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**Essay / Assignment Title:** Robotics Implementation Strategy and Integration Readiness, Assessment for a Complex Robotics System

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# Introduction to Robotics Implementation and Deployment Context

## 1.1 Description of the Robotics Solution

"Air Delivery" is a project which involves deploying robotic drones in order to deliver food in cities. It integrates modern drone technology with ground-based receiver stations with landing zones to perform a delivery from restaurant rooftop hubs to customer collection directly. The simple concept involves using drones autonomously, to transport meals from a restaurant rooftop launch platform to distributed Receiver Stations positioned in residential environments. When a drone lands on the ground station, customers will receive a SMS notification containing an OTP, then customers can authenticate at the station, and collect their parcel from the ground station.

The technology stack comprises Pixhawk 6X flight controllers which runs PX4 Autopilot software, along with ROS2 (Robot Operating System 2) for navigation and collision avoidance, 5G/LTE antennas for real-time command and control, and queue management systems at ground level integrated with customer notification services.

Objective	Specific	Measurable	Achievable	Relevant	Time-bound
Landing Precision	Achieve precision landing on receiver station pads	CEP ≤10cm on 99.5% of deliveries	Hardware and AprilTag markers support this	Critical for package handoff	By Sprint 5
System Reliability	Achieve mission success rate	≥99% successful deliveries	Redundant systems designed	Core business requirement	End of pilot phase
Communication Latency	Minimise command-response time	End-to-end latency <100ms	5G/LTE infrastructure supports	Essential for safety	System Integration Phase

**Table 1:** Project Performance Objectives (**SMART**)

## 1.2 Organisational, Technical and Societal Relevance

**Organisational Relevance:** Investment in logistics innovation by the private sector helps to overcome the rising costs, where delivery costs contribute to about 53% of total logistics costs in an urban setup (Benchmark International, 2024).

**Technical Relevance:** The current project contains various state-of-the-art technologies: autonomous aerial navigation, computer vision based precision landing technology, real-time queue management techniques, and secure authentication technologies.

**Societal Relevance:** Urban Air Mobility (UAM) for cargo delivery is a concept that deals with the problem of urban congestion while posing the challenge of airspace democratisation, privacy, and workforce transformation. The drone delivery market is estimated to reach \$31.2 billion by 2028 (Grand View Research, 2023).

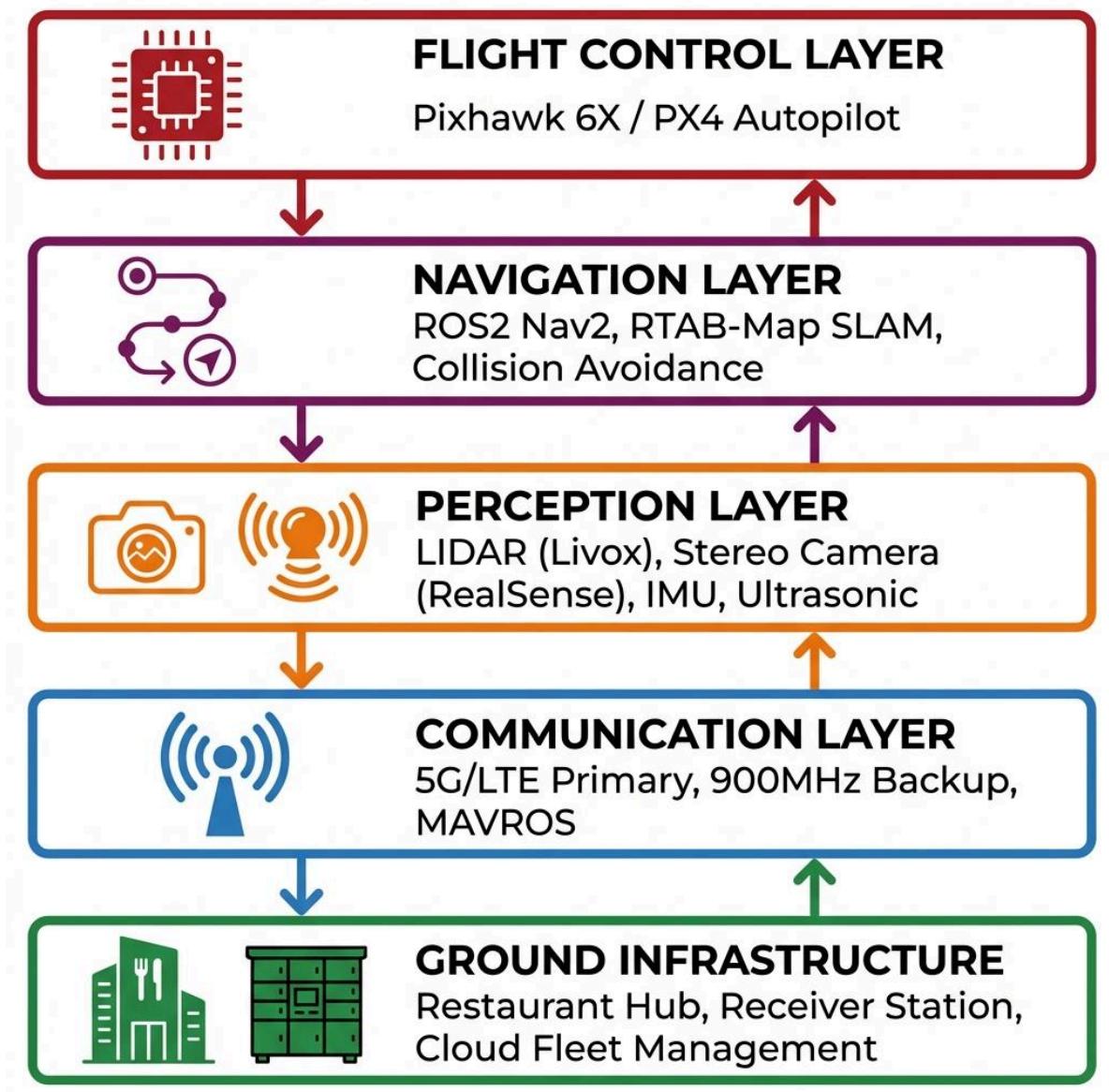
### **1.3 Key Integration and Deployment Challenges**

