APSAS SYSTEM AND MODELING REPORT

ISE-2 | HSHL
Group 7

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1. Abstract
This document provides structured guidance for the conceptualization, requirement modeling, and behavior analysis of the Automated Pit Stop Assistance System (APSAS). The goal of APSAS is to combine safety and precision with the spirit of high-stakes motorsport, ensuring both innovation and human consideration remain at the center of pit operations.

2. Introduction
The Automated Pit Stop Assistance System (APSAS) is a safety-critical platform designed to enhance the operational reliability and safety of Formula 1 pit stops. It is built around the idea of augmenting human performance without compromising the spirit of competitive racing. APSAS ensures that race cars are only released from the pit box when it is verifiably safe to do so, based on a synchronized decision framework that monitors crew readiness, mechanical task completion, and pit lane conditions in real time.

While the thrill and speed of pit stops are a core part of the sport, APSAS aims to reduce preventable human error, protect team personnel, and ensure fair and transparent decision-making, especially under pressure. This system is not about slowing down the action; rather, it's about enabling teams to push harder, knowing the margins are being safely and intelligently managed.

APSAS is composed of three tightly integrated subsystems:
- WWES – Wheel, Wing, and Jack Engagement System
- CRPDS – Crew Readiness and Position Detection System
- PLMS – Pit Lane Monitoring System

Each system enforces timing, spatial, and operational constraints through the use of RFID tracking, computer vision, laser-based vehicle detection, and automated actuation. These systems work in concert to provide a single readiness signal to the pit release control logic.

3. System/Sub-Systems

3.1. WWES – Wheel, Wing, and Jack Engagement System
WWES manages the physical and mechanical aspects of a pitstop, including tire servicing, aerodynamic adjustments, and the automated lifting and lowering of the vehicle. This subsystem is designed to reduce reliance on manual signaling, improve timing consistency, and lower the number of crew members directly exposed to moving parts.

Subsystems: 1. Wheel Operations
Control 2. Wing Adjustment
Management 3. Auto-Jack Control Subsystem

Key Functions:
- Tracks crew using RFID and computer vision
- Monitors tool engagement and technician posture to determine task progression
- Detects and manages aerodynamic adjustments
- Raises and lowers the vehicle using laser-detected auto-jack triggers
- Controls a visual floor signal (red/green light) to indicate pit release authorization

3.2. CRPDS – Crew Readiness and Position Detection System

CRPDS safeguards human involvement in the pit stop process by ensuring crew members are where they should be, when they should be, and are in safe postures before release authorization is considered.

This subsystem balances real-time positional awareness with role-based logic. It cross-references crew assignments with allowed zones, posture detection, and timing thresholds.

Technologies Employed:
- Redundant RFID tagging (embedded in gloves, vests, or helmets)
- Real-time computer vision (PoseNet, YOLO) for human pose and zone validation
- Defined pit box zoning (Z1–Z4) to categorize danger and safety areas

Operational Flow:
1. Car enters pit box; crew approach monitored
2. Crew tags are tracked against assigned zones
3. Vision system detects pose and task posture
4. If any crew is detected in restricted zones, or their tag is missing, release is blocked
5. Release is only authorized when all crew are confirmed to have completed their roles and retreated to safe zones.

Requirements Overview:
- Zone correctness must be verified before and after task execution
- Posture and time windows are required to infer task completion
- Redundancy in detection ensures safety even during RFID dropouts

3.3. PLMS – Pit Lane Monitoring System

The PLMS component of APSAS exists to monitor the wider dynamic environment around the pit box. While WWES and CRPDS focus on internal operations, PLMS watches the pit lane for high-speed traffic that may pose a threat during release.

This system operates using computer vision to detect and classify approaching vehicles, assess their trajectory, and determine whether conditions are safe for release.

Core Functions:
- Detect rearward and lateral pit lane traffic via rear-facing cameras
- Use real-time visual tracking to estimate approach speed and direction
- Classify the severity of potential conflicts (safe, caution, block)
- Integrate with APSAS logic to override release when unsafe

Decision Logic:
- If any vehicle is approaching above a critical speed within a defined proximity, the system withholds the green light
- Only when no threats are detected and all internal systems report ready does PLMS contribute a "safe to release" signal

Requirements Overview:
- Vision system must maintain accuracy under varied lighting and weather conditions
- Threat classification logic must operate within tight latency windows
- System must react in under 50ms to any sudden threat emergence

Cross-System Readiness Integration

APSAS uses a simple boolean AND logic to integrate signals from all three subsystems.
Release is only allowed when all systems report their respective "READY" status.

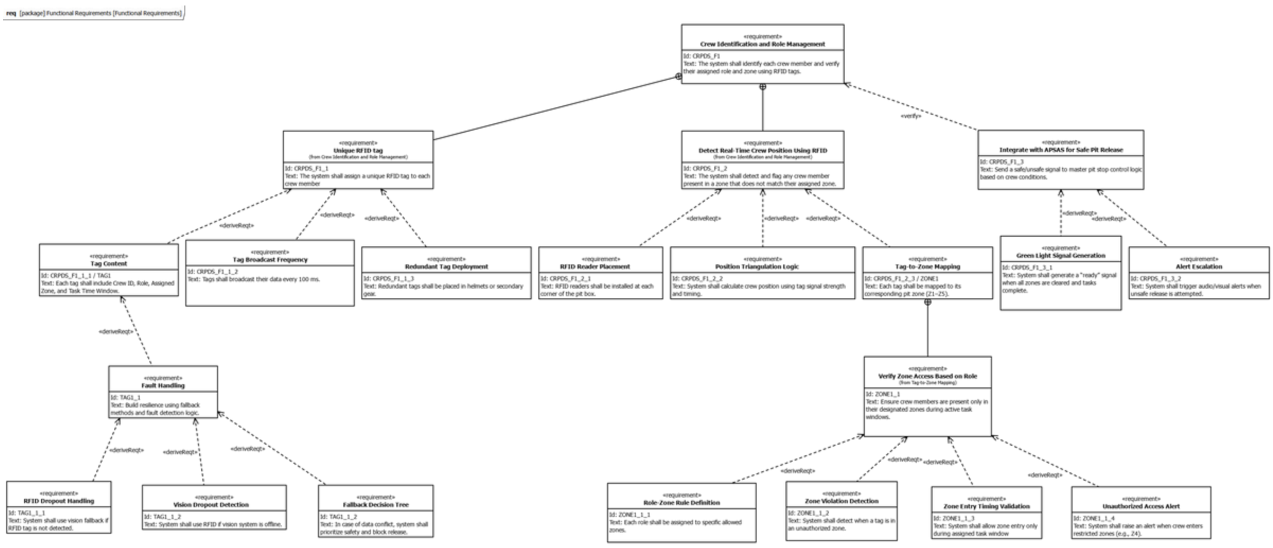
```
ifWWES_READY && CRPDS_READY && PLMS_READY:
    Signal Release = GREEN
else:
    Signal Release = RED
```

