CMP5354 Software Design
Physical Asset Tracking Vision Platform
(BMW Hams Hall Plant)

D2 Software Solution

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System Overview

The solution proposed for BMW Hams Hall is an indoor vehicle tracking platform that uses the plant's existing CCTV cameras alongside computer vision to monitor logistics vehicles in real time. Vehicles are identified using unique AprilTags, allowing the system to distinguish between them reliably as they move through the facility.

The platform keeps a constantly updated snapshot of each detected vehicle's latest X, Y, and Z position against the plant layout. This gives the Logistics Control Operator a live view of vehicle locations through the tracking interface. It can also highlight maintenance-related issues when a vehicle needs attention and recognise non-vehicle obstructions that may interfere with tracking or affect route planning.

To support integration across the wider environment, the platform sends tracking data to BMW's Digital Twin System through a secure authenticated API. The IT Engineer is responsible for tasks such as maintaining the tag-to-vehicle mapping and monitoring camera status so that the system remains accurate and dependable. Access to tracking data is restricted to authorised systems, in line with security and data protection requirements.

Functional Requirements (FRs)

Table 1 describes the key functional requirements for the BMW logistics vehicle tracking system. The first four requirements, FR1 to FR4, were carried over from D1, while FR5 to FR7 were introduced in D2. Additional sub-requirements have been added to make the system requirements clearer and easier to trace through the later design models.

FR ID	Description	Functional Requirement
FR1	**Vehicle detection and tracking**	**The system must detect and track the actual logistics vehicles in real-time through the existing CCTV video feeds.**
FR1.1	Multi-vehicle detection	The system must detect multiple logistics vehicles within the same CCTV frame where they are visible at the same time.
FR1.2	Continuous tracking update	The system must continuously update the tracked position of each detected logistics vehicle while it remains within camera's field of view.
FR2	**Monitor vehicle positions**	**The system must track and show where each logistics vehicle is within the facility using its coordinates.**
FR2.1	Layout-relative positioning	The system must display each tracked logistics vehicle within the facility layout or monitored plant area.
FR2.2	Coordinate generation	The system must generate coordinate values for each tracked logistics vehicle to represent its current position.
FR3	**Maintenance alerting**	**The system should be able to raise the operating status of each logistics vehicle through a system alert for any necessary maintenance to be applied.**
FR3.1	Maintenance alert creation	The system should generate an alert when a logistics vehicle is flagged for maintenance.
FR3.2	Alert information display	The system should present the relevant vehicle identifier and operating status information in the alert.

FR4	**Obstruction awareness**	**The system must regard any other obstructions besides the logistics vehicles within the facility that can potentially affect the journey to improve tracking and influence path decisions.**
FR4.1	Obstruction detection	The system must detect non-vehicle obstructions within the monitored facility area.
FR4.2	Obstruction impact flagging	The system must flag when a detected obstruction could disrupt vehicle tracking or affect path decisions.
FR5 (Added)	**Vehicle differentiation**	**The system must distinguish between individual logistics vehicles during tracking by using a unique fiducial marker identifier.**
FR5.1	Marker recognition	The system must recognise and decode the fiducial marker attached to each logistics vehicle.
FR5.2	Identity assignment	The system must assign a unique identity to each detected logistics vehicle during tracking.
FR6 (Added)	**CCTV status monitoring**	**The system must continuously monitor the status of all connected CCTV cameras.**
FR6.1	Offline camera detection	The system must flag a connected camera as offline if it does not provide a frame within a defined time limit.
FR6.2	Technical fault notification	The system must notify the IT Engineer when a connected camera goes offline.
FR7 (Added)	**Digital Twin API integration**	**The system must provide a secure API that allows BMW's Digital Twin to request vehicle tracking data.**
FR7.1	Authenticated access	The system must restrict API access to authorised requests only.
FR7.2	Structured data output	The system must return vehicle tracking data in a consistent format compatible with Digital Twin integration.