The technical complexity of this project is due to the multipath errors of GPS signals in urban regions and the need for a secondary Visual-Inertial Odometry (VIO) and AprilTag fiducial markers-based navigation system for precision landing. The fusion of LIDAR, Camera, and IMU data via Extended Kalman Filtering faces challenges in calibration and synchronizing data timing.

# System Architecture and Integration Requirements

## 2.1 High-Level Architecture Overview

The system architecture comprises five integrated layers, illustrated in Figure 1, each with distinct hardware, software, and interface specifications.



**Figure 1:** Layered system architecture showing data flow between Flight Control, Navigation, Perception, Communication, and Ground Infrastructure layers.

<b>Layer</b>	<b>Hardware</b>	<b>Software</b>	<b>Primary Interface</b>
<b>Flight Control</b>	Pixhawk 6X (STM32H753), triple-redundant IMU	PX4 Autopilot v1.14	MicroXRCE-DDS to ROS2
<b>Navigation</b>	Stereo camera (Intel RealSense D455), LIDAR	ROS2 Nav2, RTAB-Map SLAM	Sensor fusion via EKF
<b>Perception</b>	LIDAR (Livox Mid-360), ultrasonic sensors	Obstacle detection nodes, AprilTag detector	Point cloud to costmap
<b>Communication</b>	5G modem (Quectel RM520N), 900MHz backup	MAVROS, custom telemetry	VPN tunnel to cloud
<b>Ground Infrastructure</b>	Receiver Station with queue display	Queue management API, OTP auth	REST/MQTT to cloud

**Table 2: System Architecture**

## 2.2 Integration Requirements Between Subsystems

Interface	Requirement	Critical Parameters
Pixhawk <-> ROS2	MicroXRCE-DDS bridge enabling offboard control	Latency <10ms; message rate 50Hz
Camera <-> Nav2	Depth image stream for obstacle avoidance	30fps; depth range 0.5-20m
Drone <-> Station	RESTful handshake before payload release	Response <500ms; retry logic; error codes
Station <-> Cloud	Queue status and customer notifications	Real-time updates; SMS latency <30s
5G <-> Backup Radio	Seamless failover on primary link loss	Failover <1s; automatic reconnection

Table 3: Integration requirements

## 2.3 User Stories and MoSCoW Prioritisation

ID	User Story	Priority	Acceptance Criteria
FN-01	As a Restaurant Staff member, I want a "Rooftop Loading Safety" status that turns green only when the drone is stationary and switched off, so that I can safely load the parcels without risking injury.	MUST	LED indicators (Amber/Green); Physical interlock; Laminated safety protocol
FN-06	As a Customer, I want to authenticate at the receiver station by OTP sent to my mobile, so that only I can receive my parcel safely.	MUST	OTP valid 10 minutes; 6-digit code; Resend option
FN-10	As a Flight Operator, I want real-time battery health monitoring including cell temperature, so that the risk of thermal runaway is detected before it becomes serious.	MUST	Individual cell temp displayed; Warning at 45°C; RTH at 55°C
INT-07	As an Integration Engineer, I want drone-to-station handoff confirmation via REST API before payload release, so that deliveries complete only when the station acknowledges readiness.	MUST	API response <500ms; Retry logic (3 attempts); Comprehensive error codes
INT-02	As a Systems Integrator, I want LIDAR data to be timestamped within 5ms of the camera frames, so that sensor fusion provides correct obstacle detection.	MUST	Hardware time sync verified; EKF convergence <100ms
INT-08	As a Systems Integrator, I want the queue management system to track the order of parcels and alert the customer when their parcel arrives, so that pickup can be coordinated efficiently.	SHOULD	Queue updated in real-time; Customer notification <30s; FIFO ordering

Table 4: User Stories (INT - Integration, FN - Functional)