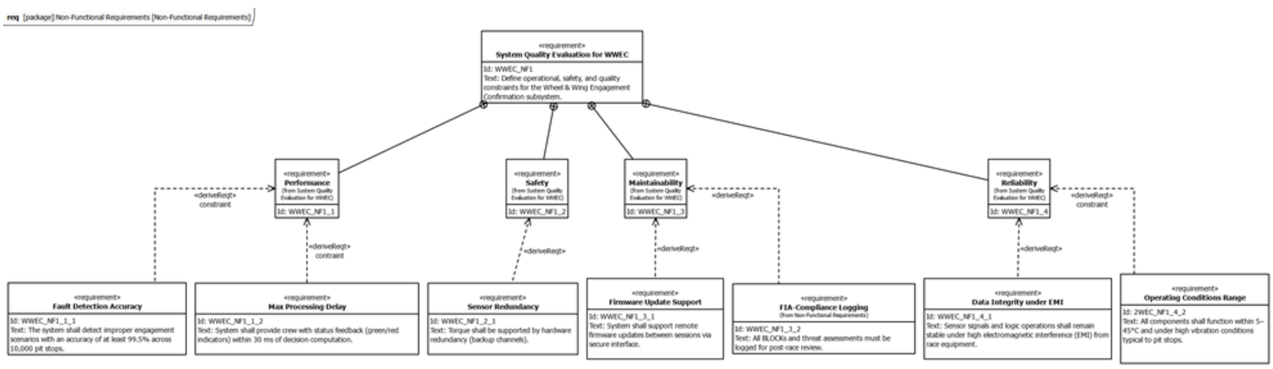
4. Requirement Diagrams

WWES – Wheel, Wing, and Jack Engagement System

The functional requirements of the WWES focus on ensuring that mechanical tasks during a pit stop are carried out safely and efficiently. This includes verifying that all tire operations are fully completed and that crew members have returned to designated safe zones before the car is cleared for release. It also ensures that wing adjustments are performed by authorized personnel with correct posture, and that the automated jack system raises and lowers the vehicle based on laser-based input and task completion. A visual red/green signal system is used to indicate when it is safe to release the car.

From a non-functional standpoint, WWES must operate under strict timing constraints, particularly for jack actuation, which should occur within milliseconds. The system is expected to maintain high reliability through redundancy, using both RFID and computer vision to detect crew activity. It must also deliver accurate posture and task recognition (with confidence levels above 95%), function correctly in various lighting conditions, and be designed for easy maintenance and fault recovery during high-stress scenarios.

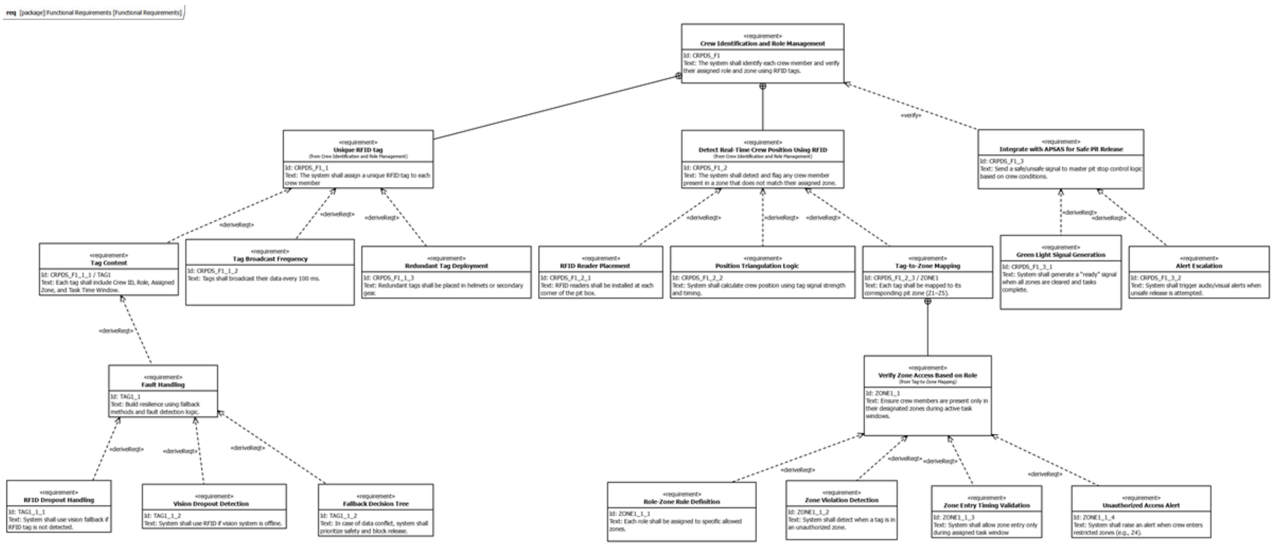


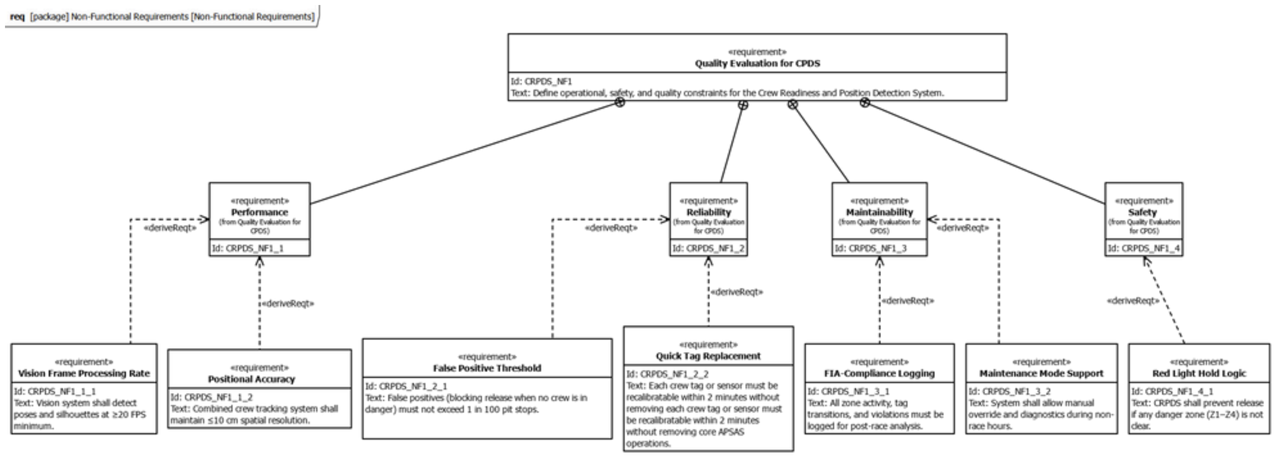


CRPDS – Crew Readiness and Position Detection System

The CRPDS subsystem is functionally responsible for monitoring crew behavior and ensuring safety compliance during pit stops. It tracks crew locations using RFID tags and computer vision and validates that each member is in their assigned zone and displaying a safe working posture. It also verifies that crew have completed their tasks and moved to safe areas before the system authorizes vehicle release.

Non-functional requirements for CRPDS emphasize robust and redundant detection mechanisms. The system must maintain posture detection accuracy of at least 95% and compensate for potential RFID failures through vision-based confirmation. It is required to function in real-time with minimal delay and must handle variable lighting and motion conditions typical of a Formula 1 pit lane. Safety remains the highest priority, with the system ensuring that no release occurs unless all crew-related checks are satisfied.