Table 1. Functional Requirements

Non-Functional Requirements (NFRs)

Table 2 describes the non-functional requirements for the BMW vehicle tracking platform. These requirements define the measurable quality expectations placed on the system. Performance, identification reliability, and security are emphasised because they are central to effective real-time tracking, dependable vehicle differentiation, and integration with the Digital Twin system.

NFR ID	Description	Non-Functional Requirement
NFR1	Performance under concurrent load	The system must provide vehicle position updates via the API within 1 second of capturing a camera frame while handling up to 50 concurrent API requests.
NFR2	Identification reliability	The system must recognise and decode fiducial marker identifiers with at least 95% accuracy within a specified operating range of 0.5 to 5 metres under normal factory lighting conditions.
NFR3	Data security	The system must reject 100% of API requests that do not contain a valid authentication token.

Table 2. Non-Functional Requirements

Ethical & Legal Issues

The issues in Table 3 identify the main ethical and legal concerns associated with deploying the proposed BMW tracking platform in a live manufacturing environment. The focus here is on why these issues are problematic for the system and its use context, rather than how they would be mitigated.

ID	Issue	Justification	Related FR/NFR
E1	Indirect employee surveillance	Continuous CCTV-based vehicle tracking may indirectly reveal worker movement patterns, routines, or behaviours even when the system is designed to monitor vehicles rather than people. In a workplace environment, this creates ethical concerns around whether the level of monitoring is justified, transparency, and staff awareness.	FR1, FR5, FR7, NFR3
L1	UK GDPR and indirect identifiability	Under Article 4(1) of Regulation (EU) 2016/679, personal data includes information relating to an identified or identifiable natural person. If vehicle location data, marker identities, and shift or access records are combined, operators may become indirectly identifiable, bringing the system under data protection obligations (European Parliament and Council, 2016).	FR5, FR7, NFR3
L2	Liability from inaccurate location or identification data	If the system generates incorrect vehicle positions or misidentifies a tracked vehicle, operational decisions may be made using inaccurate information. In a live industrial environment, this could contribute to unsafe movement, workflow disruption, or collisions, creating potential legal and organisational liability under workplace health and safety duties (Health and Safety at Work etc. Act 1974).	FR2, FR5, NFR2
E2	Uneven system accuracy and unfair operator inference	If tracking is less accurate in some parts of the plant because of lighting, camera angle, or partial occlusion, some vehicles or operators may not be tracked as reliably as others. If that data is later used to assess efficiency, compliance, or behaviour, it could lead to unfair judgements and weaken trust in the system.	FR1, FR5, FR6, NFR2
L3	HSE compliance in safety-critical use	If BMW later relies on this platform for safety-critical purposes such as collision avoidance, movement control, or hazard prevention, incorrect or delayed outputs could create compliance issues. A tracking platform used beyond its intended purpose may fail to satisfy the legal duties required by workplace safety law (Health and Safety at Work etc. Act 1974; The Management of Health and Safety at Work Regulations 1999).	FR2, FR4, NFR1, NFR2

Table 3. Ethical & Legal Issues

Risk Assessment

The risks in Table 4 identify the main technical and operational failure scenarios that could affect the reliability, performance, and safe deployment of the proposed BMW vehicle tracking platform. Each risk is linked to the relevant functional or non-functional requirements and paired with a targeted mitigation to reduce disruption in a live factory environment.

ID	Risk	Severity	Mitigation	Related FR/NFR
Ri1	Occlusion or lighting variation causes temporary loss of vehicle tracking.	Serious	Implement trajectory prediction using Kalman filtering during short visibility loss and use high-contrast fiducial markers with built-in error correction to improve detection reliability under varying lighting and partial occlusion.	FR1, FR1.2, FR5, NFR2
Ri2	Marker aliasing causes incorrect vehicle identification.	Serious	Ensure a minimum Hamming distance between marker IDs and apply cross-frame consistency checks to reject incorrect identity switches between frames.	FR5, FR5.1, FR5.2, NFR2
Ri3	Network latency causes API updates to miss the real-time performance target.	Moderate	Use edge processing so video frames are processed locally, and only structured tracking data is sent to the API layer instead of full video streams.	FR2, FR7, NFR1
Ri4	CCTV camera failure or network disconnection interrupts active monitoring.	Serious	Continuously monitor camera status and flag a camera as offline if no frame is received within the specified time limit, then send an automated notification to the IT Engineer.	FR6, FR6.1, FR6.2
Ri5	Excessive concurrent API requests from the Digital Twin overload the endpoint.	Moderate	Apply API rate limiting and request throttling at the gateway to prevent bursts of requests from affecting the tracking engine’s response time.	FR7, FR7.1, NFR1