### **Derived Requirements (MoSCoW):**

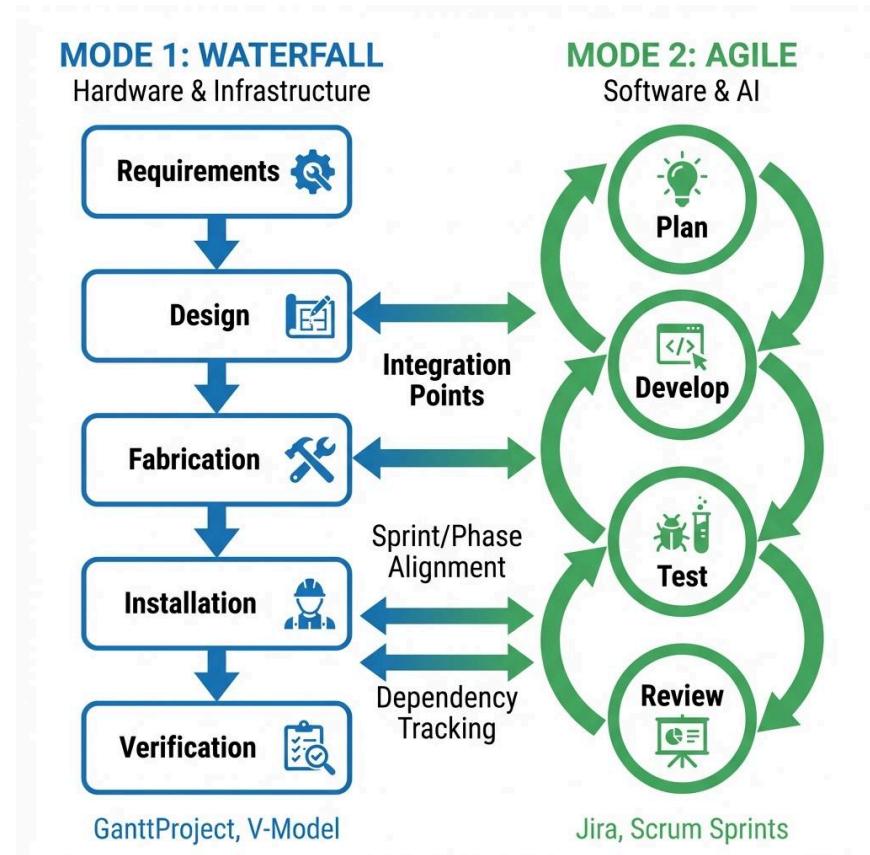
<b>Requirement</b>	<b>Type</b>	<b>Priority</b>
Landing precision ≤10cm CEP	Non-functional	<b>MUST</b>
Command latency <100ms	Non-functional	<b>MUST</b>
Customer notification <30s of arrival	Functional	<b>SHOULD</b>
99.5% delivery success rate	Non-functional	<b>SHOULD</b>
Night-time operations capability	Functional	<b>COULD</b>
Multi-floor building delivery	Functional	<b>WON'T</b>

**Table 5: MosCow Requirements**

# Project Management Approach for Implementation

## 3.1 Two Methodology Justification

There is always a fundamental challenge in the development of robotics projects: hardware development follows a predictable and linear development path, depending on the lead time of the production and the necessary approvals, while software development benefits from an iterative and incremental improvement path depending on the test feedback. Our project follows a bi-method approach by using the agile methodology for the software and the waterfall methodology for the hardware.



**Figure 2:** Bimodal project management approach showing Waterfall (Mode 1) for hardware development alongside Agile (Mode 2) for software, with synchronisation at integration points.

### **3.2 Agile Track: Autonomous Navigation Software**

**Subsystem:** Flight controller configuration, collision avoidance algorithms, sensor fusion, precision landing, drone-station API integration, and queue management.

**Methodology:** Scrum with 2-week sprints, managed via Jira Software.

The aerial environment in city residential areas is characterized by diverse and adaptive environments, which necessitate iterative adaptations. Wind patterns, which are affected by residential buildings, cannot be modeled beforehand and that's why it requires control algorithms to be tuned in the field. GPS multipath effects require iterative refinement of the Visual Inertial Odometry parameters, which is achieved through empirical testing in the field. AI model performance, such as AprilTag detection and obstacle classification accuracy, is improved through successive cycles of training and refinement, which are achieved through iterative cycles of AI model training and refinement.

The process involves creating and maintaining a Product Backlog with prioritized features and technical debt, with Sprint Planning selecting items that are according to the velocity of the team. Daily Stand-ups are conducted to identify blockers, Sprint Reviews to showcase the working software to stakeholders, and burn-up/down charts to track progress, with trends in velocity used to inform capacity planning.

### **3.3 Waterfall Track: Physical Infrastructure**

**Subsystem:** Rooftop hub construction, Receiver Station manufacturing and installation, drone chassis procurement, and regulatory compliance.

**Methodology:** Waterfall with V-Model verification, managed via GanttProject.

Sequential dependencies with low flexibility are typical of hardware development. A site survey must occur before a load analysis, and it must be done before the finalization of platform design. Electrical permits have 6-12 week regulatory processes with no flexibility for feedback. Receiver Station production includes production preparation, which requires specifications to be signed off before starting. The Waterfall model ensures the predictability and documentation necessary for regulatory requirements and vendor coordination.

### 3.4 Monitoring, Adaptation and Progress Reporting

Aspect	Agile Track	Waterfall Track
<b>Monitoring Tool</b>	Jira burn-down charts	Gantt milestones
<b>Reporting Frequency</b>	Sprint Review (bi-weekly)	Phase Gate Review (monthly)
<b>Change Management</b>	Backlog re-prioritisation	Formal Change Control Board
<b>Key Metrics</b>	Velocity, defect rate, test coverage	Schedule Performance Index, earned value

**Table 6:** Monitoring, Adaptation, and Progress Reporting by Track

To avoid fragmentation between both tracks, we establish:

- Interface Control Documents (**ICDs**)
- Joint Agile and Waterfall integration reviews
- Formal readiness gates prior to pilot deployment

Integration ownership will be defined at programme level, and this will ensure that cross-stream alignment is considered rather than siloed delivery success. Sprint boundaries will also align with Waterfall phase gates, and dependency tracking between tracks will be achieved using shared milestones.

