Bilkent University
Department of Computer Engineering

Senior Design Project
T2514-TırGöz

Analysis and Requirement Report

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19/12/2025

This report is submitted to the Department of Computer Engineering of Bilkent University in partial fulfilment of the requirements of the Senior Design Project course CS491/2.

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1 Introduction

The logistics industry is a dynamic and continuously expanding sector that includes warehouses, trucks, loads, routes, time limitations, and cost considerations. Due to the inherent complexity of this business, technology may be needed to help manage all of these components. Based on this concept, TırGöz offers a user-friendly system for companies in the logistics sector, utilizing computer vision technology and route optimization algorithms to enhance the effectiveness of logistical operations. TırGöz proposes a system that provides a holistic view of logistics operations by merging perception and planning layers. TırGöz provides operational efficiency by reducing manual inspection time and optimizing workforce usage. TırGöz offers cost reduction by minimizing late deliveries and unnecessary travel through adaptive route planning. TırGöz offers work quality by preventing shipment mistakes with the generation of real-time alerts. TırGöz also considers the scalability by ensuring low latency and dynamic route optimization even with a large number of trucks and warehouses.

2 Proposed System

2.1 Overview

TırGöz aims to develop a logistics monitoring and optimization platform that integrates computer vision and vehicle routing optimization to enhance efficiency in loading/unloading and transportation processes. The main functionalities of TırGöz can be divided into three modules: streaming, detection, and route optimization. The streaming module demonstrates the process of loading/unloading the truck in real-time, and the detection module utilizes computer vision to detect item counts and anomalies from this stream, such as misplaced or damaged items. The route optimization module utilizes the item count information in trucks/warehouses, along with other constraints such as time and cost, to calculate the optimal routes for the trucks in the system. This is how TırGöz aims to simplify and expedite logistics operations.

2.2 Functional Requirements

2.2.1 Streaming

- TırGöz must demonstrate the live stream of the truck loading/unloading with minimal possible delay.
- TırGöz must allow users to record desired parts of the live streams.
- TırGöz must record the short clips of detected events to provide visual evidence for alerts.

2.2.2 Detection

- TırGöz must detect the location of the items in the warehouse.
- TırGöz must detect the physically damaged items during the loading/unloading.
- TırGöz must send alerts for the detection of physically damaged items.
- TırGöz must detect the count of the item loaded/unloaded.
- TırGöz must detect if the item is loaded into the wrong truck.
- TırGöz must send alerts for the detection of wrongly loaded items.
- Based on the detections, TırGöz must demonstrate the
    - warehouse occupancy percentage for every warehouse.
    - Truck occupancy percentage for every truck.
    - Item counts in the trucks and warehouses.
    - Locations of the items in the warehouse.

2.2.3 Route Optimization

- TırGöz must demonstrate the truck and warehouse counts in the system.
- TırGöz must calculate and demonstrate the optimal routes for the trucks based on the desired cost and time constraints.
- TırGöz must dynamically recalculate the optimal routes based on the changes in the truck loads.
- TırGöz must let stores request items from the warehouse, then use these requests as input for optimal route calculation.

2.3 Non-functional Requirements

2.3.1 Usability

TırGöz focuses on high-efficiency usage for logistics operations. The system can be used with minimal effort due to its simple and user-friendly interface. The core functionalities are intuitive and can be learned easily. For instance, clear and immediate vehicle location, optimized path, and real-time alert displays do not require the user to search or interpret complex data. Additionally, to enhance usability, anomaly detection alerts are accompanied by short event clips for easy visual verification, thereby minimizing the time required for manual inspection.

2.3.2 Reliability

TırGöz ensures high operational reliability. Since the Computer Vision and Route Optimization Services are isolated, a failure in one independent module does not affect the other independent modules. Additionally, TırGöz prioritizes rapid recovery from any failure to maintain the integrity of real-time events and data, particularly during the critical hours of the day. Additionally, the anomaly detection function aims to achieve a high accuracy rate through deterministic validation checks.

2.3.3 Performance

The primary goal of TırGöz is to ensure low-latency processing due to its real-time functional nature. To maintain real-time alerts, TırGöz processes live video streams and detects anomalies with an end-to-end latency of no more than **1000** milliseconds. Also, the Route Optimization Module aims to recalculate the optimal route based on warehouse and truck occupancies within a desired time constraint for the standard operational load.

2.3.4 Supportability

TırGöz is designed to be straightforward, making it easier to understand bugs and problems, thereby reducing the time required to fix errors and install new features. This is why logs are used to record detailed notes in a consistent and easy-to-read format. Additionally, TırGöz aims to minimize complete system restarts, thereby keeping the system operational during minor system changes. To further increase supportability, up-to-date technical documentation is maintained for the system completely and accurately.

2.3.5 Scalability

TırGöz must be able to handle the growth in the number of cameras, trucks, and more deliveries. For instance, the Computer Vision Service and Event Processing API should not exceed the expected real-time constraint, even when the number of cameras and streams is increased. The Route Optimization Service must perform calculations for both smaller and larger numbers of trucks and deliveries. Additionally, TırGöz must efficiently manage the rapidly growing volume of stored data, including short video clips of detected anomalies, events, and metrics.

2.4 System Models

2.4.1 Scenarios

2.4.1.1 Normal Truck Loading

Participating Actors: Warehouse Operator, CV Subsystem, Analysis Service, Route Optimisation Service

Entry Conditions:

- A truck is in the loading dock.
- Streaming available from the dock camera.
- Trucks are registered in the system with an initial empty state.

Exit Conditions:

- Truck occupancy reflects loaded items.
- The loading event is logged to the database.

Main Flow Events:

1. CV subsystem ingests video frames from a streaming service.
2. The object detection module identifies boxes and pallets in frames.
3. Tracking module assigns IDs to detected systems.
4. When a detected object moves from the warehouse to the truck, it is logged as loading.
5. Item count and truck occupancy states are updated in the digital twin.
6. The updated digital twin is transmitted to the analysis service.
7. The route optimization service receives truck occupancy status.

2.4.1.2 Damage Detection During Truck Loading

Participating Actors: Warehouse Operator, CV Subsystem, Alert Service

Entry Conditions:

- Loading detected and it is in process.
- Anomaly detection is active.

Exit Conditions:

- Damage alert is shown on the operator dashboard.
- Damaged items are logged including severity and confidence.

Main Flow Events:

1. CV subsystem detects items entering the truck region.
2. Anomaly Detection module analyses the item.
3. Module assigns high probability for damage, exceeding predefined conditions.
4. Event generated and sent to Alert Service.
5. A short video for the event is generated with timestamps and stored for verification.
6. Warehouse views alert on the dashboard

Alternative Flows:

1. **Uncertain damage**
2. **Operator Rejects Damage Alert**
3. **Video Storage Fails**

2.4.1.3 Exceeded Truck Capacity

Participating Actors: Warehouse Operator, CV Subsystem, Alert Service, Route Optimisation Service

Entry Conditions:

- The truck is near its capacity.
- Maximum occupancy threshold is defined.
- CV subsystem updates occupancy after each detected loading event.

Exit Conditions:

- Future truck loading plans are adjusted.
- A warning is generated on the operator dashboard.

Main Flow Events:

1. A new item is detected in the loading dock.
2. Computed occupancy exceeds the defined threshold.
3. CV subsystem generates an “Exceeded Truck Capacity” event.
4. An event is passed to alert subsystems.

2.4.1.4 Idle Loading Detected

Participating Actors: Warehouse Operator, CV Subsystem, Store

Entry Conditions:

- A truck is docked and registered at a specific loading area.
- The loading process status is set to "Active" or "In Progress" in the system.
- The CV subsystem is actively monitoring the designated loading zone and the truck's rear entrance.
- A predefined inactivity threshold (e.g., 10 minutes) is configured in the system.

Exit Conditions:

- An "Idle Loading" alert is dispatched to the Warehouse Operator.
- The loading status for that specific dock is flagged for supervisor review.

Main Flow Events:

1. The CV subsystem monitors the movement of personnel and goods within the dock.
2. The system detects a total lack of motion or item transfer for a duration exceeding the threshold.
3. The CV subsystem references the lack of activity with the Store to confirm the truck is still scheduled for loading.
4. The system generates an "Idle Loading" event trigger.
5. A real-time notification is sent to the Warehouse Operator's dashboard.
6. The operator acknowledges the alert and investigates the cause of the delay.

2.4.1.5 CV Inference Stream Interrupted

Participating Actors: CV Subsystem, Admin, Warehouse Operator

Entry Conditions:

- The CV subsystem is processing video streams from dock cameras.
- Inference engines are running and sending metadata to the monitoring server.
- The system monitor is active.

Exit Conditions:

- The system fails over to a secondary stream or triggers a safe-state protocol.
- The staff receive an urgent system health alert with error logs.
- The Warehouse Operator is notified that automated tracking is temporarily offline for a specific zone.

Main Flow Events:

1. The system detects a loss of video input or a critical failure in the inference engine.
2. The heartbeat monitor fails to receive a "Success" signal from the CV worker node within the required millisecond window.
3. The system attempts an immediate automatic restart of the inference service.
4. If the restart fails, the CV Subsystem flags the stream as "Interrupted" and logs the timestamp of the last successful frame.
5. An urgent notification is sent to the Warehouse Operator via the system dashboard or SMS/email.
6. The UI for the Warehouse Operator displays a "Visual Tracking Offline" warning for the affected dock.

2.4.1.6 New Route Calculation

Participating Actors: Warehouse Operator, Analysis Service, Route Optimization Service

Entry Conditions:

- The Warehouse Operator is logged in to the system.
- The truck is registered in the system.

Exit Conditions:

- The optimal route is displayed on the system interface.

Main Flow Events:

1. The Warehouse Operator accesses the Route Optimization Service.
2. The Warehouse Operator initiates the route calculation process for the desired truck.
3. The route optimization service gets the inputs from the Analysis Service (truck occupancy, orders).
4. The Route Optimization Service calculates the best route from the given input.
5. The Route Optimization Service gives the resulting route to the system interface.

Alternative Flows:

1. **No Order in the System:**
    - The system notifies the interface that no orders are available to meet.
2. **No Truck Occupancy Information in the System:**
    - The system notifies the interface that the desired truck has no valid information to start the calculation.

2.4.1.7 Wrong Truck Assignment Detection

Participating Actors: Warehouse Operator, CV Subsystem, Analysis Service, Alert Service

Entry Conditions:

- Multiple trucks are present at adjacent loading docks.
- Each truck has a registered destination and an expected item list.
- CV subsystem is actively tracking items and truck regions.

Exit Conditions:

- Wrongly loaded items are flagged.
- The operator receives an alert with visual evidence.
- The item's state is marked as misassigned in the system.