Table 4. Risk Assessment

Use Case Diagram (UCD)

Figure 1 presents the Use Case Diagram for the Vehicle Tracking Platform. It shows the main external interactions between the system and its three actors: the Logistics Control Operator, the Digital Twin System, and the IT Engineer. The diagram covers FR1–FR7 and uses verb-based use cases, along with <<include>> and <<extend>> relationships, to represent mandatory and conditional system behaviour.

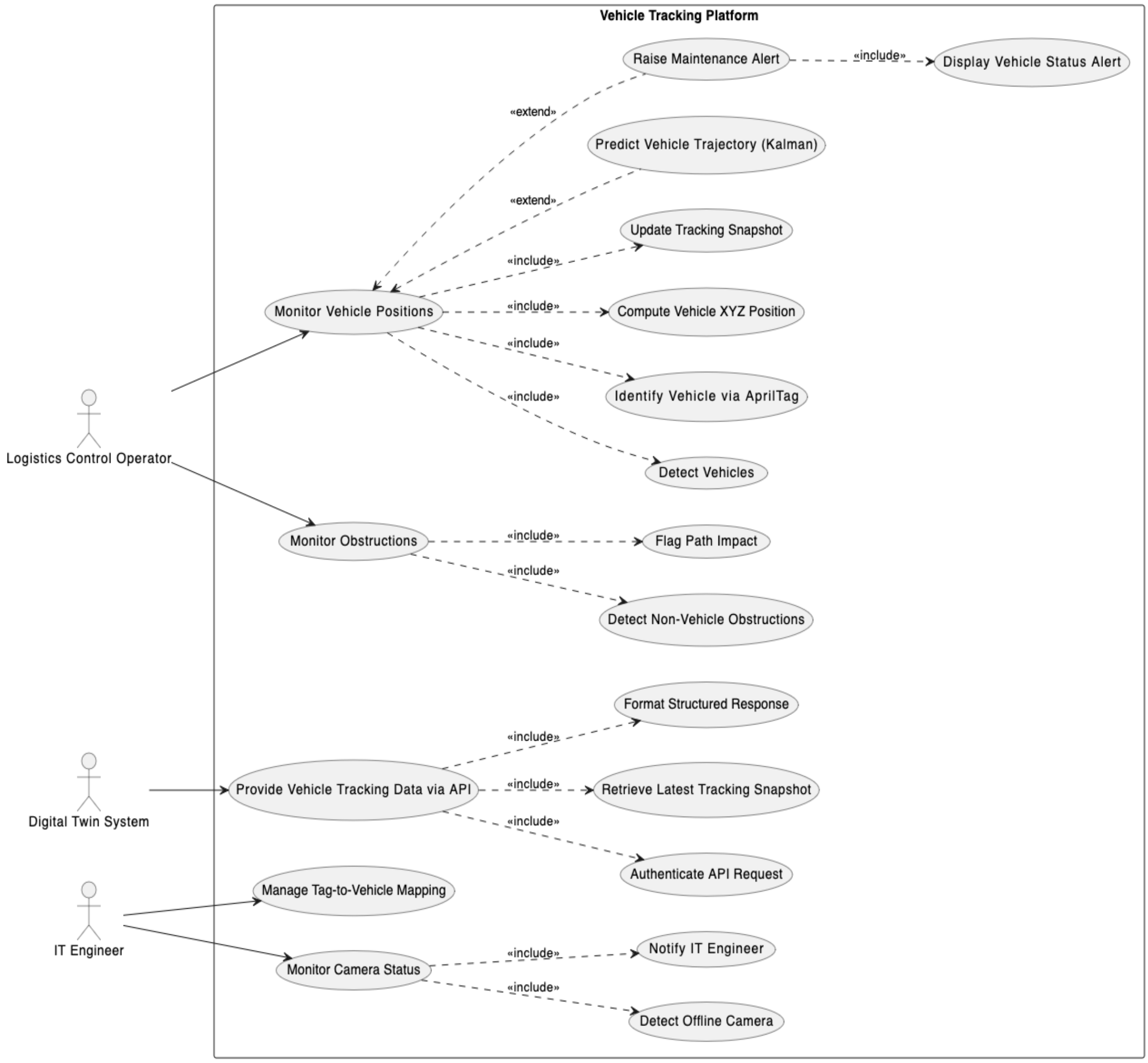

Figure 1. Use Case Diagram (UCD)

Use Case Specification (UCS)

Table 5 expands FR2, “Monitor Vehicle Positions” shown in Figure 1. It describes the normal monitoring flow as well as the main alternative flows related to vehicle detection, AprilTag-based identification, XYZ position calculation, and tracking snapshot updates.

Name	Monitor Vehicle Positions
Purpose	To allow the Logistics Control Operator to monitor the real-time XYZ positions of logistics vehicles by continuously detecting vehicles, identifying them using AprilTags, computing their XYZ positions, and updating the tracking snapshot.
Prerequisites	1. CCTV camera streams are active. 2. Tag-to-vehicle mappings are configured. 3. Calibration data is in place for XYZ position computation. 4. The processing pipeline is active.
Narrative	1. The Logistics Control Operator initiates live monitoring. 2. The system captures a CCTV frame. 3. The system detects vehicles within the frame. 4. The system identifies each detected vehicle via AprilTag. 5. The system computes each vehicle’s XYZ position based on the facility layout. 6. The system updates the tracking snapshot with the current vehicle identity and XYZ position. 7. The system displays live vehicle positions and repeats steps 2-7 continuously for as long as monitoring is active.