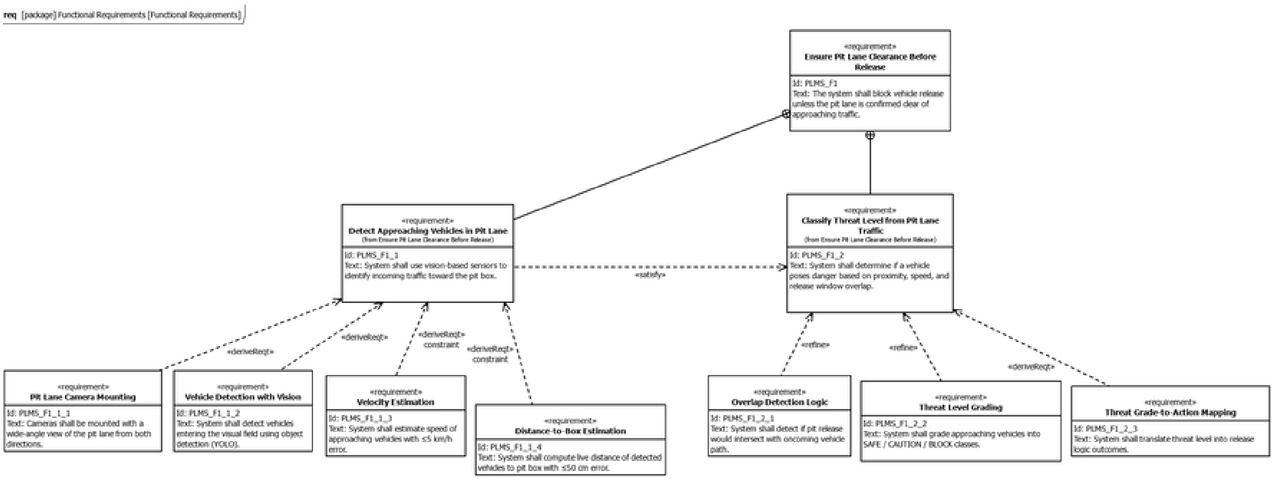


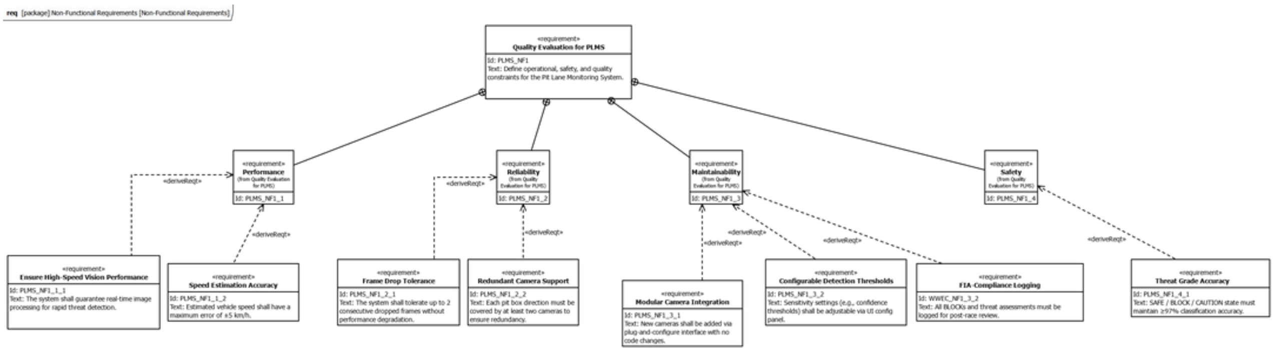


PLMS – Pit Lane Monitoring System

The PLMS is designed to observe and evaluate traffic conditions around the pit box. Functionally, it detects and classifies vehicles approaching the pit lane using rear-facing cameras. It estimates their speed and trajectory to determine whether it is safe to release the serviced vehicle. The system flags potential hazards as either safe, caution, or block, contributing directly to the final release decision.

Its non-functional requirements demand extremely low latency, with the system expected to assess and respond to threats in under 50 milliseconds. It must also perform reliably under different lighting and weather conditions, such as rain or glare. The visual tracking components must maintain high accuracy, and integration with the central APSAS logic must be seamless to ensure immediate override capability when dangerous situations arise.

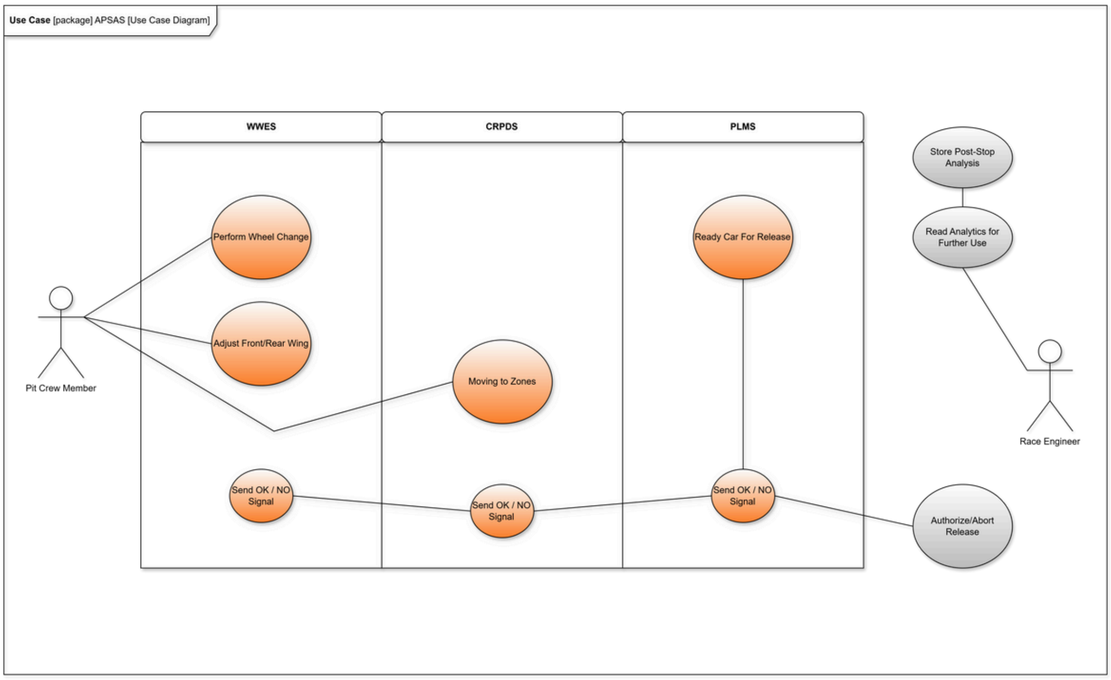




5. Behavior Diagrams

5.1. **Use-Case Diagram**

Actors such as Pit Crew Members, Car Sensors, and Race Engineers interact with APSAS use cases like wheel changes, monitoring pit lane safety, and authorizing release.



Use Case Diagram – External System Overview

This external use case diagram outlines the primary actors that interact with APSAS and the core functions they rely on. The main actors include the Pit Crew, Driver, Race Engineer, and Race Control Authority. The central use case is Manage Pit Stop Coordination, which includes sub-functions like Prevent Unsafe Release, Monitor Pit Crew Safety, and Validate Car Readiness for Release. These are essential operations that ensure safe and timely pit stop execution. The Generate System Reports function is extended by Monitor Pit Crew Safety, indicating that the system continuously logs safety metrics and performance for post-race review.

This diagram helps define how safety, readiness, and oversight are distributed across human and system roles, ensuring a holistic safety net during high-pressure pit stops.

