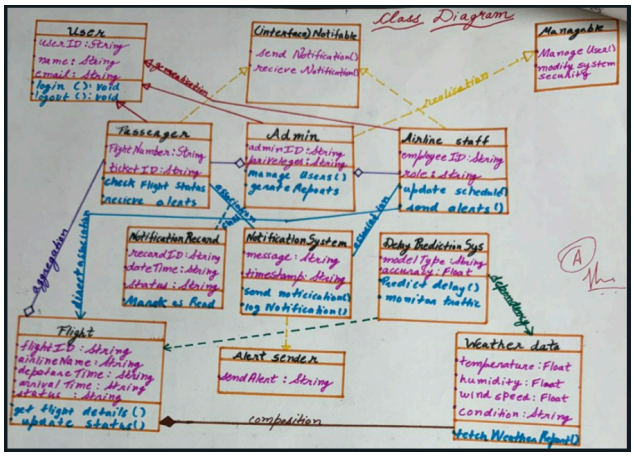
Appendix

Include clearly labeled diagrams from your provided class activities:

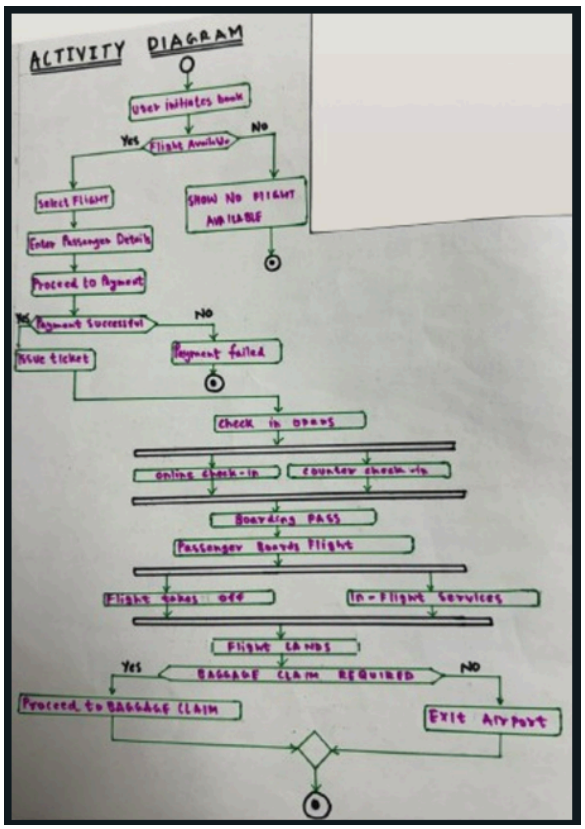
- **Fig. 1:** Agile (Scrum) Methodology Diagram



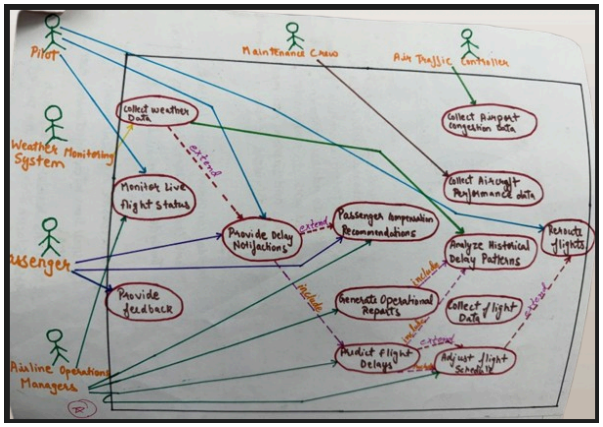
- **Fig. 2:** Class Diagram and Attributes



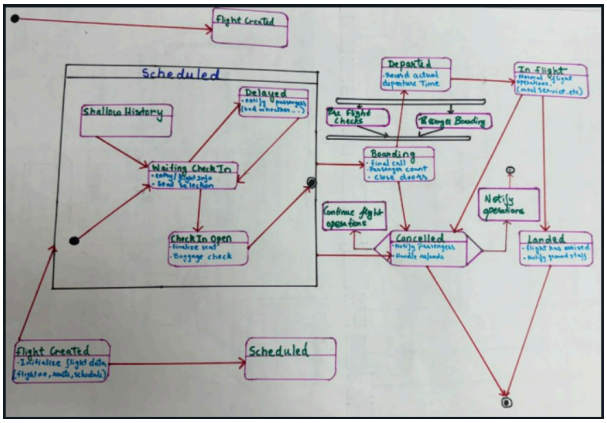
- **Fig. 3:** Activity Diagram (Flight Booking and Check-In)



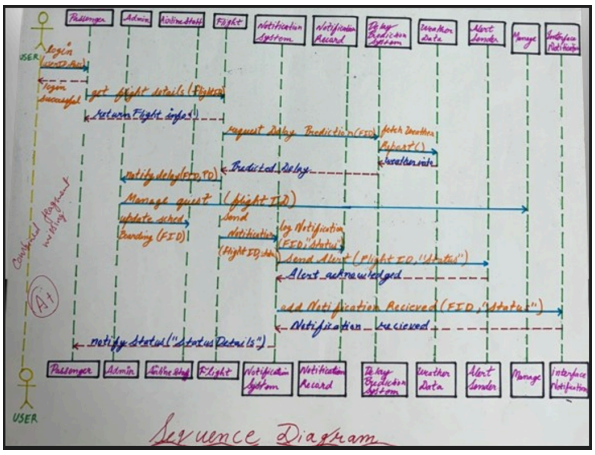
- **Fig. 4:** Use Case Diagram (Stakeholder Interactions)



- **Fig. 5:** State Diagram (Flight Status Transitions)



- **Fig. 6:** Detailed Sequence Diagrams



L001-Aadarsh Rawat

L002-Aditya Singh

L029-Pridwimn Jha

L032- R.Venkat Kalyan

L042-Shayaan Shaikh