Outcome	The tracking snapshot consistently shows the most recent vehicle IDs and XYZ positions, allowing real-time monitoring.
Alternative Narrative	**Occlusion Detected (Ri1):** If tag visibility is temporarily lost, the system uses **Predict Vehicle Trajectory (Kalman)** to estimate a temporary vehicle position.

	No Vehicles Detected (A1): If no vehicles are detected in the frame being processed, the system records **“no detections”** for that frame and keeps monitoring. **AprilTag Unreadable (A2):** If a vehicle is detected but its AprilTag is unreadable, the system labels it with the temporary identity **“Unknown”** and continues tracking the vehicle. **Computation Failure (A3):** If the system cannot compute the XYZ position of a detected vehicle, it logs the failure for that frame and does not save invalid position data to the tracking snapshot.
Alternative Narrative Outcome	The system continues processing the following frames without stopping. When prediction is used, temporary positions are labelled **“estimated”** until direct visibility returns. If no detection or a computation failure occurs in a frame, the system does not record invalid tracking data and resumes normal processing in the next frame.

Table 5. Use Case Specification

Class Diagram (CD)

Figure 2 shows the Class Diagram for the Vehicle Tracking Platform. It models the static structure of the solution by showing the main classes, attributes, operations, data types, and associations required to support tracking, vehicle differentiation, obstruction awareness, maintenance alerting, camera status monitoring, and authenticated API integration.