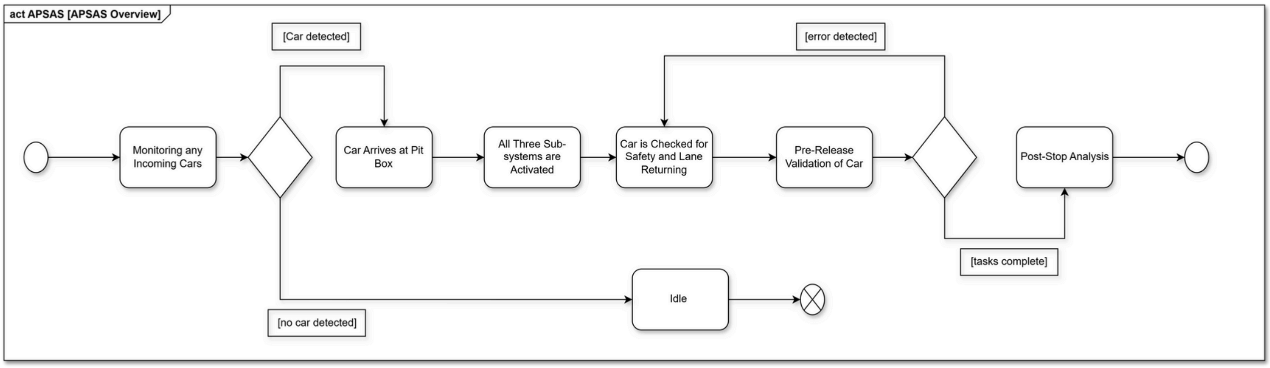
Use Case Diagram – Subsystem Interaction

This internal use case diagram breaks down APSAS into its three core subsystems—WWES, CRPDS, and PLMS—and shows how each contributes to the pit stop process. A single Pit Crew Member interacts with all three subsystems to perform operations such as Perform Wheel Change and Adjust Front/Rear Wing (WWES), Move to Zones (CRPDS), and Ready Car for Release (PLMS). Each subsystem includes a use case to Send OK/NO Signal, which feeds into the APSAS central logic for release authorization.

The Race Engineer actor is responsible for post-operation tasks such as Store Post-Stop Analysis, Read Analytics for Further Use, and Authorize or Abort Release. This ensures that all collected data is not only used for real-time decisions but also for future optimization and traceability. Together, the diagrams illustrate both operational responsibilities during the pit stop and the decision-making roles that support system integrity.

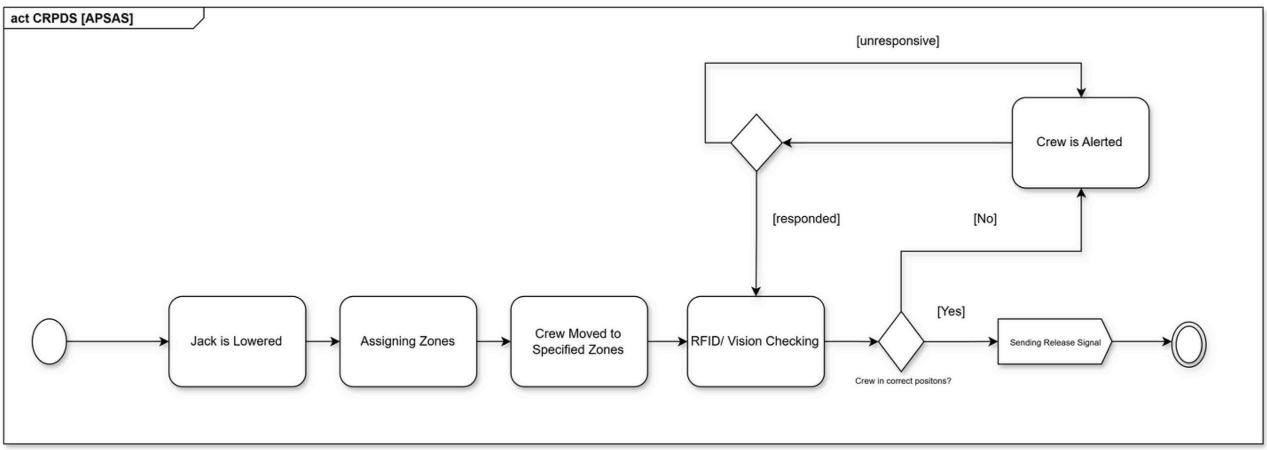
5.2 **Activity Diagram**

Outlines each subsystem's internal flow—from task detection to clearance signals. Example: WWES starts with car arrival and ends with readiness notification.



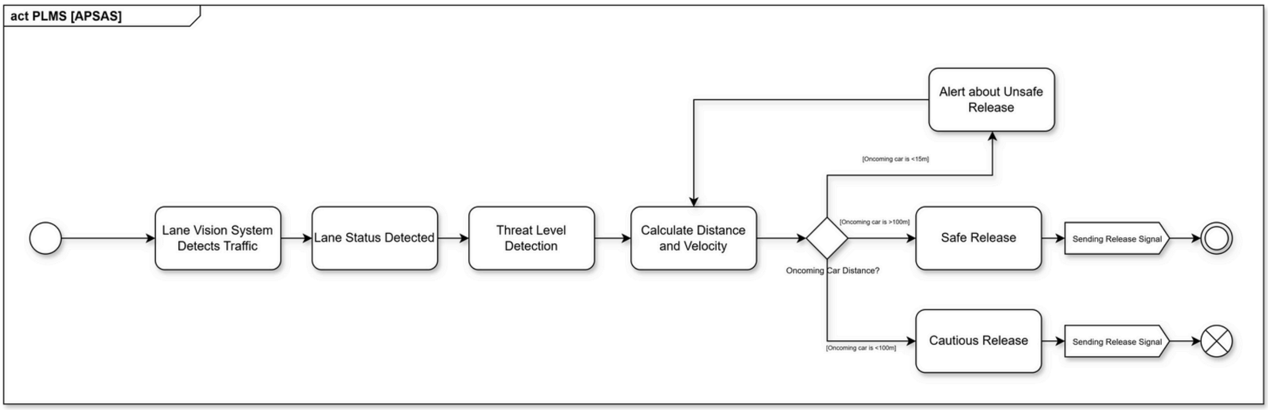
APSAS Overview Activity Diagram

This top-level activity diagram gives an overview of how APSAS orchestrates all subsystem actions. The process is triggered by detecting an incoming car. Once the car reaches the pit box, all three subsystems—CRPDS, PLMS, and WWES—are activated simultaneously. The car is then checked for overall safety and correct pit lane alignment. A pre-release validation step confirms if the car is ready. If no errors are found, the system concludes with post-stop analytics. If there are issues, the process loops back for correction, ensuring that the car is never released prematurely.



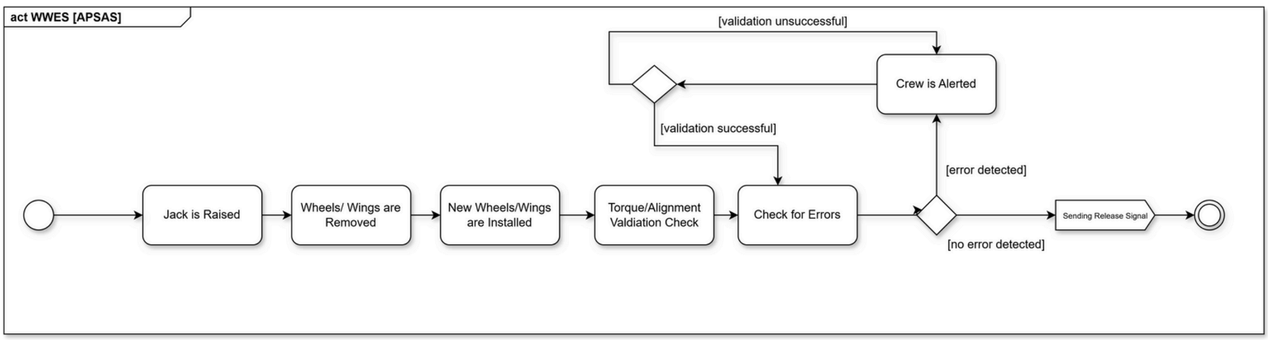
CRPDS Activity Diagram

This activity diagram illustrates the step-by-step process that the Crew Position Detection Subsystem (CRPDS) follows during a pit stop. It begins with the car's jack being lowered, triggering the assignment of crew members to specific operational zones. The crew then physically moves into these zones, after which RFID tags or vision-based sensors verify their positions. If any crew member is unresponsive or incorrectly placed, the system raises an alert. Only when all crew positions are validated does the CRPDS send a release signal to proceed.