Main Flow Events:

1. CV subsystem detects an item being moved toward a truck region.
2. Object classification identifies the item type and label.
3. The tracking module assigns a persistent ID to the item.
4. The system compares the detected item’s destination metadata with the truck’s registered route.
5. A mismatch is detected between the item's destination and the truck assignment.
6. An event is generated indicating a wrong truck loading anomaly.
7. A short video clip is extracted from object storage with timestamps.
8. Alert Service notifies the operator dashboard with item details, confidence score, and replay option.
9. Analysis Service updates the system on loading accuracy.

2.4.1.8 Order Request from Store

Participating Actors: Warehouse Operator, Store, Analysis Service

Entry Conditions:

- Warehouse Operator and Store are logged into the system
- Analysis Service knows the item count inside the warehouse.

Exit Conditions:

- The order request is accepted by the Analytics Service.
- The order request cannot be satisfied.

Main Flow Events:

1. The Store initiates an order request.
2. The Store enters required items with counts using the form interface.
3. The Analytics Service decides whether the request is satisfyable by checking the known data.
4. The Analytics Service accepts the order if it is satisfactory.
5. The order request is saved in the system.

Alternative Flows:

1) The system cannot satisfy the order:

a) The system prompts the user to edit the order.

2.4.1.9 Unauthorized Item Removal

Participating Actors: CV Subsystem, Warehouse Operator, Store

Entry Conditions:

- The security monitoring zone is defined and active within the CV subsystem.
- An inventory baseline exists in the system.

Exit Conditions:

- A security alert is triggered on the dashboard.
- The unauthorized removal is logged as a security breach with visual evidence.
- The store and the warehouse operator receive a notification.

Main Flow Events:

1. The CV subsystem detects an item being moved out of its designated storage.
2. Anomaly detection module identifies the movement as a potential risk.
3. The system checks if there is an active loading or relocation task of the moved object.
4. If no authorized task is found, confirm an “Unauthorized Removal”.
5. An alert is sent to the warehouse operator including a short clip and item details.

Alternative Flows:

1 Identification Failure

- The CV subsystem detects movement but cannot recognize the item itself
- The system triggers a “General Security Anomaly” alert.
- The warehouse operator is prompted to verify the object.

2 Authorized Manual Movement

- The item must be moved for non-system reasons (e.g. floor maintenance)
- The Warehouse Operator uses the system interface to manually override for the zone.

2.4.1.10 Worker Safety Equipment Check

Participating Actors: Warehouse Operator, CV Subsystem, Alert Service

Entry Conditions:

- The Warehouse Operator is logged into the system.
- CV subsystem is actively tracking humans.

Exit Conditions:

- The Warehouse Operator receives an alert with visual evidence.

Main Flow Events:

1. The CV subsystem detects a worker without safety equipment.
2. An event is generated indicating a worker without safety equipment.
3. A short video clip is extracted from object storage with timestamps.
4. The Alert Service notifies the operator dashboard with event details, a confidence score, and a replay option.
5. The Analysis Service updates the system's safety analytics.

2.4.1.11 System Installation Inventory Count

Participating Actors: Warehouse Operator, CV Subsystem, Analysis Service, Inventory Database, Store

Entry Conditions:

- The system is at the “Setup Phase”.
- Cameras are correctly positioned and streaming to the CV Subsystem.

Exit Conditions:

- An initial “Inventory Report” is generated and saved.
- The system is ready to track incoming/outcoming items

Main Flow Events:

1. The Warehouse Operator starts the “Baseline Count” command via the Store panel.
2. The CV subsystem identifies all visible items.
3. The CV subsystem assigns coordinates to each identified item to create an inventory map.
4. The CV subsystem sends this aggregated data to Analysis Service and saves it as ground truth.
5. A summary report is displayed on the operators’ dashboard.

Alternative Flows:

1 Recognition Failure

- The CV subsystem detects items that do not match the pretrained object classes.
- The system captures these items as “Unknown Objects”.
- The Warehouse Operator is asked to manually classify these items or update the model parameters.

2 Discrepancy with Expected Inventory

- The Analysis Service compares the CV count with existing digital records (if available).
- A significant discrepancy is detected between the CV count and the expected stock.
- The system flags the specific storage locations for manual confirmation by the Warehouse Operator.

2.4.1.12 Barcode Detection

Participating Actors: CV Subsystem, Warehouse Operator, Inventory Management System

Entry Points:

- An item is moving through the scanning zone.
- The CV Subsytsems' "Anomaly Detection" and "Object Detection" modules are active.
- The barcode protocol is defined in the system settings.

Exit Conditions:

- The item ID is successfully registered and updated in the Inventory Management System.
- Any unreadable barcodes are flagged for manual intervention.

Main Flow Events:

1. The CV Subsystem detects an item entering the camera's field of view.
2. The Object Detection module locates the barcode or QR code on the item's surface.
3. The system attempts to decode the barcode metadata.
4. The CV Subsystem references the decoded ID with the Inventory database.
5. Upon successful validation, the item's location and "count" state are updated.
6. The system signals a "Success" status to the Warehouse Operator.

Alternative Flows:

1 Broken or Unreadable Barcode

- The CV Subsystem detects a barcode but the Anomaly Detection module identifies it as "Broken".
- An alert is sent to the Warehouse Operator's dashboard.
- The item is moved to a "Exception Zone" for relabeling.

2 Mismatched Item Data

- The barcode is read successfully, but the metadata does not match the expected item list.
- The system triggers a "Wrong Item Assignment" alert.
- The operator is prompted to verify the item before it is loaded or stored

2.4.1.13 Anomaly Video Playback and Verification

Participating Actors: Warehouse Operator, Alert Service, Analysis Service

Entry Conditions:

- An anomaly event (e.g., Damage Detection, Unauthorized Removal, or Dropped Box) has been triggered by the CV Subsystem.
- A specific video clip of the event has been extracted and saved in the Object Storage Service.
- The Warehouse Operator is logged into the monitoring dashboard.

Exit Conditions:

- The operator has reviewed the visual evidence of the anomaly.
- The event status is updated in the system.
- Feedback is logged for the Analysis Service.

Main Flow Events:

1. The Warehouse Operator receives a notification or accesses the "Incident Log" on the dashboard.
2. The operator selects a specific anomaly entry to view detailed metadata.
3. The Alert Service fetches the associated video clip from the Object Storage Service.
4. The dashboard displays an integrated video player with the prerecorded clip.

5. The operator plays the video to verify the anomaly.
6. The operator uses playback controls (pause, rewind, or slow-motion) to perform a detailed inspection.
7. The operator selects an action: "Confirm Incident" or "Dismiss Incident" if the CV detection was incorrect.
8. The system updates the event record and transmits the operator's feedback to the Analysis Service.

Alternative Flows:

1 Video Retrieval Failure

- The system attempts to fetch the clip, but the Object Storage Service returns an error.
- The UI displays a "Video Unavailable" message to the operator.
- The operator is prompted to check the live camera stream or view the system error logs.

2 Low Confidence Flagging

- The operator notices the video quality is too low to make a determination.
- The operator flags the video for "Technical Review."
- An alert is sent to the Store to check the camera's status or environmental conditions.

2.4.1.14 Forklift Speed and Safety Monitoring

Participating Actors: CV Subsystem, Forklift Operator, Safety Officer, Alert Service.

Entry Conditions:

- A forklift is being tracked within the warehouse.
- Maximum speed limits are defined for different warehouse sections.
- Proximity thresholds for "Interaction" with workers or infrastructure are configured.

Exit Conditions:

- Safety violations are logged with visual evidence.
- The Warehouse Operator receives an alert on the dashboard.

Main Flow Events:

1. The CV Subsystem tracks the spatial coordinates and velocity of the forklift.
2. The system calculates the current speed and compares it against the zone's predefined limit.
3. The system analyzes the vehicle's trajectory.
4. A violation is detected when the forklift exceeds the speed limit.
5. The CV Subsystem generates a "Safety Violation" event and triggers the Alert Service.
6. The system automatically extracts a video clip of the violation.
7. The Warehouse Operator is notified via the dashboard, displaying the speed data and a replay of the incident.