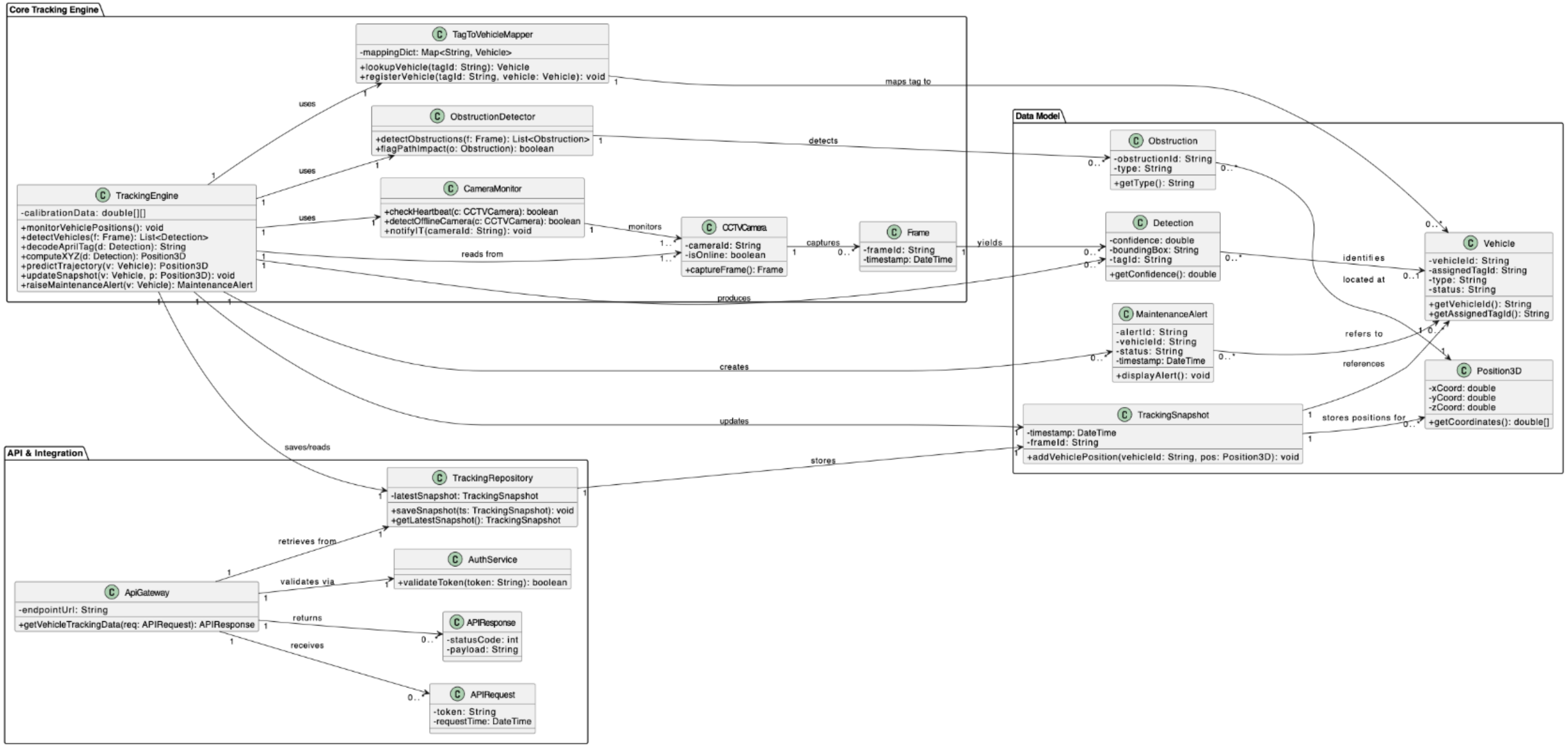

Figure 2. Class Diagram (CD)

Sequence Diagram (SD)

Figure 3 shows how the system behaves during the “Monitor Vehicle Positions” use case. The objects involved come from the Class Diagram, which keeps the runtime interaction consistent with the system’s static structure. The sequence uses loop and alt fragments to show continuous monitoring and the main alternative scenarios from the UCS, including occlusion, unreadable tags, no detections, and computation failure.