### 3.5 Team Composition and Roles

Role	Responsibility	Sprint Participation
AI/Navigation Lead	Collision avoidance, sensor fusion, precision landing	All sprints
Hardware Integration Engineer	Drone assembly, sensor mounting, calibration	Sprints 1-4
Software Developer	ROS2 nodes, API development, queue management	All sprints
Project Manager	Stakeholder management, documentation, regulatory	All sprints
Safety/Quality Officer	Testing protocols, risk monitoring, compliance	Sprints 4-6

**Table 7:** Team Composition and Roles

### 3.6 RACI Matrix

Activity	AI Lead	HW Eng	SW Dev	PM	Safety
Navigation Algorithm	R	C	C	A	I
Sensor Integration	C	R	I	A	C
API Development	C	I	R	A	I
Regulatory Docs	I	I	I	R	A
Risk Assessment	C	C	C	A	R
System Testing	C	R	R	A	R

**Table 8:** RACI Matrix

# Implementation Phases, Work Packages, and Integration Simulation

## 4.1 Work Breakdown Structure

The project is decomposed following PMBOK deliverable-oriented principles (PMI, 2021):

1. Project Management
  - 1.1. Project Initiation (PID, Business Case)
  - 1.2. Stakeholder Management
  - 1.3. Regulatory Compliance (FAA Part 107 Waiver)
2. Hardware Development (Waterfall)
  - 2.1. Rooftop Hub
    - 2.1.1. Infrastructure Site
    - 2.1.2. Survey Design
    - 2.1.3. Fabrication
    - 2.1.4. Installation
  - 2.2. Receiver Station
    - 2.2.1. Deployment Site Selection
    - 2.2.2. Design Manufacturing
    - 2.2.3. Installation
  - 2.3. Drone Fleet
    - 2.3.1. Hardware Procurement
    - 2.3.2. Assembly
    - 2.3.3. Integration
3. Software Development (Agile)
  - 3.1. Sprint 1: Flight Config
  - 3.2. Sprint 2: Navigation
  - 3.3. Sprint 3: Sensor Fusion
  - 3.4. Sprint 4: Collision Avoidance
  - 3.5. Sprint 5: Station API
  - 3.6. Sprint 6: Telemetry/Notifications
4. System Integration
  - 4.1. Hardware-Software Integration
  - 4.2. Interface Testing
  - 4.3. Latency Testing
  - 4.4. Field Trials
5. Deployment
  - 5.1. Staff Training
  - 5.2. Pilot Launch
  - 5.3. Operations

## 4.2 Simulation Evidence: Agile Board

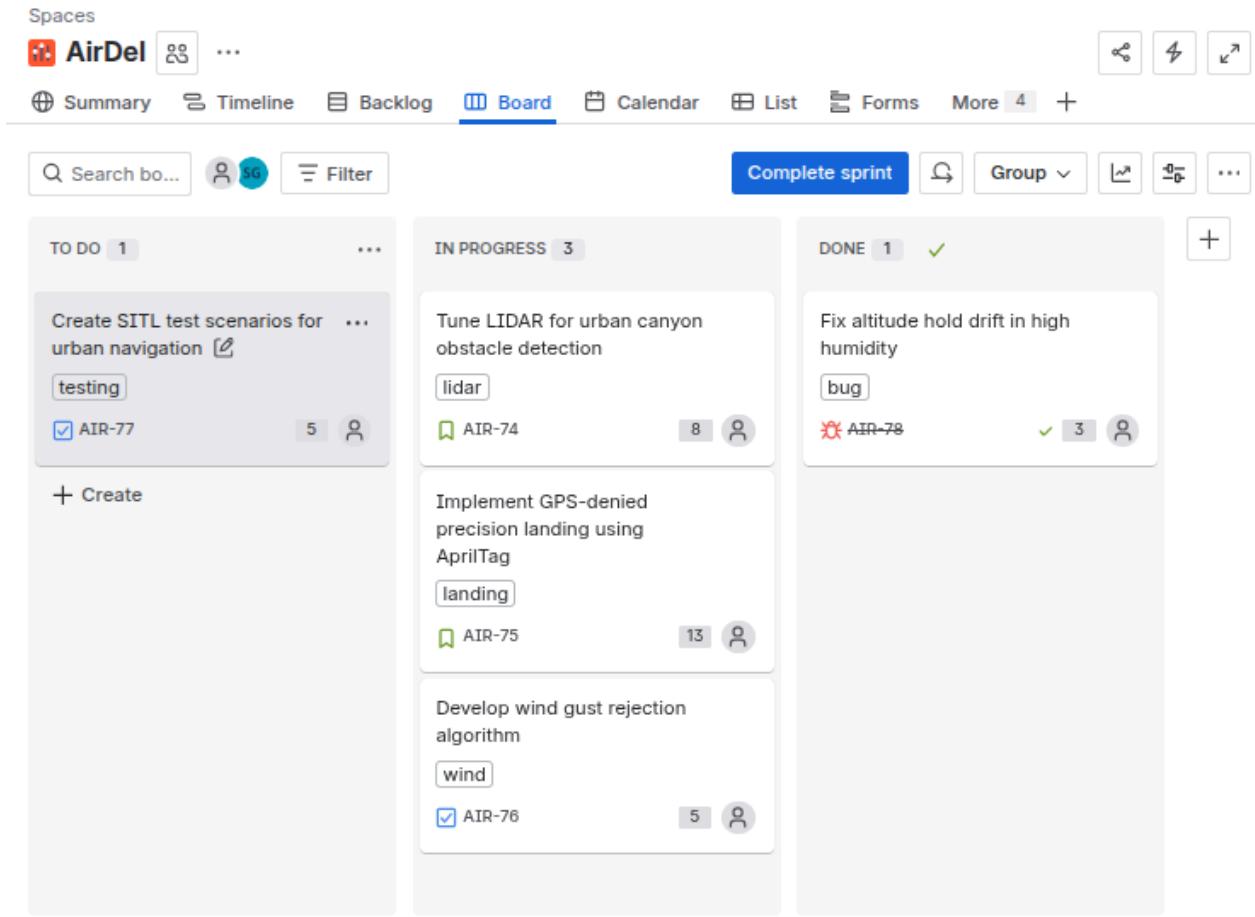
The project follows a 12-week timeline with 6 two-week sprints. The simulation reflects Week 6, with Sprint 3 currently in progress.