2.4.2 Use-Case Models

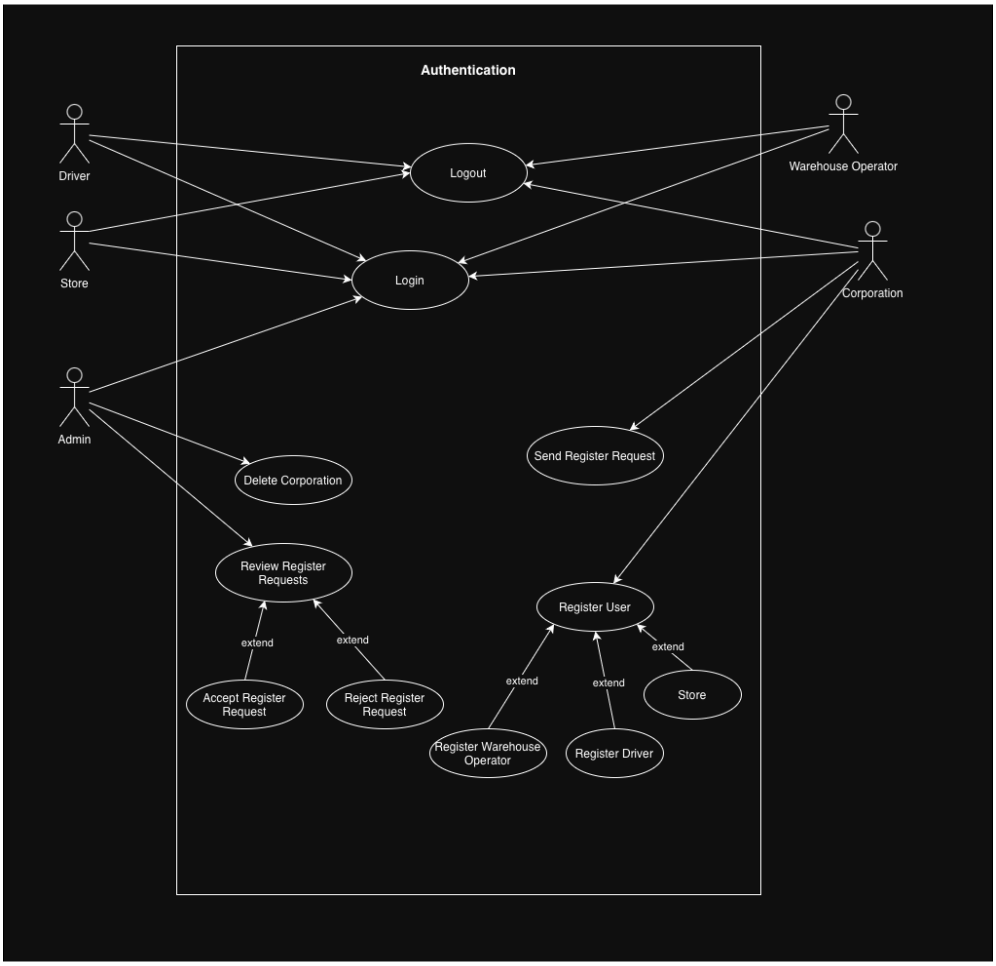

Figure 1: Authentication Use Case

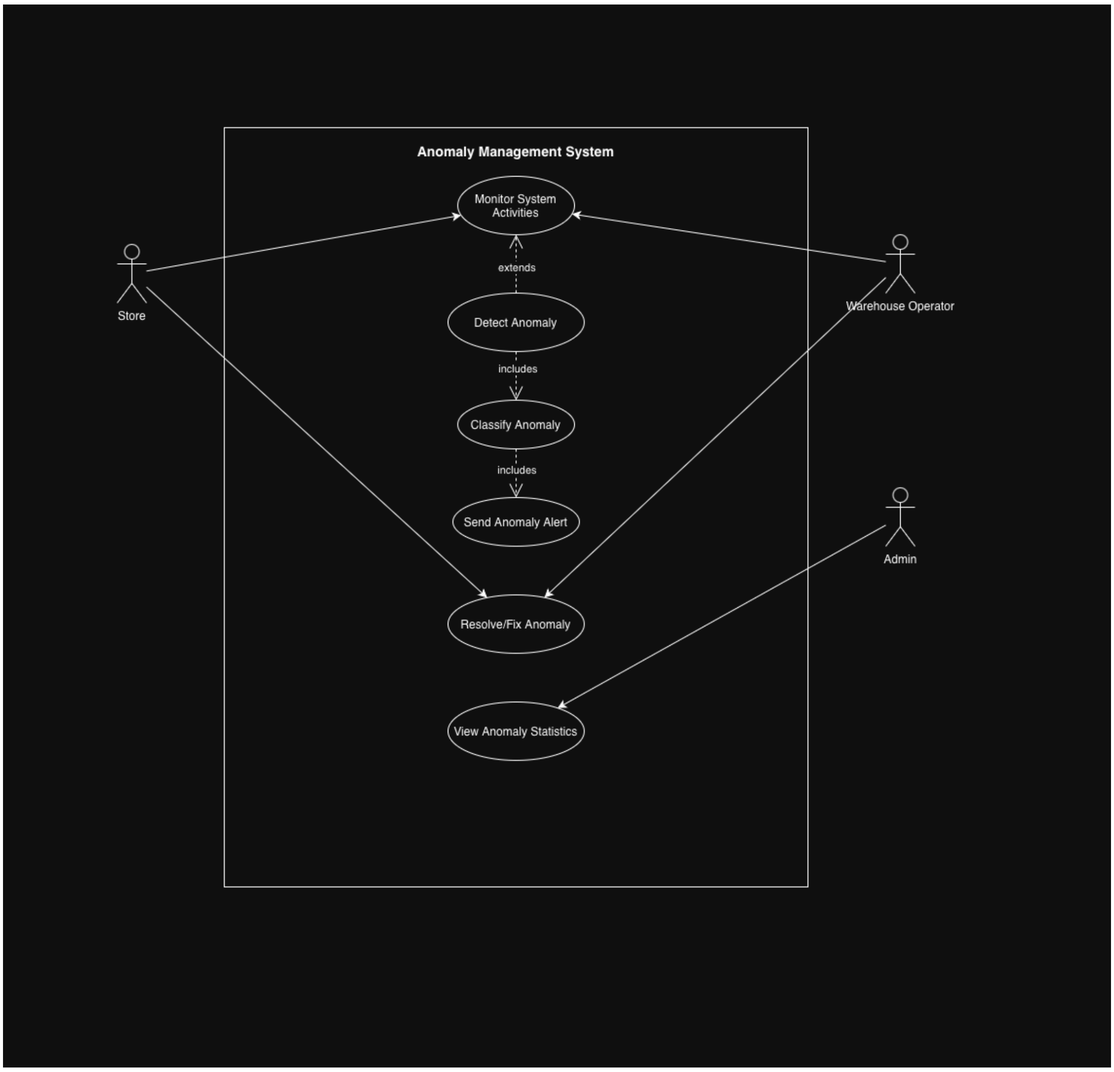

Figure 2: Anomaly Detection Use Case

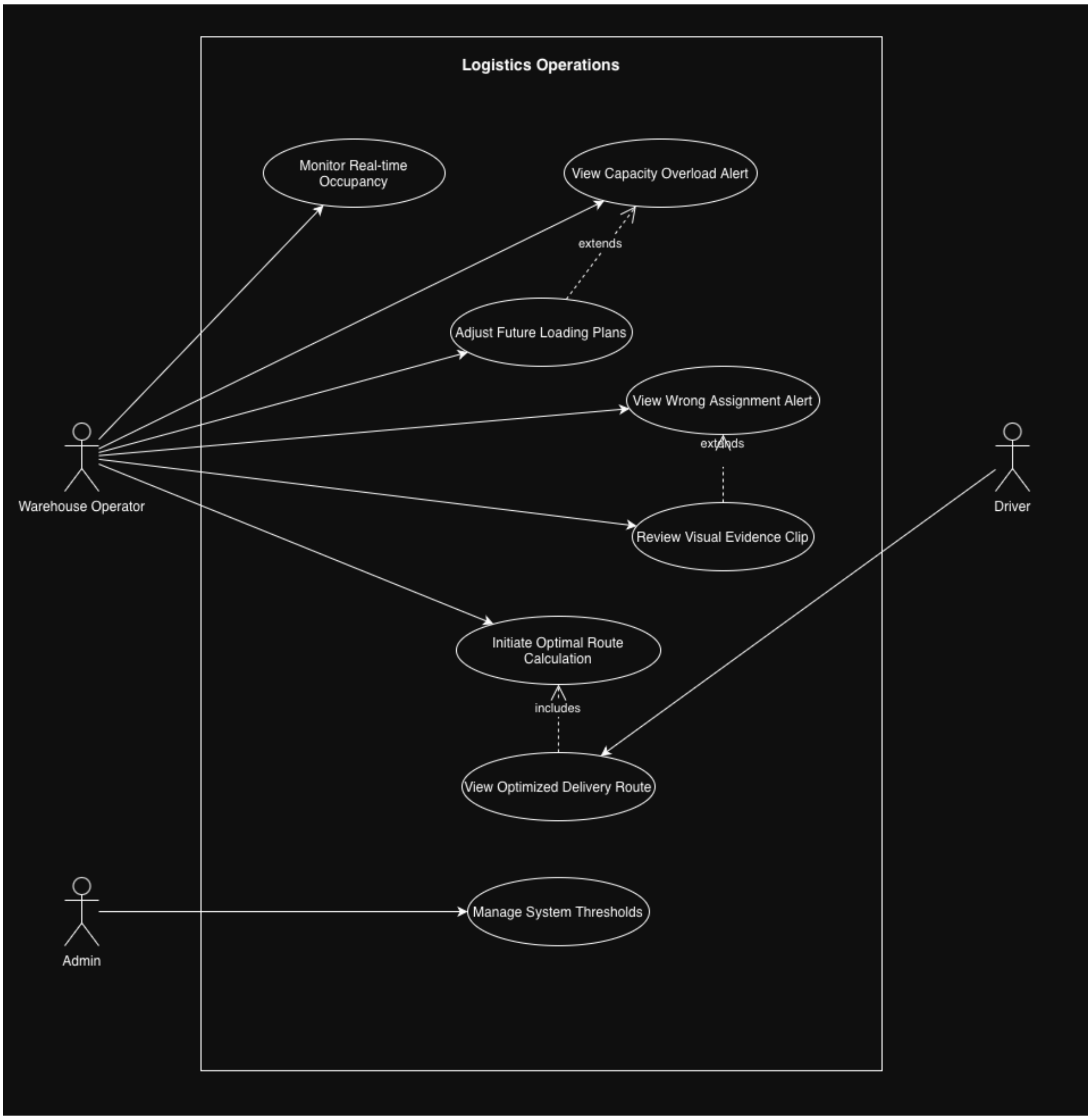

Figure 3: Logistic Monitoring Use Case

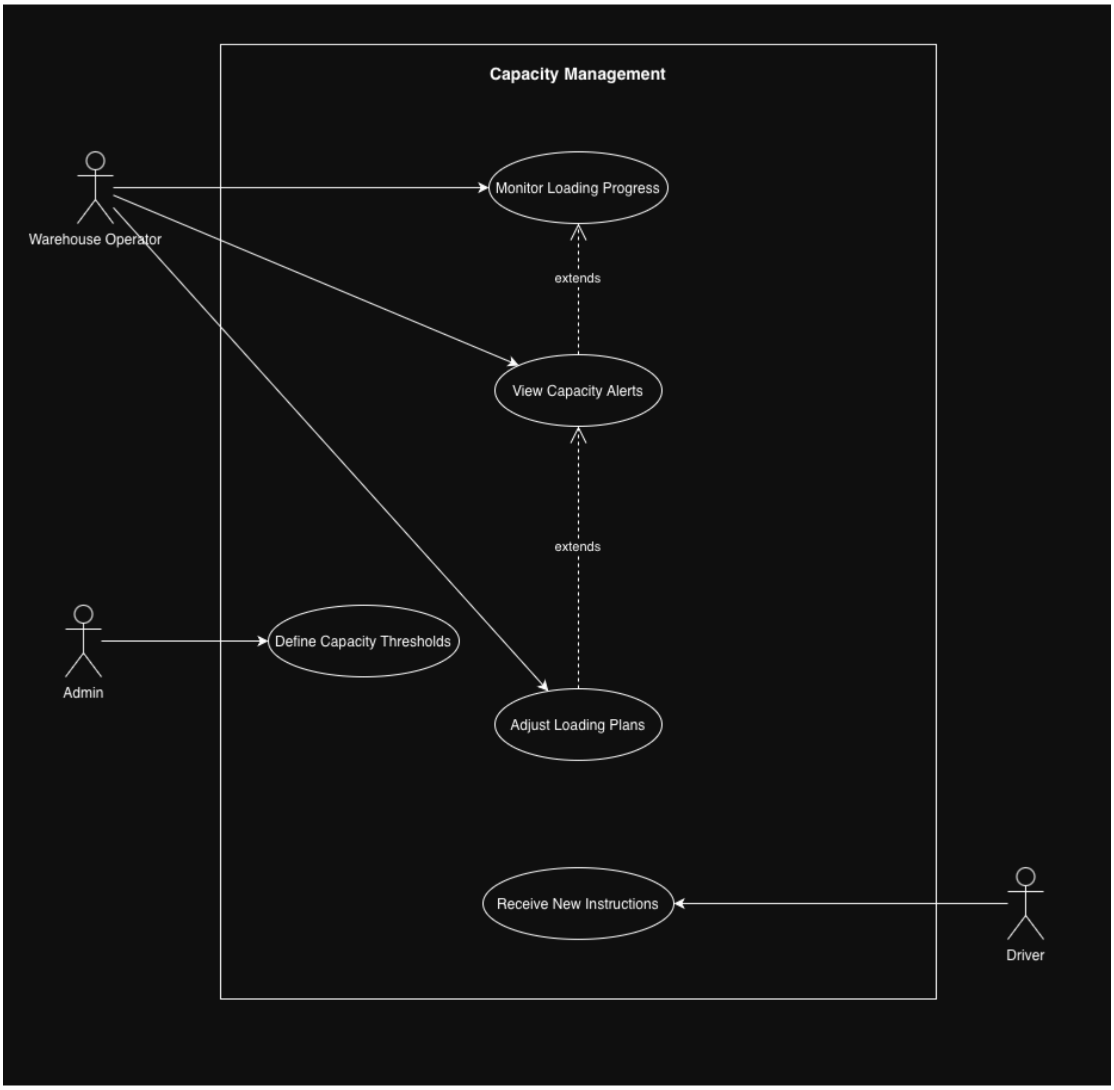

Figure 4: Capacity Management Use Case

2.4.3 Object and Class Model

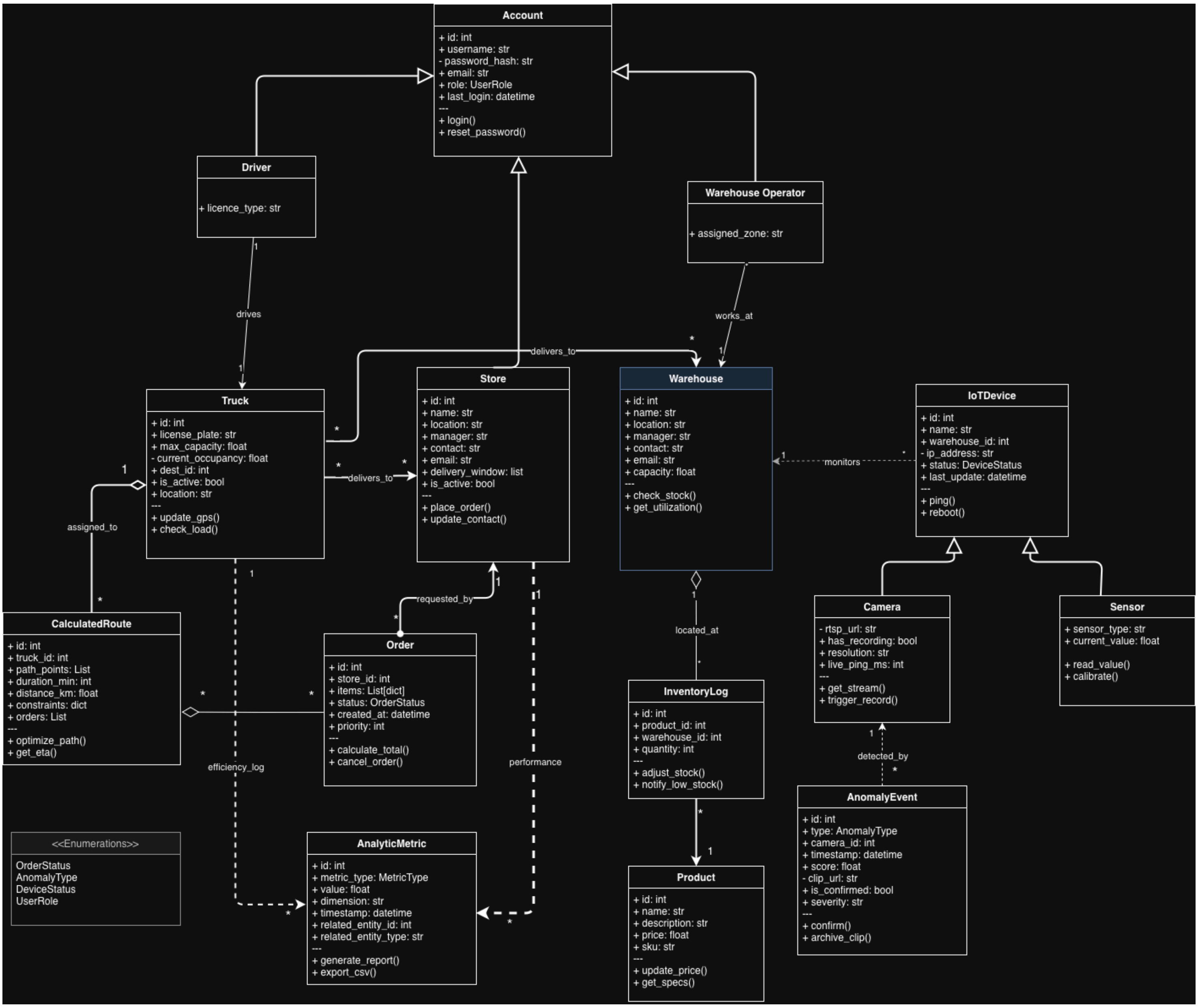

Figure 5: Object and Class Diagram

2.4.4 Dynamic Models

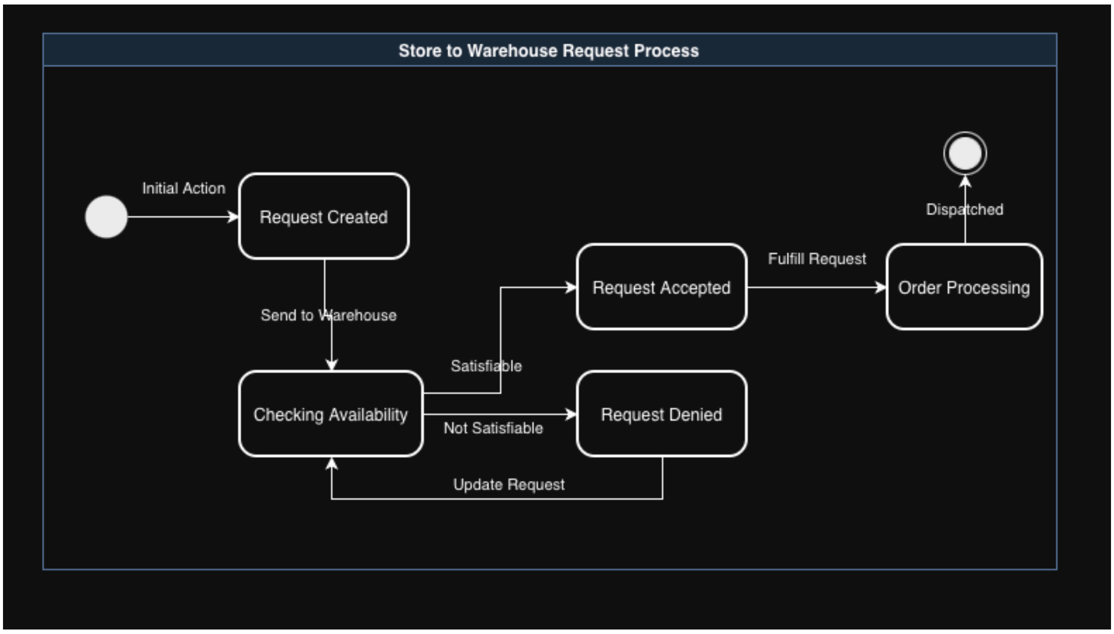