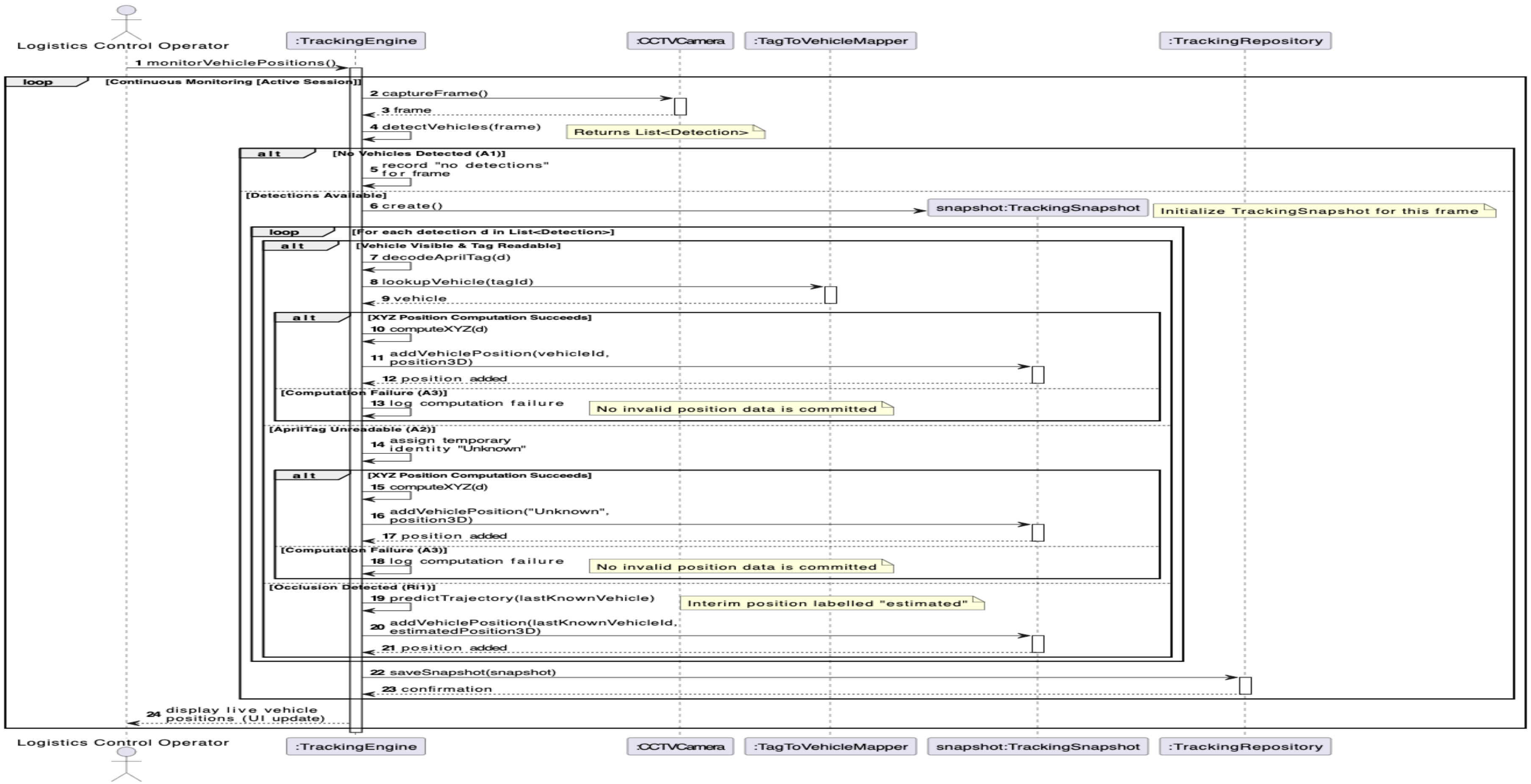

Figure 3. Sequence Diagram (SD)

References

European Parliament and Council (2016) Regulation (EU) 2016/679 of the European Parliament and of the Council of 27 April 2016 on the protection of natural persons with regard to the processing of personal data and on the free movement of such data, and repealing Directive 95/46/EC (General Data Protection Regulation). OJ, L119, 4 May, pp. 1-88.

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