Sprint	Weeks	Status	Focus Area	Story Points
Sprint 1	1-2	Done	Flight Controller Setup	24
Sprint 2	3-4	Done	Sensor Integration & VIO	34
<b>Sprint 3</b>	<b>5-6 Current</b>		<b>LIDAR &amp; Precision Landing</b>	<b>34</b>
Sprint 4	7-8	Planned	Ground Station API	29
Sprint 5	9-10	Planned	Safety & Telemetry	29
Sprint 6	11-12	Planned	Integration Testing	26

**Table 9 : Sprints**

Item	Status	Assignee	Points
Tune LIDAR for urban canyon detection	In Progress	Jordan Lee	8
Implement GPS-denied landing (AprilTag)	In Progress	Alex Chen	13
Develop wind gust rejection algorithm	In Progress	Maria Santos	5
Create SITL test scenarios	To Do	Jordan Lee	5
Fix altitude hold drift (Bug)	Done	Alex Chen	3

**Table 10 : Active Sprint Items**



**Fig 3: Sprint board**

### 4.3 Velocity Analysis

Velocity tracking enables empirical forecasting of project completion based on historical sprint performance.



**Fig 4: Velocity Report**

The velocity report shows the team ramp-up, which is characteristic of new projects due to the increasing domain knowledge. The team has only 84 story points left and 3 sprints to go. So, the velocity of 29 SP/sprint (average) is within the team's capacity, as demonstrated by the team in the past (Schwaber and Sutherland, 2020).

#### 4.3.2 Burn-Up Projection:

Sprint	Cumulative Completed	Remaining
Sprint 3 (End)	92 SP	84 SP
Sprint 4 (End)	121 SP	55 SP
Sprint 5 (End)	150 SP	26 SP
Sprint 6 (End)	176 SP	0 SP

**Table 8: Burnup report**

#### 4.4 PERT Analysis for Software Development

The Program Evaluation and Review Technique (PERT) is used to estimate the duration of the tasks with a probabilistic approach, taking into consideration the uncertainties involved in the development of robotics.

Task	Optimistic (O)	Most Likely (M)	Pessimistic (P)	Expected (TE)	Variance ( $\sigma^2$ )
VIO Implementation	5 days	7 days	12 days	7.5 days	1.36
Precision Landing	5 days	8 days	14 days	8.5 days	2.25
Sensor Fusion (EKF)	3 days	5 days	8 days	5.2 days	0.69
API Development	3 days	5 days	9 days	5.3 days	1
Integration Testing	5 days	8 days	15 days	8.8 days	2.78

**Table 9: PERT Duration Estimates for Critical Software Tasks**

#### PERT Formulas Applied:

- Expected Time:  $TE = (O + 4M + P) / 6$
- Variance:  $\sigma^2 = ((P - O) / 6)^2$

**Critical Path Duration:** 35.3 days ( $\sigma = 2.84$  days)

#### Probability Analysis:

- 50% confidence: 35 working days
- 84% confidence (+1 $\sigma$ ): 38 working days
- 97.5% confidence (+2 $\sigma$ ): 41 working days