Figure 6: Store to Warehouse Request State Diagram

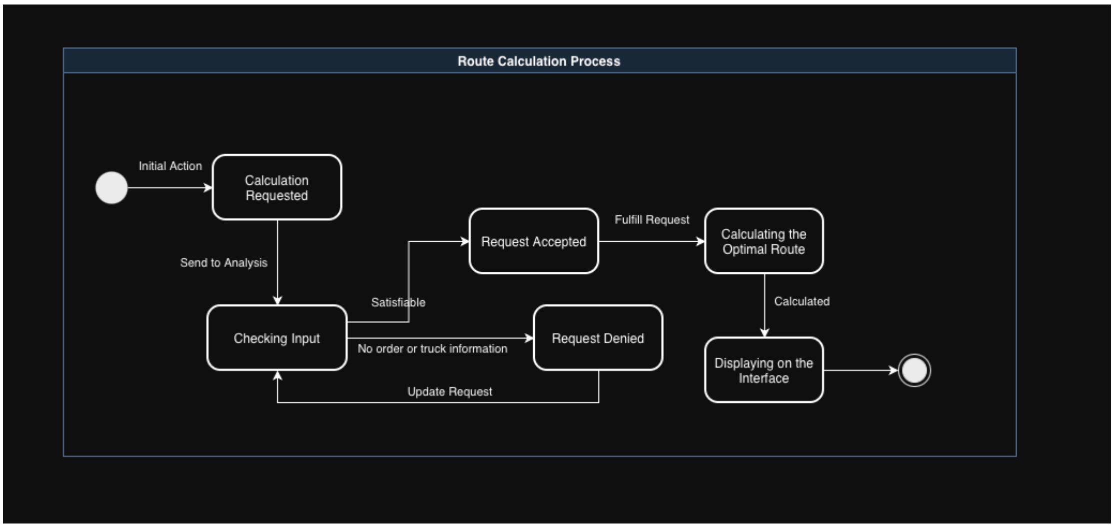

Figure 7: Route Calculation State Diagram

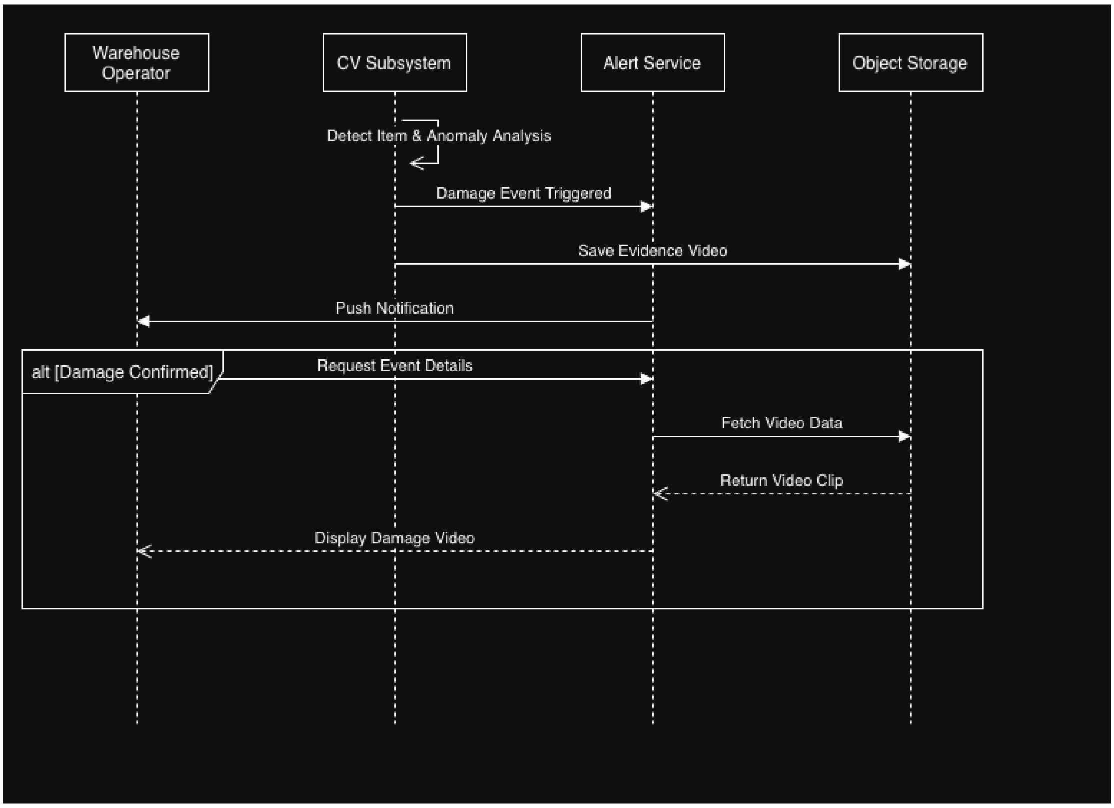

Figure 8: Damage Detection Sequence Diagram

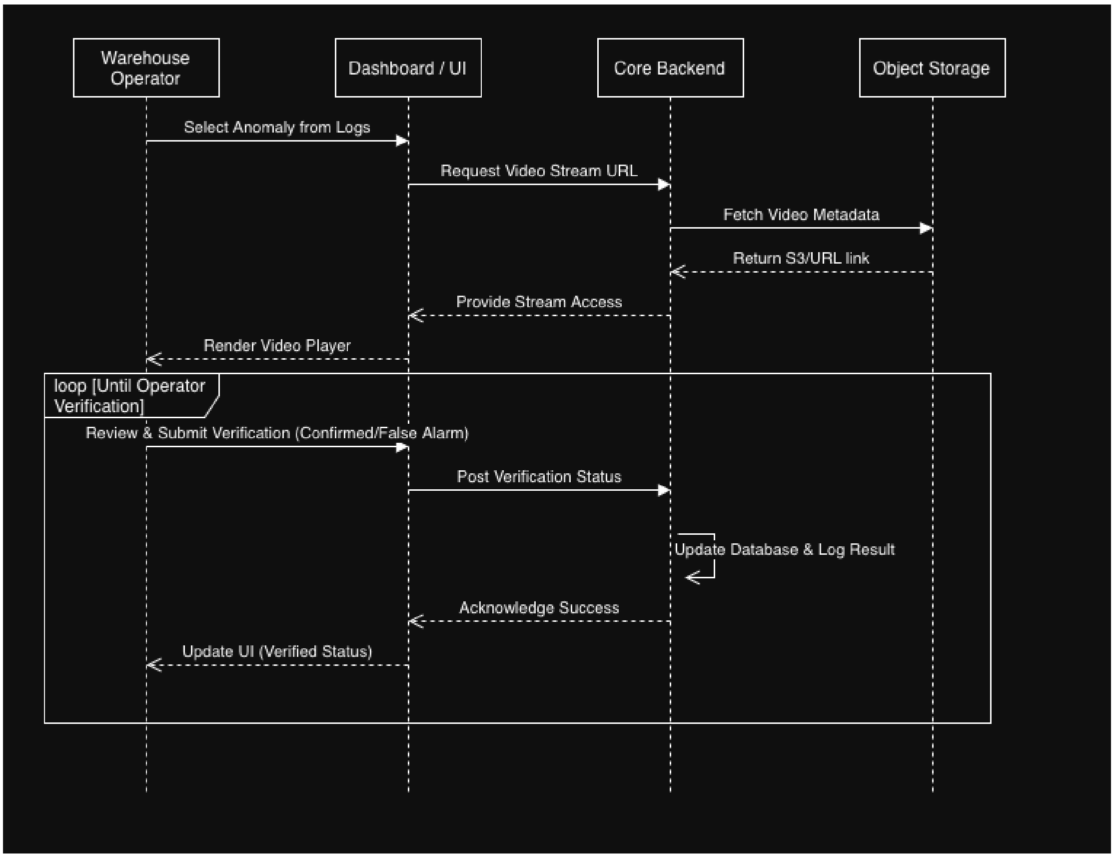

Figure 9: Video Playback Sequence Diagram

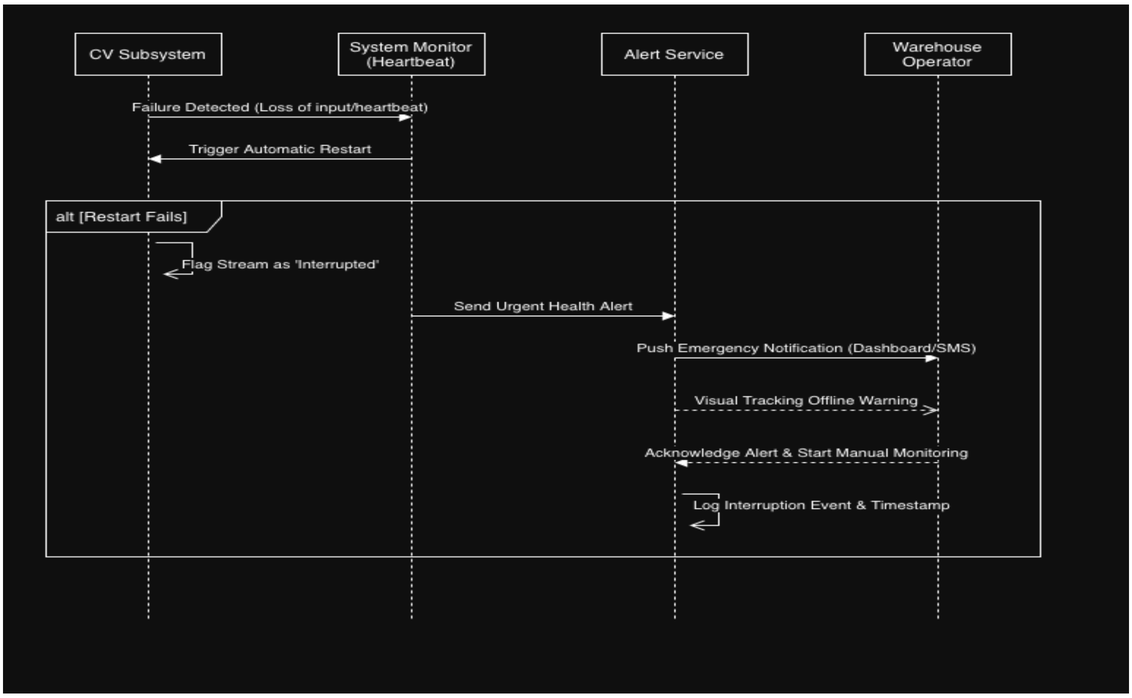

Figure 10: Video Inference Sequence Diagram

2.4.5 User Interface

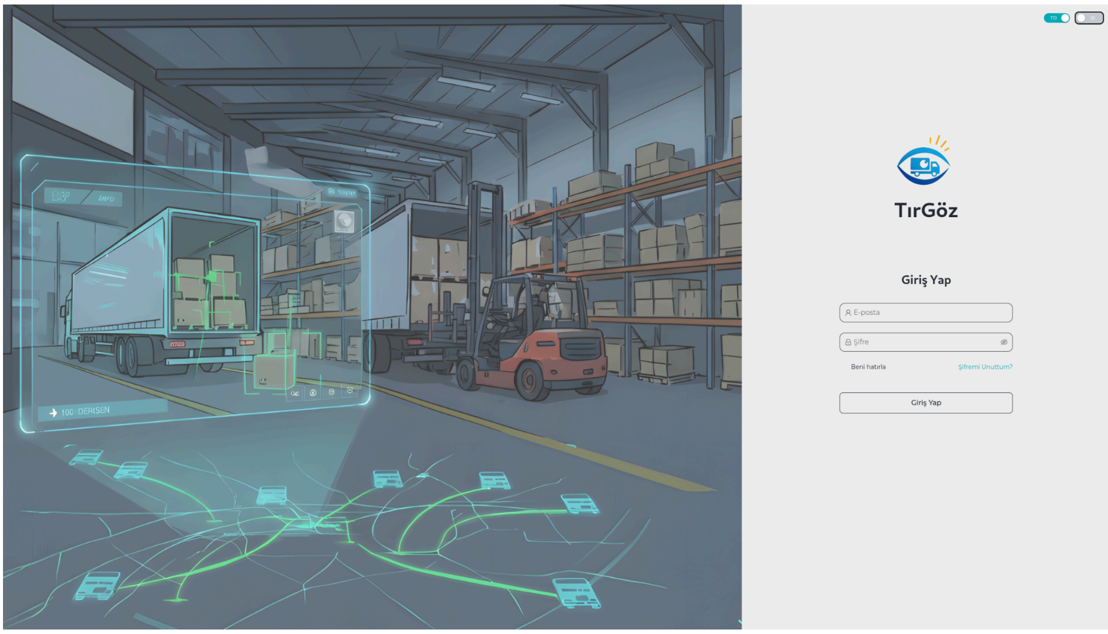

Figure 11: Login Page with Light Theme

This page demonstrates the login interface. User logs in by entering their email and password credentials. He can mark the “Remember Me” button to save his/her credentials in the cookies data. The page has two toggles for switching the interface theme and language.

Figure 12: Login Page with Dark Theme

This page illustrates the dark theme of the login page. The functionalities are the same. After this point, the pages with a dark theme will be used for the consistency of the report and to keep the interface section simple and easy to read.