PLMS Activity Diagram

This diagram captures the decision-making flow of the Pit Lane Monitoring Subsystem (PLMS). It starts when the system detects approaching pit lane traffic using vision sensors. It assesses the status of the lane and determines the threat level by calculating the distance and speed of oncoming vehicles. Based on this, it chooses between three outcomes: if the car is very close, it triggers an alert; if it's far enough, a safe release is initiated; and if it's within a cautionary range, a cautious release is carried out. Each case ends by sending a corresponding release signal.

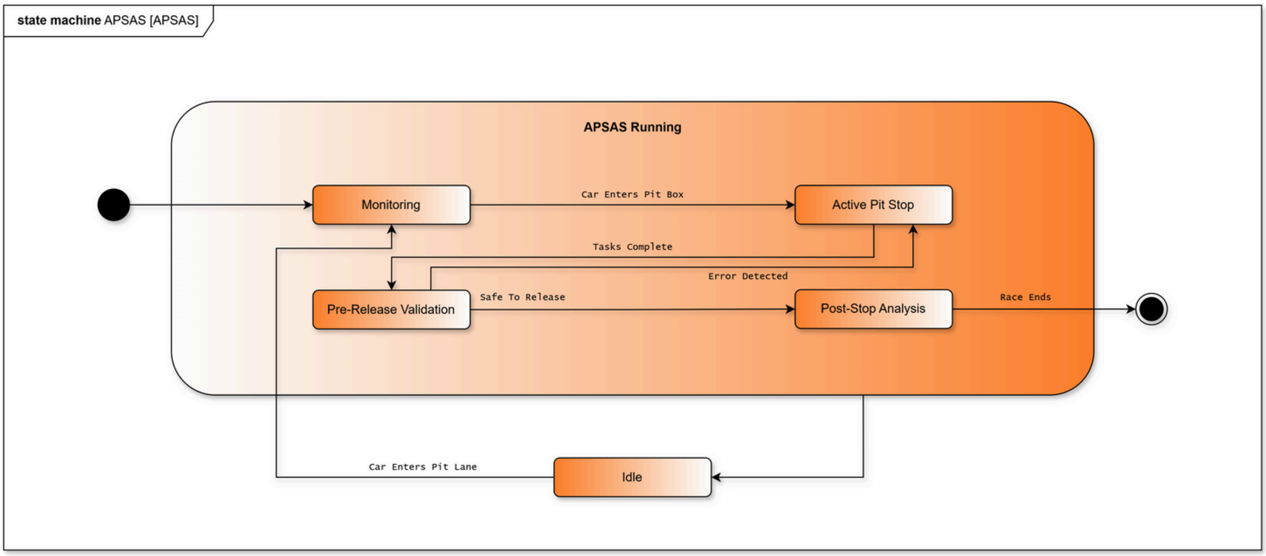


WWES Activity Diagram

The Wheel and Wing Exchange Subsystem (WWES) activity diagram outlines the full replacement and validation procedure. The process starts when the jack lifts the car, allowing old wheels and wings to be removed and new ones installed. After installation, the system checks for torque and alignment issues. If the validation fails or any errors are found, the crew is alerted. Otherwise, if everything checks out, WWES sends the green signal for the car to be released.

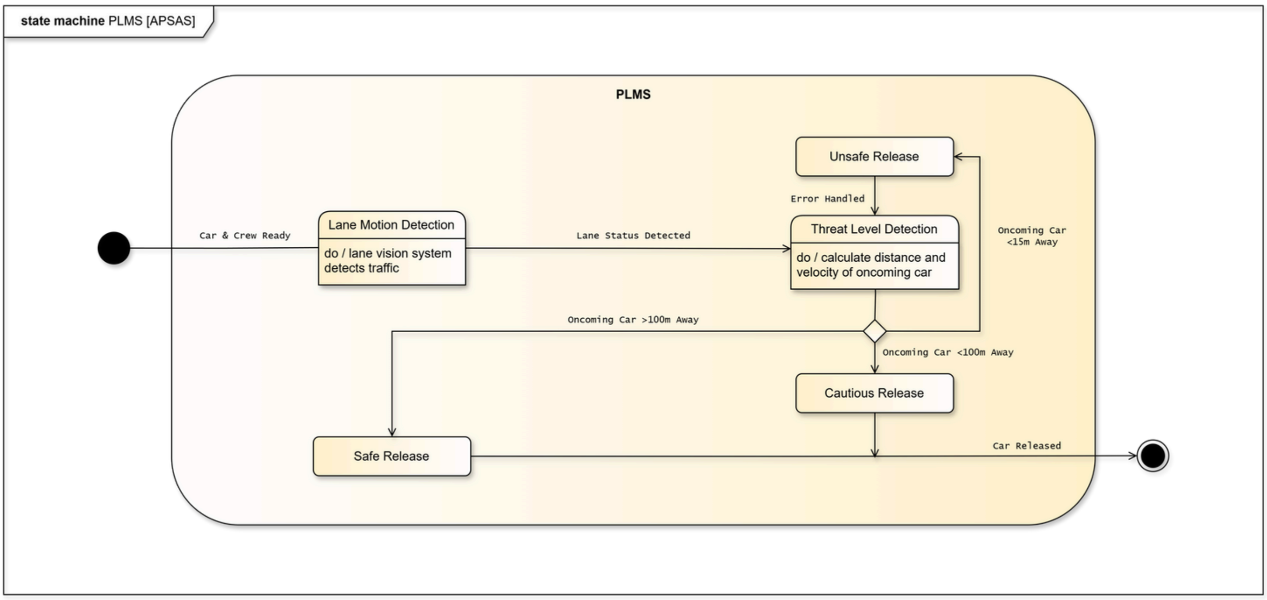
5.3 State Machine Diagram

Models system state transitions e.g. from MonitoringCrew to CrewClear in CRPDS based on posture checks and zone validation.