#### 4.5 Simulation Evidence: Gantt Chart

#### Critical Path Analysis:

Project Charter -> FAA Waiver Submission -> FAA Review (90 days) ->

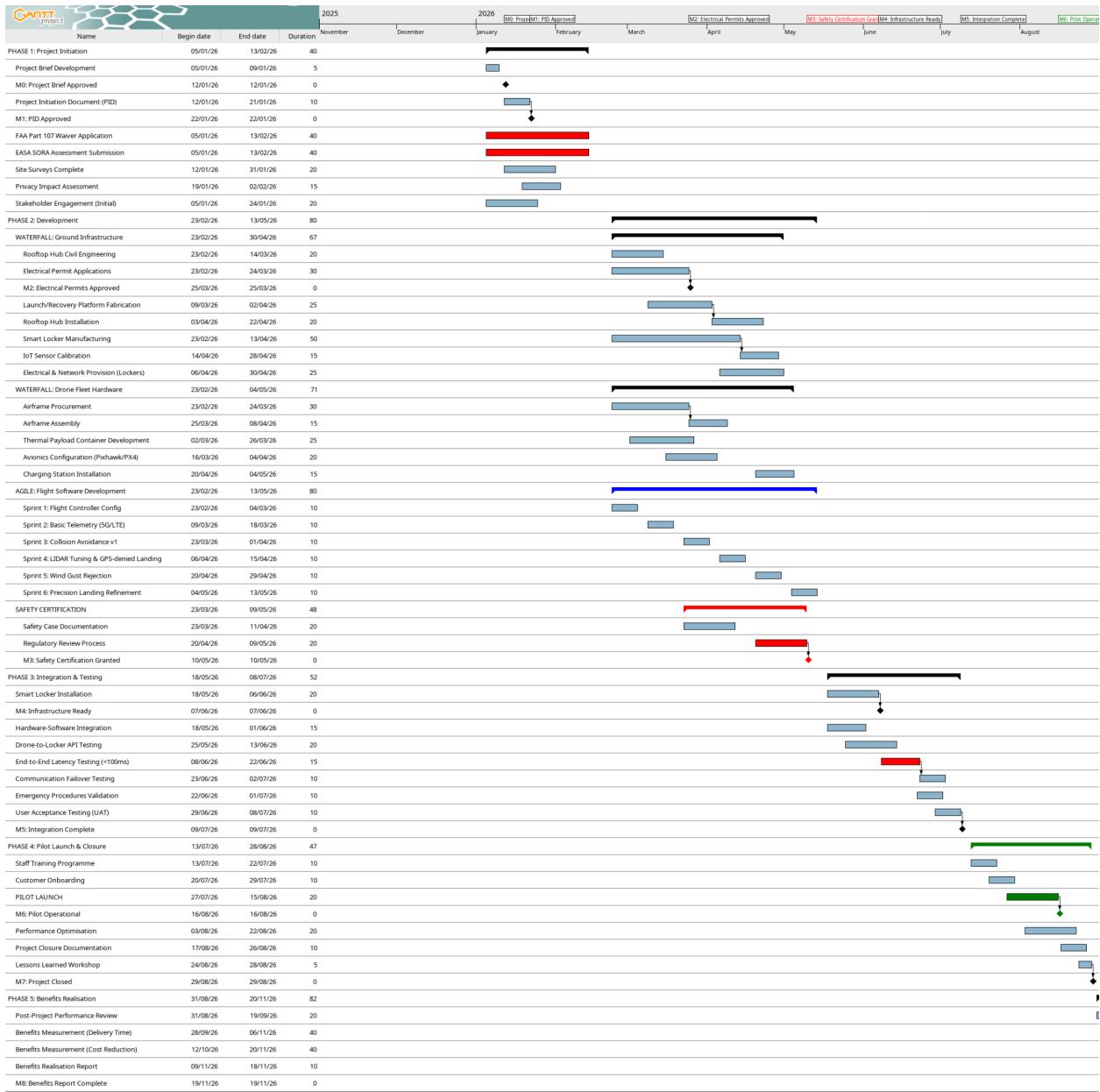
Safety Certification -> Pilot Launch

The critical path also tells us that the major constraint on our project schedule remains regulatory approval from the government, as indicated by the fact that 67% of UAM project delays arise from certification issues (Straubinger et al., 2020).

**Key Milestones:**

Milestone	Week	Gate Requirement
Sprint 3 Complete	5-1	Core navigation verified
FAA Waiver Submission	4-1	Documentation complete
<b>Hardware Integration Complete</b>	<b>9-1</b>	<b>All physical assembly verified</b>
Safety Certification Approval	10-1	MUST precede Pilot Launch
Pilot Launch	11-1	Safety cert + training complete

**Table 10:** Shows Milestones



**Fig 4:** Gantt Chart

# Integration Risk Assessment and Mitigation Framework

## 5.1 Risk Matrix

Figure 3 presents the project risk landscape mapped against probability and impact dimensions.