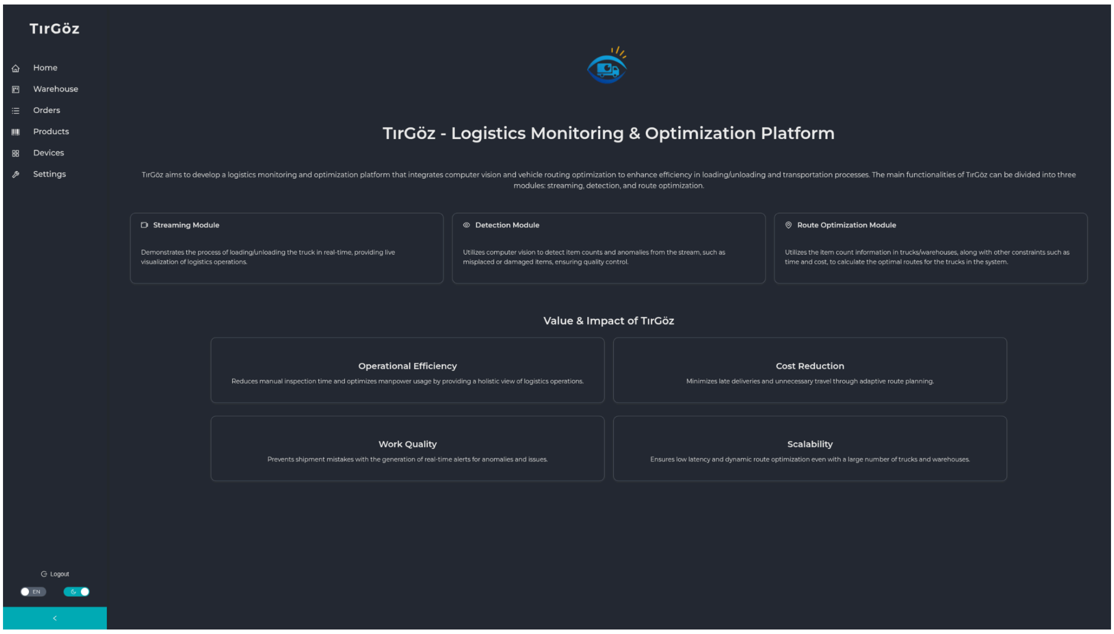

Figure 13: Home Page

This page is a simple home page that introduces the general functionalities of the app. This page can be updated after some points to insert summary informations about the warehouses and workflows about the system.

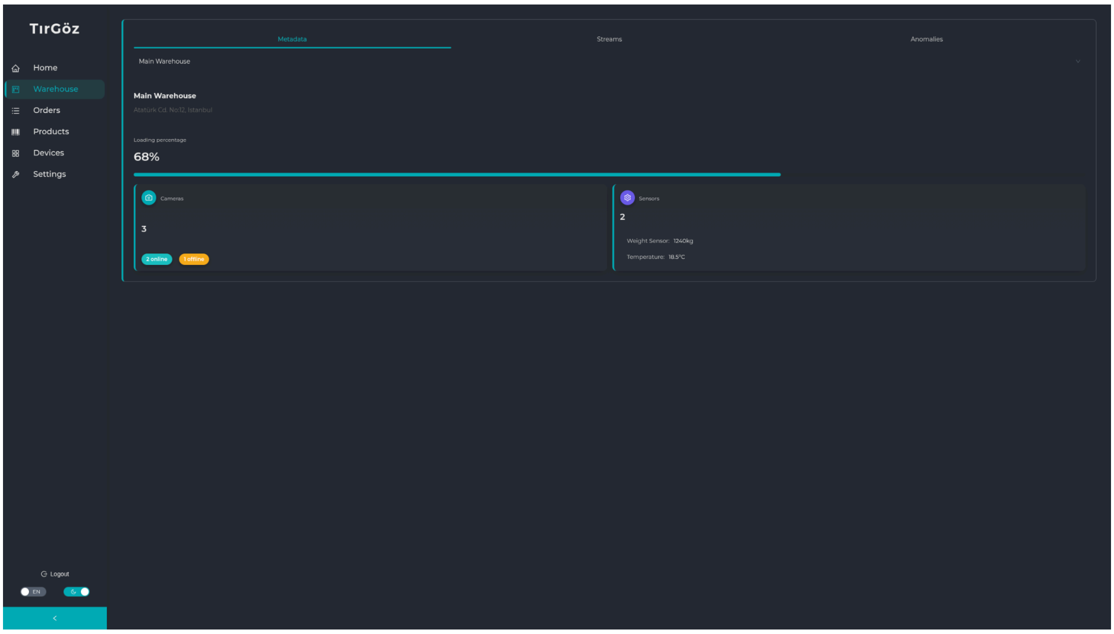

Figure 14: Warehouse Page - Metadata Tab

This section belongs entirely to the Warehouse. It has three tabs, and the first tab is the Metadata Tab. This tab presents some summary stats and checks, such as the loading rate of the warehouse and the general status of sensors and CCTV cameras deployed in the warehouse.

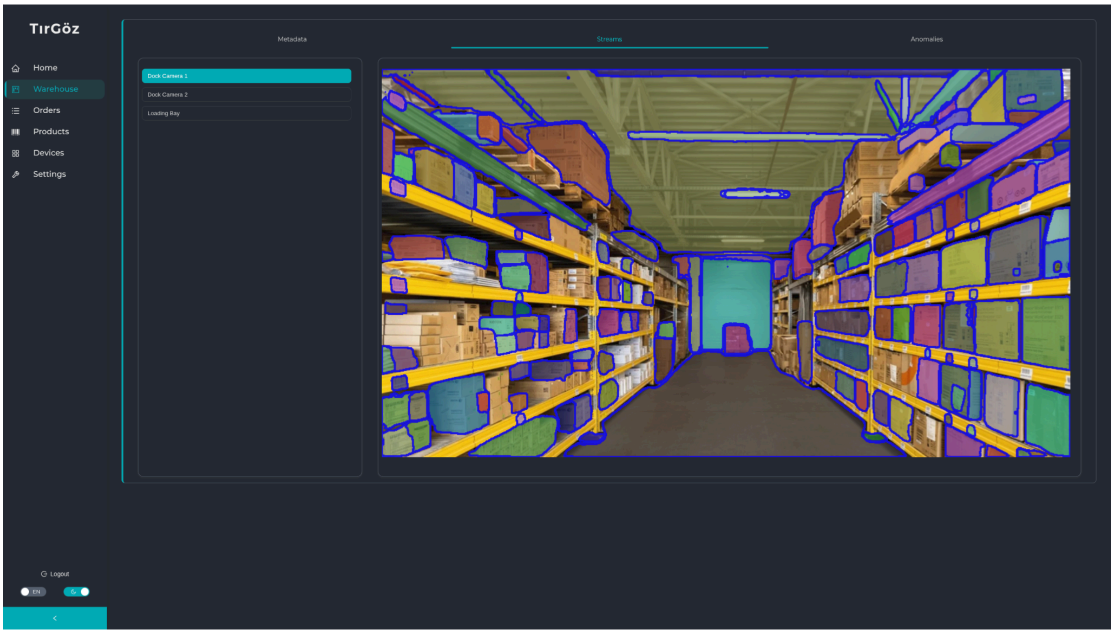

Figure 15: Warehouse Page - Streams Tab

The second tab of the warehouse page is allocated for displaying camera streams. These streams are not standard streams; they will contain insights into how the computer vision model works, displaying segmentation and boundary boxes.

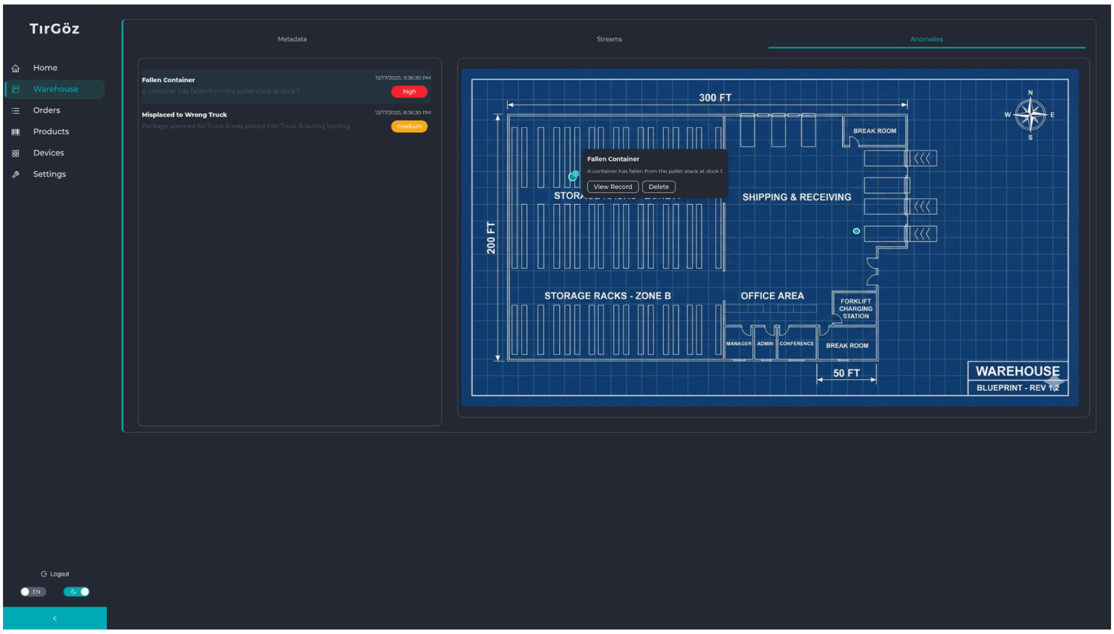

Figure 16: Warehouse Page - Anomalies Tab

The last tab of the warehouse page is anomalies. This tab displays already detected anomalies with the computer vision and their types. The user can click on the anomalies to view their exact location and details.