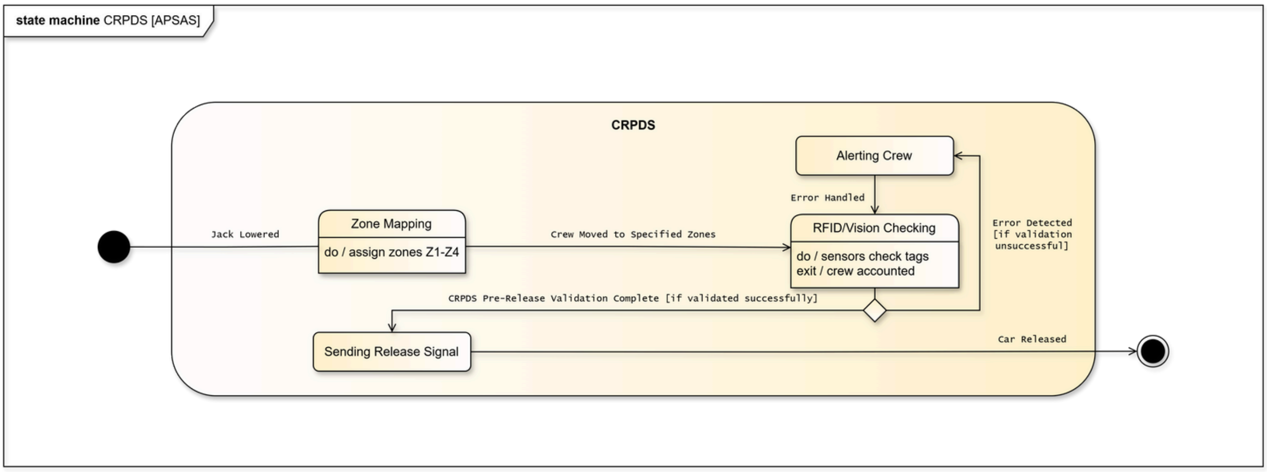
APSAS State Machine

This diagram captures the overall behavioral flow of the APSAS system during a pit stop. The system begins in an idle state and transitions to monitoring once a car enters the pit lane. After the car enters the pit box, the system moves into the active pit stop state. Upon task completion, it proceeds to a pre-release validation state to evaluate readiness. If all conditions are met, it allows safe release; otherwise, it routes to post-stop analysis. The system returns to monitoring unless the race ends.



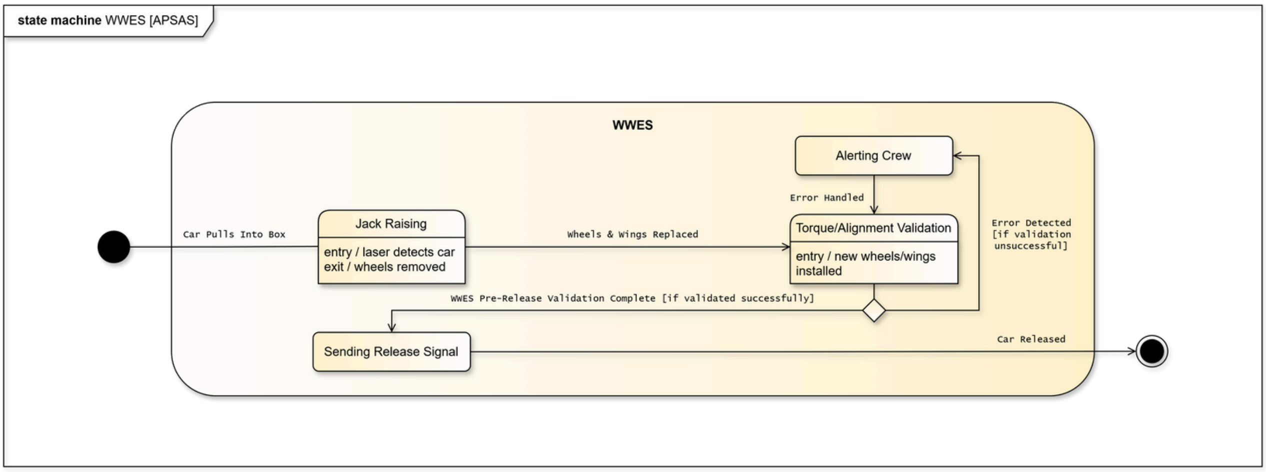
PLMS State Machine

The PLMS state machine focuses on pit lane safety. It begins by detecting motion in the lane using vision systems. Based on distance and speed, the system evaluates threat levels. If an oncoming car is too close, it blocks release; if the vehicle is within a cautious threshold, it flags a cautious release. Only when the lane is clear does it permit a safe release and terminate the process.



CRPDS State Machine

This diagram describes the behavior of the crew monitoring subsystem. It starts with zone mapping to assign safety zones (Z1–Z4) after the jack is lowered. Crew movement is monitored, and their tags and postures are validated using RFID and vision. If validation fails, the crew is alerted. On successful validation, a release signal is issued, and the system transitions to completion.

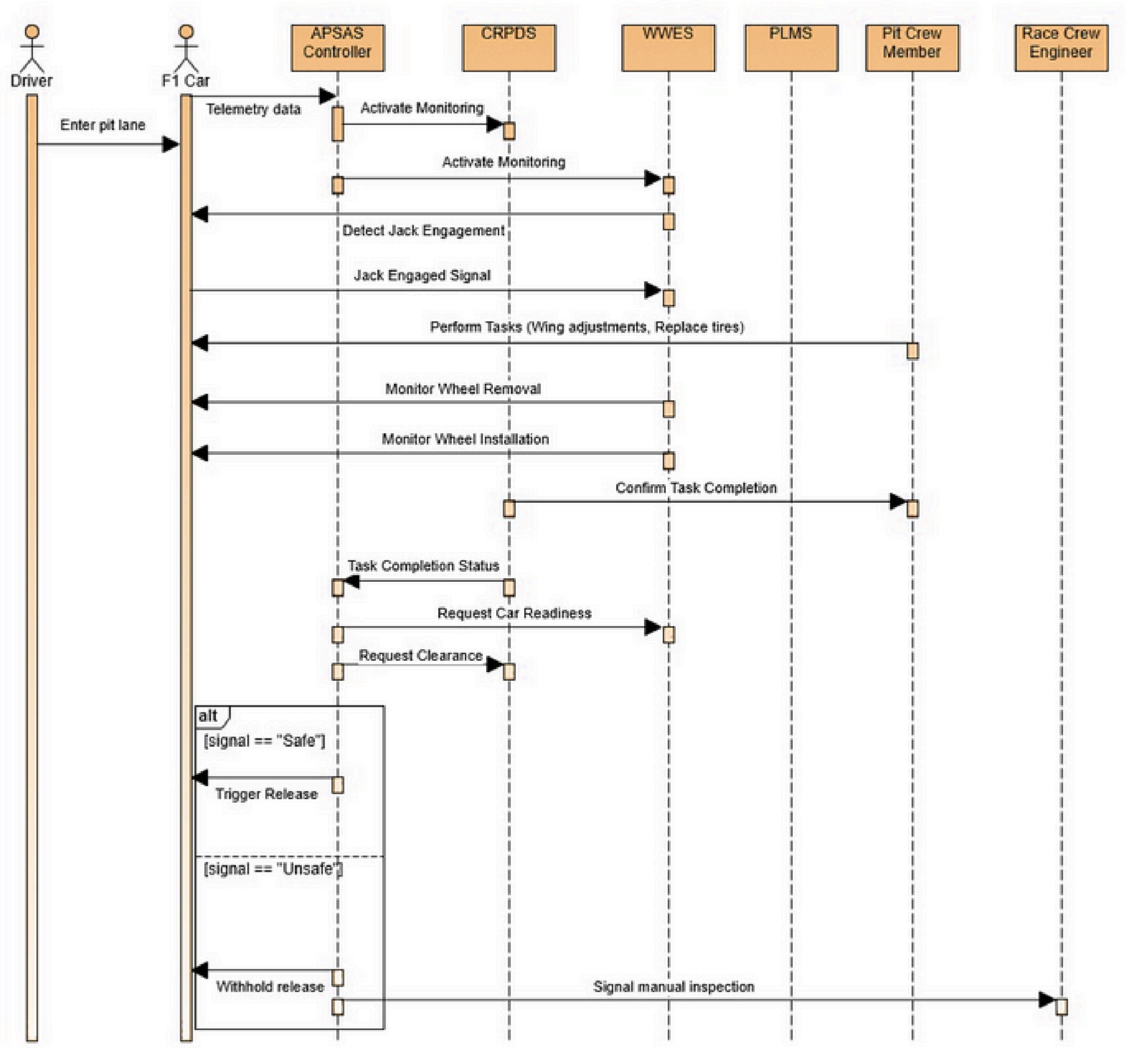


WWES State Machine

The WWES state machine outlines how the mechanical subsystem behaves during servicing. It begins when the car pulls into the pit box and transitions into the jack raising state, where the vehicle is lifted, and wheels are removed. After replacements, torque and alignment are validated. If this check fails, the crew is alerted. If successful, WWES sends a release signal and exits once the car is released.