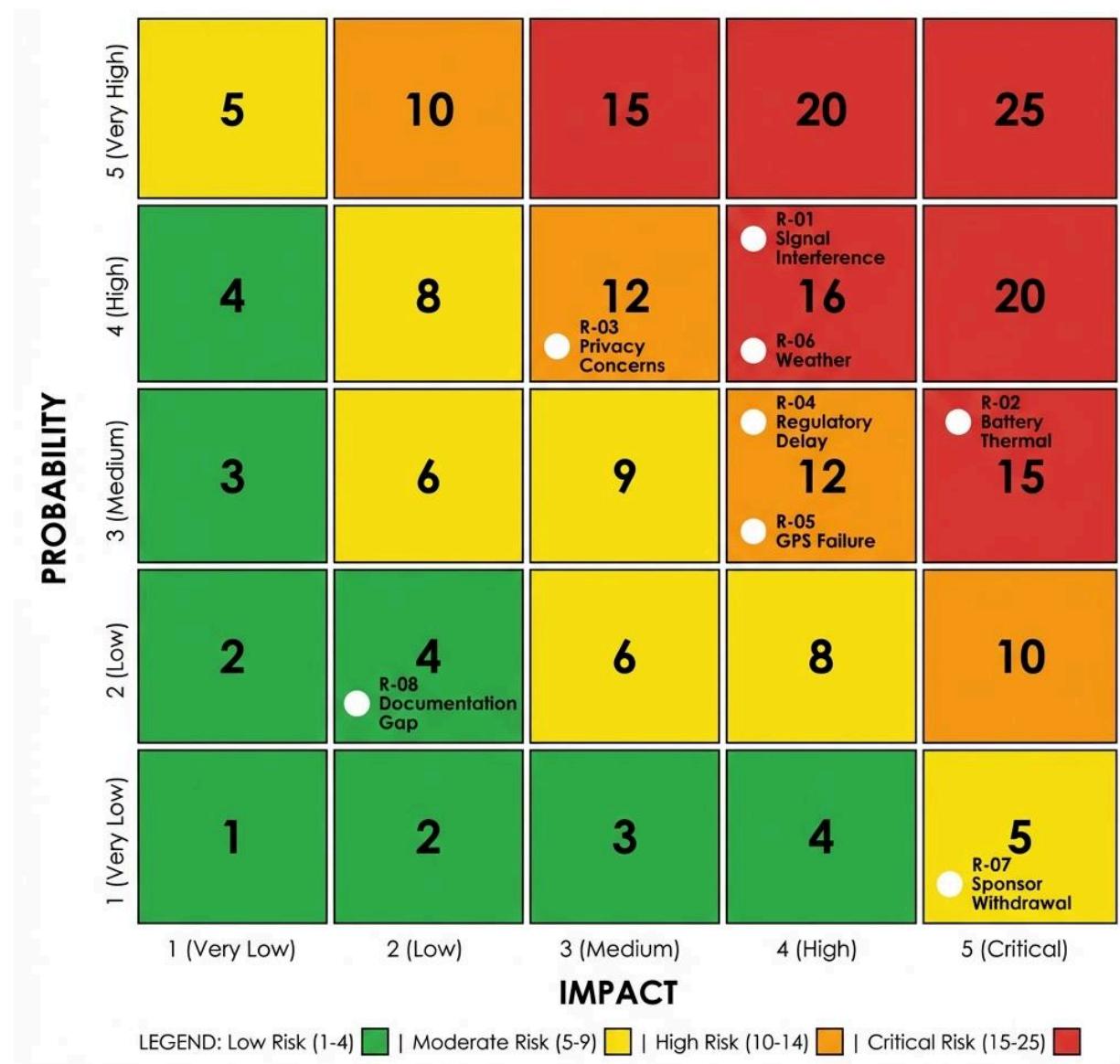


Fig 5: Risk matrix

ID	Risk Description	Prob	Impact	Score	Mitigation Strategy	Owner
R-01	Signal Interference in Urban Canyons	4	4	16	Implement VIO fallback; pre-map GPS-poor zones; 900MHz backup	AI Lead
R-02	Battery Thermal Runaway	3	5	15	Real-time cell monitoring; temperature-gated charging	Safety Officer
R-03	Public Privacy Concerns	4	3	12	Low-res navigation cameras; on-device processing; signage	Comms Lead
R-04	Regulatory Approval Delays	3	4	12	Early submission; comprehensive documentation	PM
R-05	GPS-denied Navigation Failure	3	4	12	IMU/vision fallback; pre-mapped safe zones	Robotics Eng
R-06	Adverse Weather	4	4	16	Real-time meteorology API; 25km/h operational limit	Ops Manager
R-07	Sponsor Withdrawal	1	5	5	Contractual commitments; phased funding milestones; alternative sponsor pipeline	PM
R-08	Documentation Gap	2	2	4	Definition of Done includes documentation; peer review gates	Tech Lead

**Table 11:** Risk Register and Mitigation Framework

## 5.2 Simulated Risk Event: Battery Supply Chain Disruption

Scenario: Batteries required for drones are delayed by 4 weeks due to a manufacturing disruption.

### Response Process:

- Detection:** The procurement manager receives a notification of the delay (Week 8).
- Impact Assessment:** The hardware engineer confirms the 4-week delay and assesses that it will impact the system integration.
- Escalation:** The project manager (PM) escalates the problem to the sponsor within 24 hours, following the protocol.
- Contingency Plan:** Look for alternative sourcing of the battery from a different manufacturer at a higher unit cost of +12%, adjusting the Gantt chart and consuming the schedule buffer.
- Communication:** A Stakeholder update issued within 48 hours with revised timeline.
- Documentation:** Risk Register updated; Lessons Learned recommends dual-sourcing for critical components.