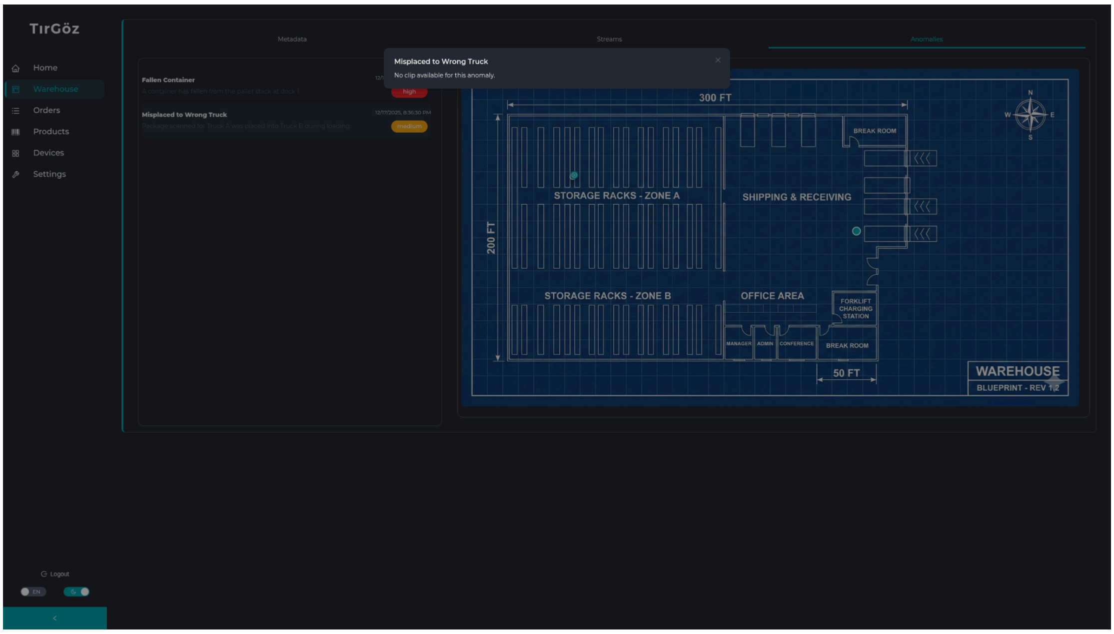

Figure 17: Warehouse Page - Anomalies Tab Displaying an Anomaly without Video Record

If requested, clips related to the anomalies can be viewed. If there is no clip, it displays an empty modal.

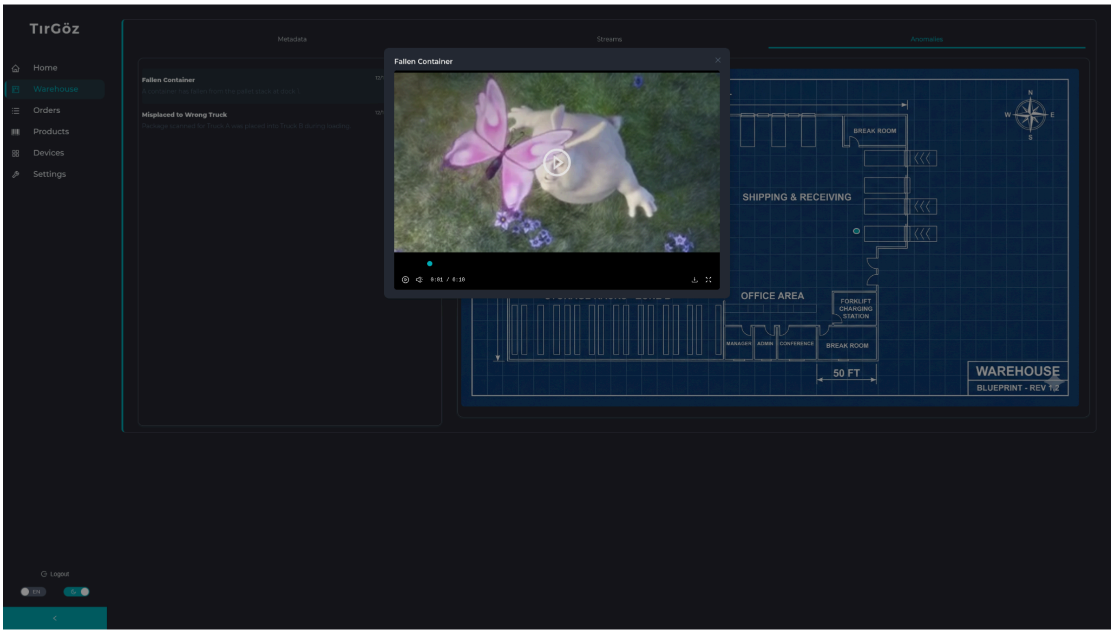

Figure 18: Warehouse Page - Anomalies Tab Displaying an Anomaly with Video Record

If a clip exists, the user can play its clip to watch.

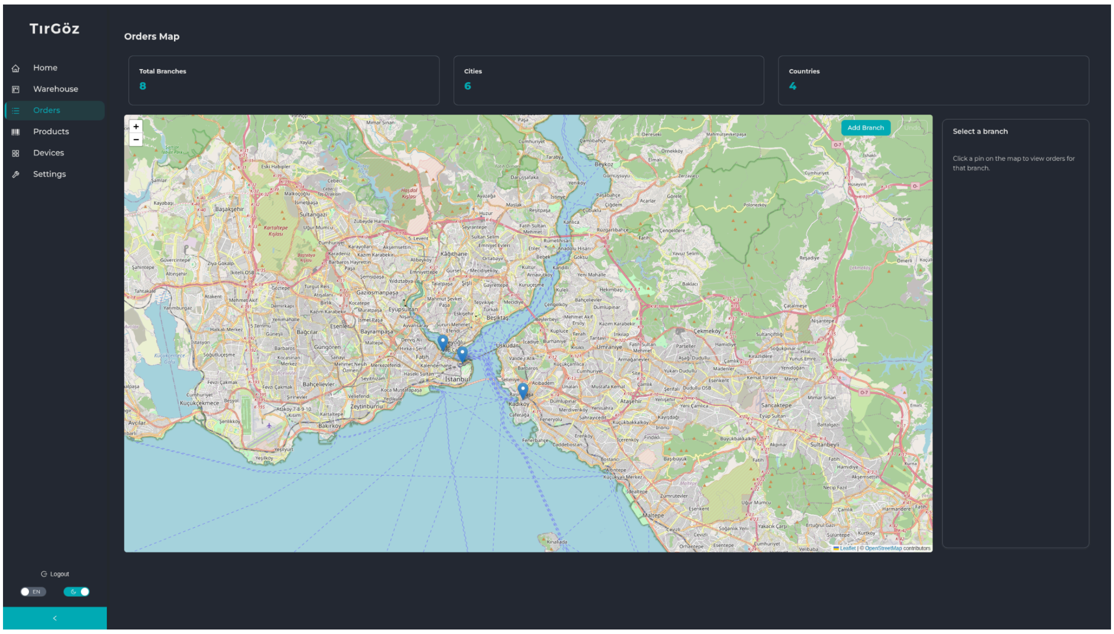

Figure 19: Orders Page

The main goal of the orders page is to display the order summaries given by the various branches. These branches are displayed on the map using markers.

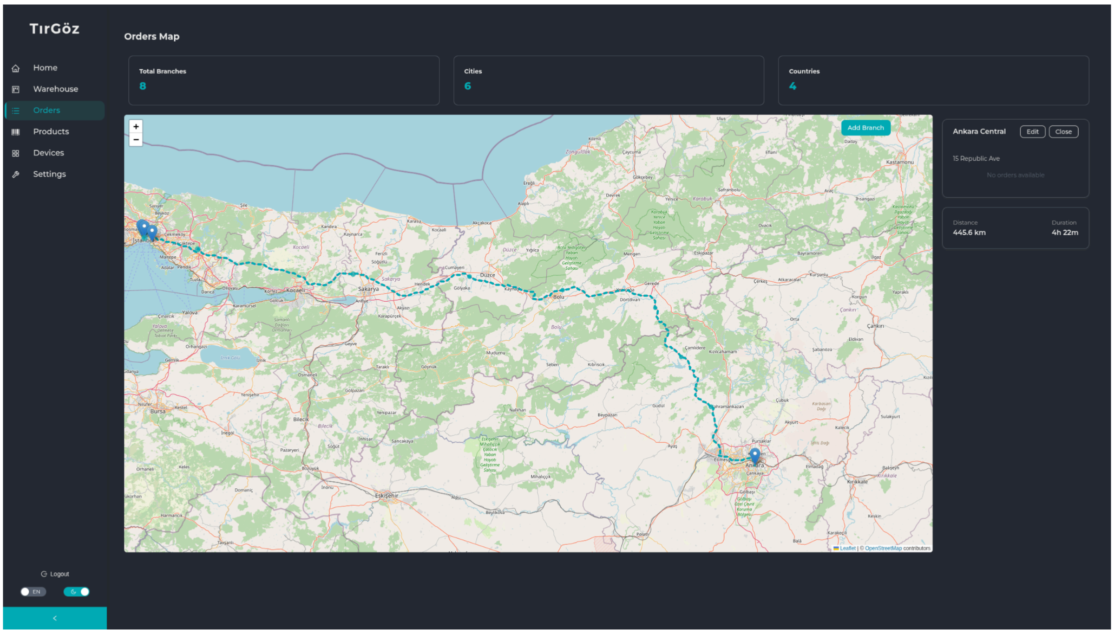

Figure 20: Orders Page - Calculated Path to the Chosen Branch

The other functionality of this page is calculating the distance and prospective duration to the chosen branch. Users can see their orders' estimated time of arrival to the warehouse. This data can be recalculated according to the traffic status and loading percentage of the warehouse, which can affect to the time for loading products into the trucks.

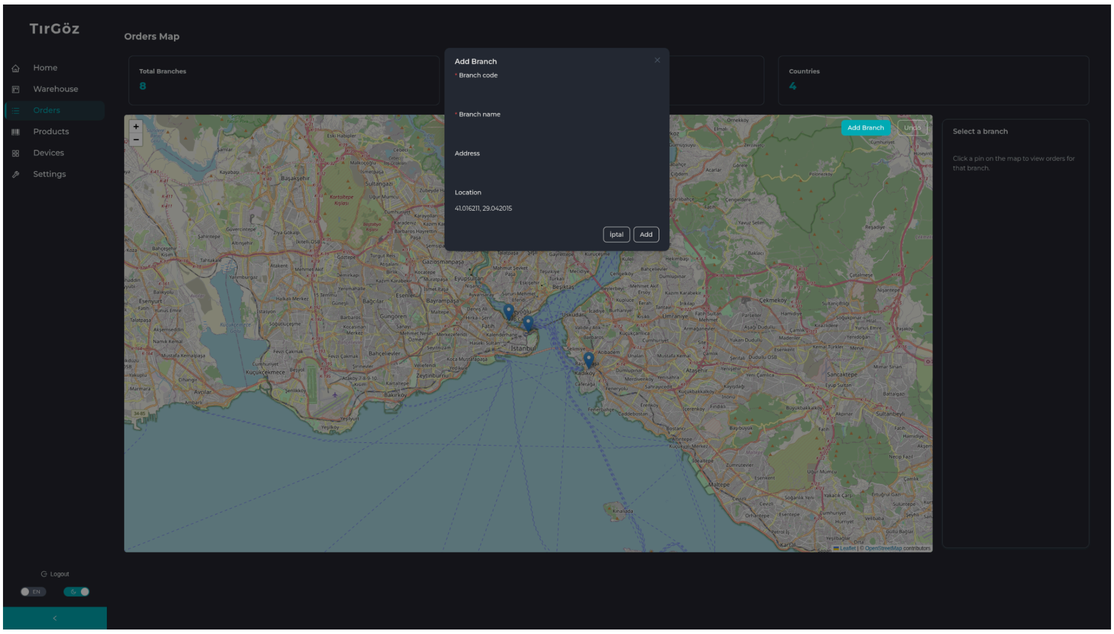

Figure 21: Orders Page - Adding Branch

To add a new branch, the user clicks the “Add Branch” button located at the top-right corner of the map. After clicking the button, the user can place a pin at the desired location on the map. The system then checks the branch code entered by the administrator against the existing records in the database.