5.4 Sequence Diagram

Models system state transitions e.g. from MonitoringCrew to CrewClear in CRPDS based on posture checks and zone validation.



This sequence diagram shows the chronological interaction between different components of the APSAS system during the pit stop. It starts when the car enters the pit lane and initiates telemetry transmission to the APSAS Controller. The controller activates monitoring subsystems like the CRPDS (Crew Readiness and Position Detection System), WWES (Wheel and Workzone Evaluation System), and PLMS (Pit Lane Monitoring System).

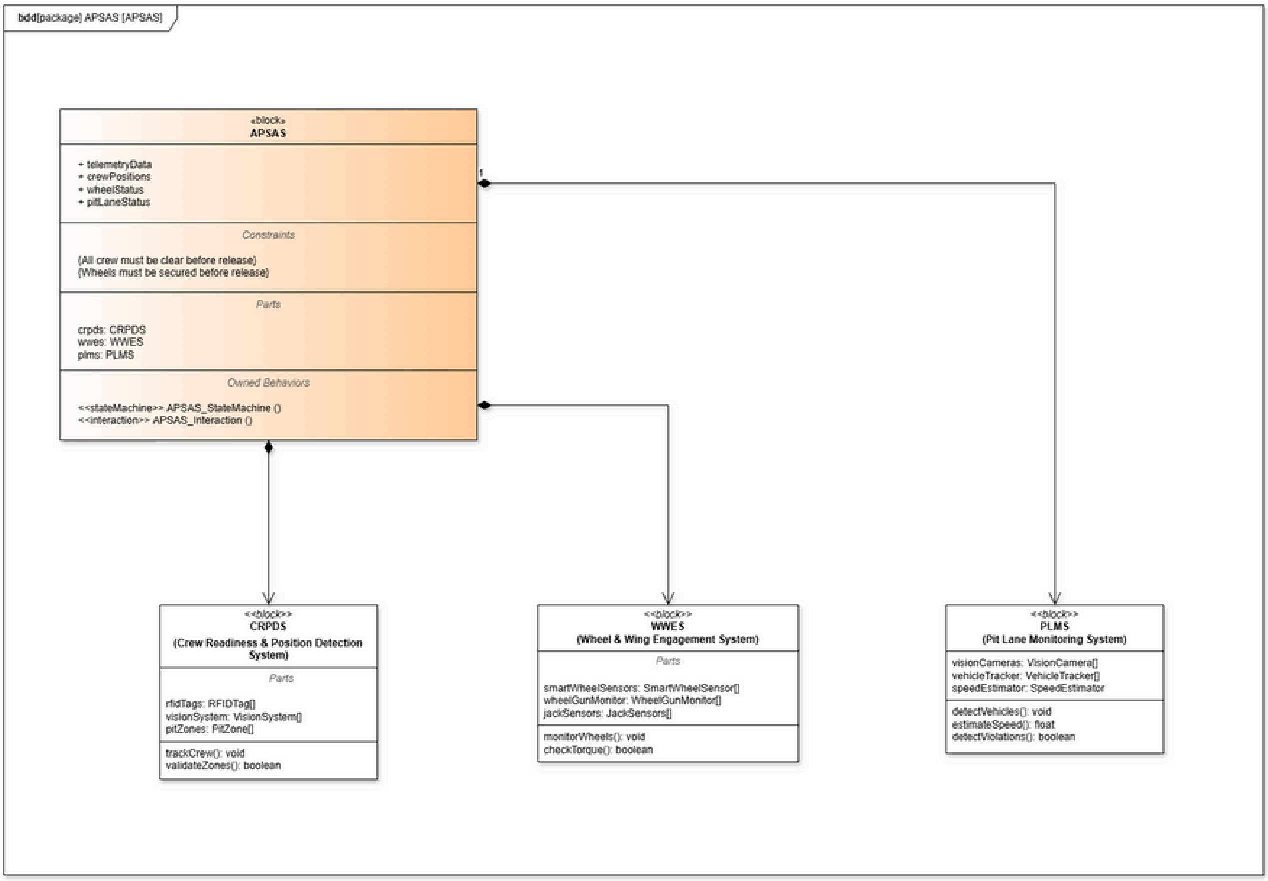
The pit crew performs tasks including jack engagement, wing adjustment and wheel changes, while WWES confirms the status of each operation.

Once all tasks are complete, CRPDS and WWES must report readiness and task completion. The APSAS controller evaluates safety and either sends a release signal if conditions are safe. If not, the release is withheld a manual inspection is performed.

6. Structure Diagrams

6.1 **Block Definition Diagram**

Outlines system hierarchy and interfaces between major blocks—sensors, subsystems, controller units. Clarifies what modules exist and how they interact at a hardware/software level.



APSAS – Top-Level System Block

At the top of the hierarchy is the APSAS block, representing the entire pit stop assistance system. This block encapsulates key data attributes such as telemetryData, crewPositions, wheelStatus, and pitLaneStatus, which are shared or monitored across the system.

Constraints are defined at this level to enforce critical safety logic, such as:
"All crew must be clear before release"
"Wheels must be secured before release"

APSAS is composed of three primary subsystem blocks, represented as parts:
crpds: CRPDS – Crew Readiness & Position Detection System
wwes: WWES – Wheel & Wing Engagement System
plms: PLMS – Pit Lane Monitoring System

Additionally, APSAS owns two behavioral elements:
A state machine (APSAS_StateMachine) that models the system's operational states.
An interaction diagram (APSAS_Interaction) that captures the communication logic between components.