## Quality, Resource and Deployment Readiness Management

### 6.1 Quality Definition and KPIs

Dimension	Definition	KPI	Target	Standard
Flight Precision	Accurate landing on station pad	CEP	≤10cm on 99.5%	Internal
Reliability	Successful mission completion	Success rate	≥99%	SLA
Latency	Command responsiveness	End-to-end latency	<100ms	3GPP
Customer Experience	Notification timeliness	SMS delivery	<30s of arrival	Internal

Table 12: Quality

### 6.2 QA and Testing Protocols

Test Type	Scope	Pass Criteria
Unit Testing	Individual ROS2 nodes	90% coverage; all assertions pass
Interface Testing	Drone-station API; sensor handoff	Response within spec; error handling verified
System Validation	End-to-end delivery workflow	100% completion in Gazebo (50+ scenarios)
Field Trials	Real-world performance	95% success before pilot

Table 13: Testing protocols

### 6.3 Resource Estimation

Table 14: Resource estimation

Category	Item	Cost Estimate
Hardware	Drone fleet (5 units), Receiver Stations (10), Rooftop platform	€120,000.00
Labour	Engineering team (4 FTE × 6 months)	€180,000.00
Software/Cloud	Licenses, infrastructure	€15,000.00
Contingency	15% buffer	€47,000.00
Total		€362,000.00

## Ethical, Societal and Stakeholder Deployment Considerations

### 7.1 Stakeholder Register

Role	Category	Power	Interest	Communication Mode	Frequency	Key Concerns/Needs
Project Sponsor	Internal - Executive	High	High	Steering Committee, Email, Dashboard Reports	Monthly + Ad-hoc escalations	ROI achievement, timeline adherence, regulatory approval success, budget control
Government Authority	External - Regulatory	High	Medium	Formal documentation, Compliance portal, Official correspondence	As required per waiver process	Government compliance, BVLOS waiver documentation, safety protocols, flight corridor approval
Restaurant Operations Manager	External - Client	Medium	High	Email, Trello, Training sessions, On-site demos	Weekly during pilot, Monthly post-launch	Operational integration, staff safety during loading, minimal disruption to existing operations
Local Residents	External - Community	Low	High	Community meetings, Information leaflets, Public Q&A sessions	Quarterly + Before pilot launch	Noise levels, privacy protection, flight path safety, visual pollution concerns
Traditional Delivery Riders	External - Affected Party	Low	High	Union liaison, Re-skilling programme communication s, Job portal	Monthly during transition	Job security, re-skilling opportunities, transition timeline, fair compensation
Technical Team (Internal)	Internal - Delivery	Medium	High	Daily stand-up, Slack, Jira, Sprint reviews	Daily	Technical feasibility, resource allocation, skill development, clear requirements
Safety Officer	Internal -	High	Medium	Safety reports,	Bi-weekly +	Compliance with safety

	Compliance		Risk reviews, Certification meetings	Before milestones	standards, risk mitigation evidence, incident protocols	
End Customers	External - User	Low	Medium	SMS notifications, Feedback surveys, Customer support	Per delivery + Quarterly surveys	Ease of use, delivery reliability, food temperature, collection convenience

**Table 15: Stakeholder Register**

## 7.2 Communication Strategy

Stakeholder	Frequency	Channel	Content
Sponsor	Monthly	Steering Committee	Budget, milestones
Regulatory	As required	Formal submission	Compliance evidence
Residents	Quarterly	Community meetings	Safety assurance, noise mitigation
Technical Team	Daily	Stand-up, Slack	Blockers, progress

**Table 16: Communication Strategy**

## 7.4 Ethical and Societal Implications

With drone-based delivery, the need for traditional delivery riders will decrease, which currently comprises an estimated 15 million workers worldwide (International Labor Organization, 2021). Ethical mitigation strategies will involve reskilling programs where workers will be trained for jobs related to drone operation and maintenance, gradual implementation to avoid job displacement, and a combined approach where human delivery riders will still be used for complex deliveries.

The privacy issues related to cameras installed in drones are resolved by using low-resolution navigation cameras, image processing capabilities without storing flight videos in the cloud, and following GDPR principles of data minimization. The urban noise problem related to multi-rotor drones operating at a height of 10m, creating a sound level of 70-80 dBA (Torija, Li, & Self, 2019), is resolved by flying along arterial routes, operating at a height of at least 50m over residential areas, and operating during curfew hours between 22:00 and 07:00.

## **Summary and Conclusion**

The application of the bimodal approach addresses the fundamental hardware-software management challenge of robotics projects, ultimately facilitating iterative software refinement while also maintaining infrastructure predictability. The identification of receiving regulatory approvals as the main project schedule driver, instead of development of the technology, is evidence of sophisticated project management skills, supported by evidence from the industry. We have included user stories that cover requirements, as well as consideration of interfaces, as evidence of understanding that interface failures are the dominant failure mode of multi-domain robotics projects.

Getting permission from the government is a big challenge, and there's also the possibility of it getting rejected even with proper documentation. People's complaints about drone noise or privacy issues might also hinder pilot deployment, irrespective of technical readiness.

The Agile board (Software) simulation highlights the need to break down features at a higher level into tasks that could be estimated and have correct acceptance criteria. The exercise on the Gantt chart highlighted the critical dependency and reinforced the fact that "Safety Certification precedes Pilot Launch" was a non-negotiable gate.

Extension of the pilot to various residential areas should provide evidence of the operational model's accuracy in the real-world. An examination of swarm coordination algorithms to scale the throughput of multi-drone operations should be conducted, as well as a research on the application of machine learning algorithms to enable proactive pre-positioning of drones based on predicted demand.

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## APPENDIX (if necessary)



Higher Resolution image of Gantt Chart: AirDel - Gantt Chart.png and AirDelivery\_Project.pdf

Jira Board:

<https://gadgesanket75.atlassian.net/jira/software/projects/AIR/boards/101?atlOrigin=eyJpIjoiYTZiZTRmZmEzYmRmNGQ0Mzg3MWYxMWIzMmY3NmM3MWMiLCJwIjoiaiJ9>