CRPDS – Crew Readiness & Position Detection System
The CRPDS block is responsible for tracking crew members and verifying that they are in safe zones before vehicle release. It contains three key parts:
rfidTags: RFIDTag[]
visionSystem: VisionSystem[]
pitZones: PitZone[]

These elements work together to monitor crew location and posture. CRPDS defines two operations:
trackCrew() – for real-time crew monitoring
validateZones() – to confirm whether all personnel are in safe positions

WWES – Wheel & Wing Engagement System
The WWES block manages the mechanical aspects of the pit stop, particularly tire operations and vehicle elevation. Its internal parts include:
smartWheelSensors: SmartWheelSensor[]
wheelGunMonitor: WheelGunMonitor[]
jackSensors: JackSensor[]

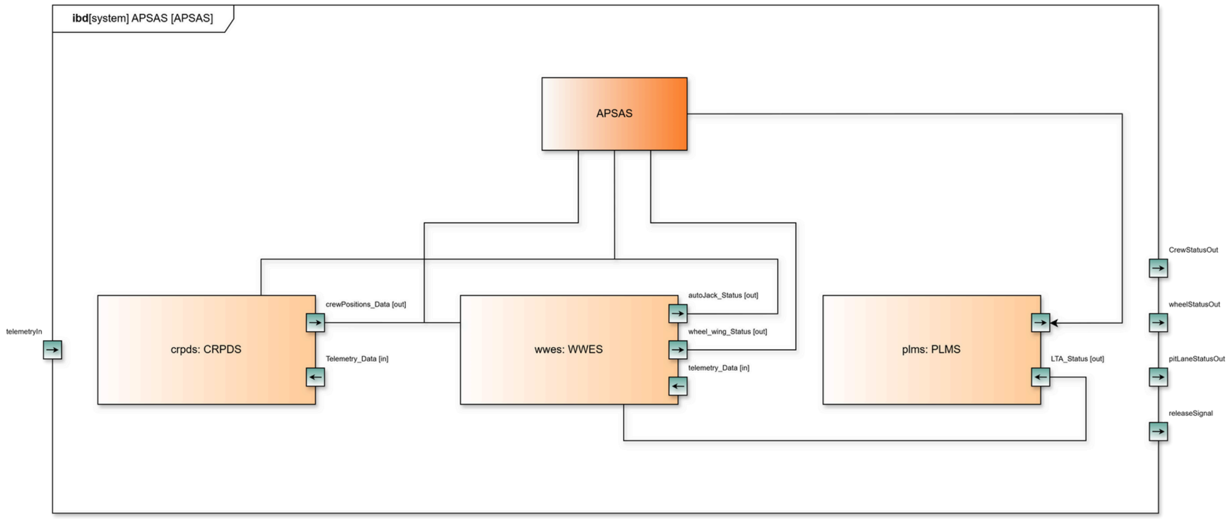
These are used to detect whether tire tasks are complete, wheel guns are disengaged, and the jack system is functioning properly. WWES defines the following operations:
monitorWheels() – to oversee tire engagement and disengagement
checkTorque() – to verify correct torque application before release

PLMS – Pit Lane Monitoring System
The PLMS block is responsible for analyzing the surrounding pit lane environment. It uses:
visionCameras: VisionCamera[]
vehicleTracker: VehicleTracker[]
speedEstimator: SpeedEstimator

These components collectively detect oncoming vehicles and assess their motion. PLMS supports three key functions:
detectVehicles() – to identify nearby cars
estimateSpeed() – to determine their velocity
detectViolations() – to identify unsafe conditions such as potential collisions

6.2. Internal Block Diagram

Outlines system hierarchy and interfaces between major blocks—sensors, subsystems, controller units. Clarifies what modules exist and how they interact at a hardware/software level.



The Internal Block Diagram (IBD) provides a detailed view of how the subsystems within the APSAS architecture interact with one another. It illustrates the flow of data between internal components and shows how each subsystem contributes to the system's overall release logic.

At the center of the diagram is the APSAS block, which acts as the central orchestrator of the system. It integrates and processes information from three internal subsystems: CRPDS, WWES, and PLMS. These subsystems exchange specific types of data with APSAS and with each other to support real-time pit stop decision-making.

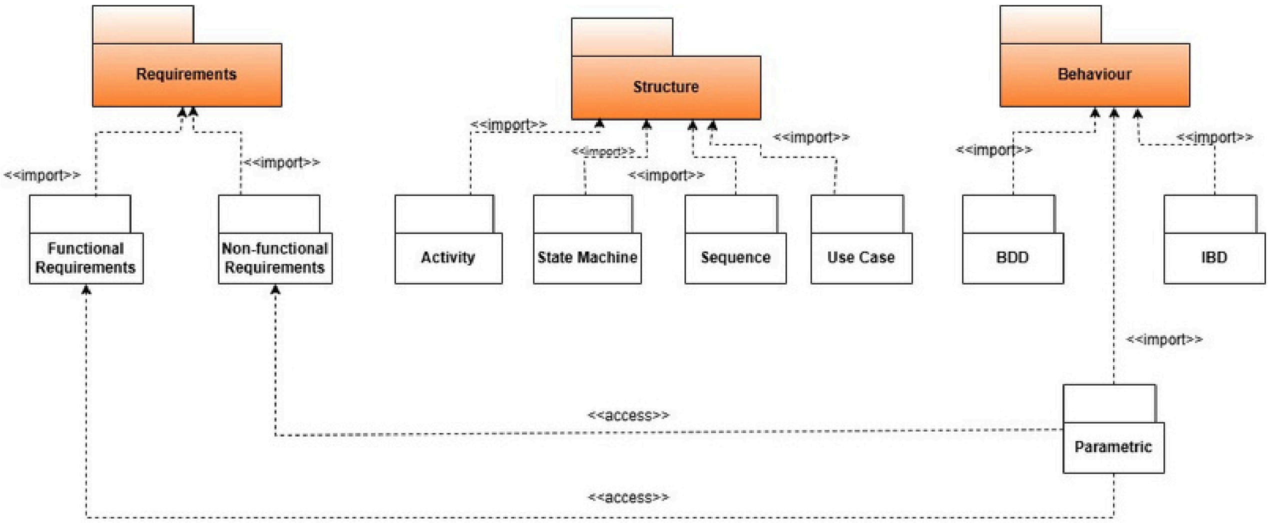
CRPDS – Crew Readiness & Position Detection System
The crpds block receives telemetry input (Telemetry_Data [in]) from APSAS and outputs crewPositions_Data [out]. This data represents the real-time status of the crew, including their location and posture. The output is used to determine whether the crew is safely positioned and ready for vehicle release. This information is further routed to generate the external signal CrewStatusOut.

WWES – Wheel & Wing Engagement System
The wwes block also receives telemetry data and is responsible for producing two key outputs: autoJack_Status [out] and wheel_wing_Status [out]. These outputs indicate whether mechanical servicing has been completed safely, and whether the jack system is disengaged. This information contributes to wheelStatusOut, which is forwarded to APSAS for final release validation.

PLMS – Pit Lane Monitoring System
The plms block independently monitors the pit lane and outputs LTA_Status [out], which represents the current lane traffic assessment. This data is evaluated to determine whether any oncoming cars pose a hazard. The output feeds into the generation of pitLaneStatusOut.

System-Level Outputs
Based on the collective status signals from CRPDS, WWES, and PLMS, the APSAS system determines whether the conditions are safe for a car to be released. When all internal signals are clear, the releaseSignal is generated, authorizing the car to exit the pit.

6.3. **Package Diagram**



Safety Constraints & System Performance

Representative Constraints:
- release_delay ≥ 1.5s (minimum time before green signal)
- distance_error ≤ 0.5m (PLMS margin of error)
- zone_cleared == TRUE before release (CRPDS safety gate)
- posture_confidence ≥ 95% (vision confidence requirement)

Performance Metrics:
RFID update rate: ≥ 10 Hz
Positional accuracy: ≤ 10 cm
Vision posture accuracy: ≥ 95%
Jack actuation latency: ≤ 300 ms
Threat level latency: ≤ 50 ms

7. **Conclusion**

APSAS is designed with the ethos of Formula 1 in mind. It does not intend to sterilize or over-control the pit stop—one of the sport's most intense and human-driven elements. Rather, it ensures that the increasing demands on precision and performance are met with systems that support, rather than hinder, human excellence.

By introducing high-fidelity sensors, real-time decision logic, and automated fail-safes, APSAS improves team safety without dulling the competitive edge. In doing so, it allows teams to push closer to the edge, knowing that system oversight is watching the margins.