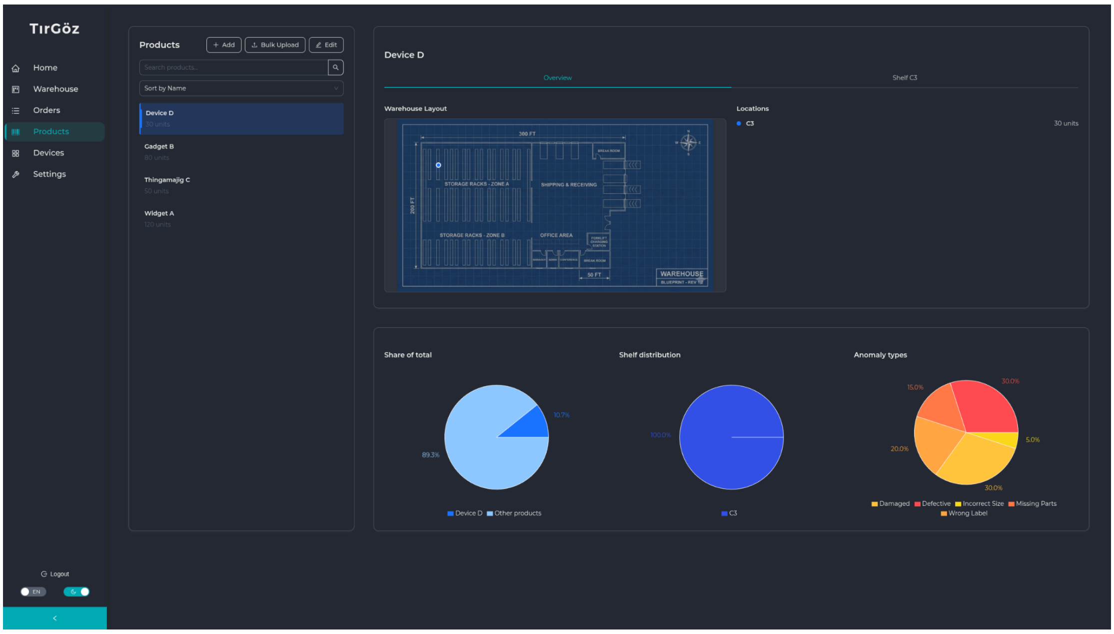

Figure 22: Products Page - Overview

The product page is the key page where users can view general information about the products, such as quantity and the shelf they are on. The location of the shelf that contains the chosen product can be seen on the blueprint. Furthermore, basic statistics are available, including the percentage of the product and shelf selected, distribution among other products, and the most frequent anomaly types observed for the product.

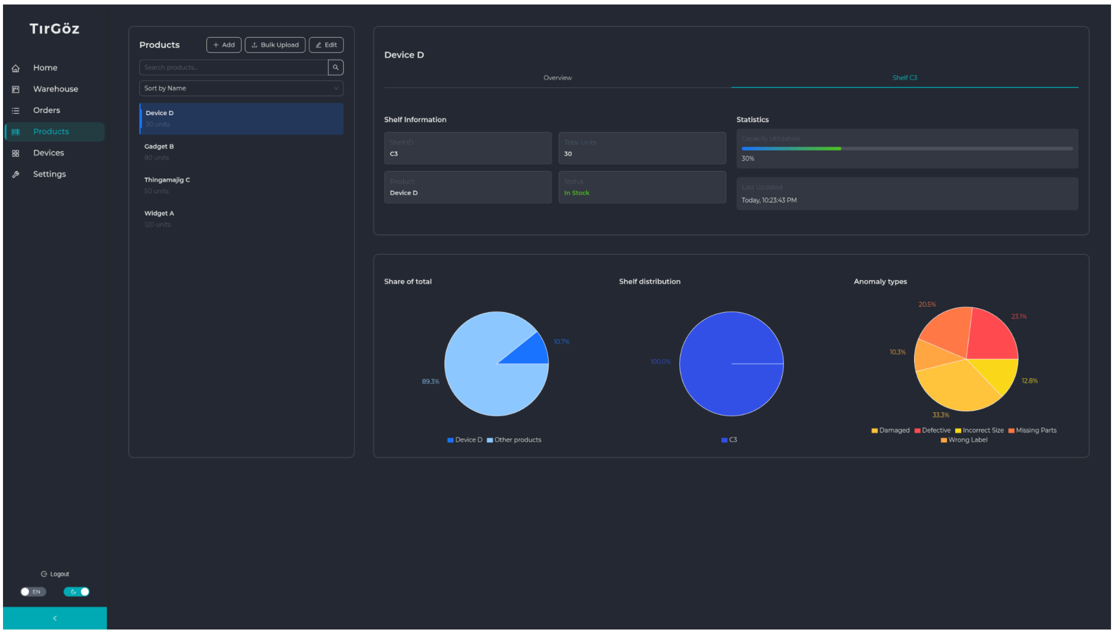

Figure 23: Products Page - Displaying Shelf Stats

This page not only displays product data but also shows some shelf statistics, including the shelf's capacity, the last updated date, and the number of products chosen in the left bar that the shelf contains.

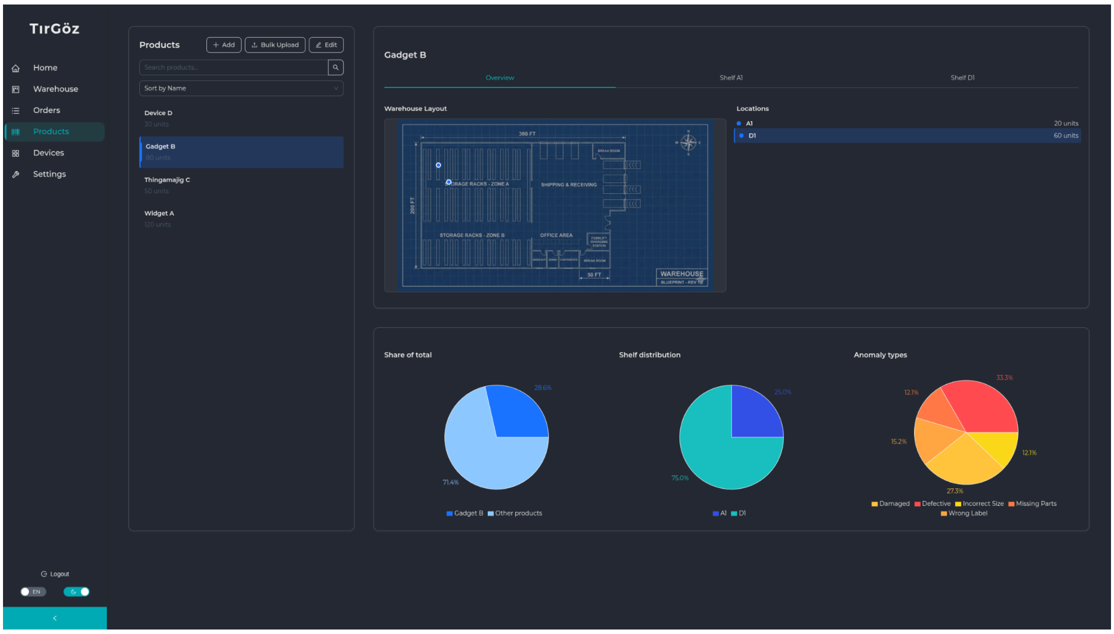

Figure 24: Products Page - Displaying Product Locations on the Blueprint

The shelf stats can be displayed by clicking on the bullet points on the blueprint that represent the shelves and their locations.

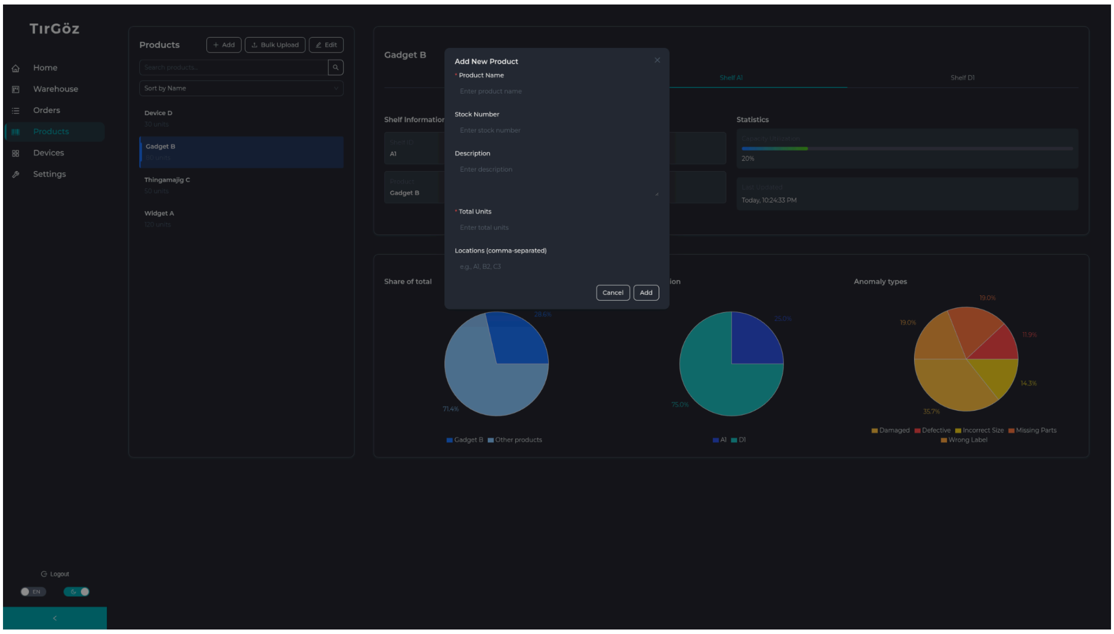

Figure 25: Products Page - Adding Product

The new product can be added by clicking the add button at the top of the card list. It emerges as a modal displayed as in the picture above. After filling out the form, a new product can be inserted.

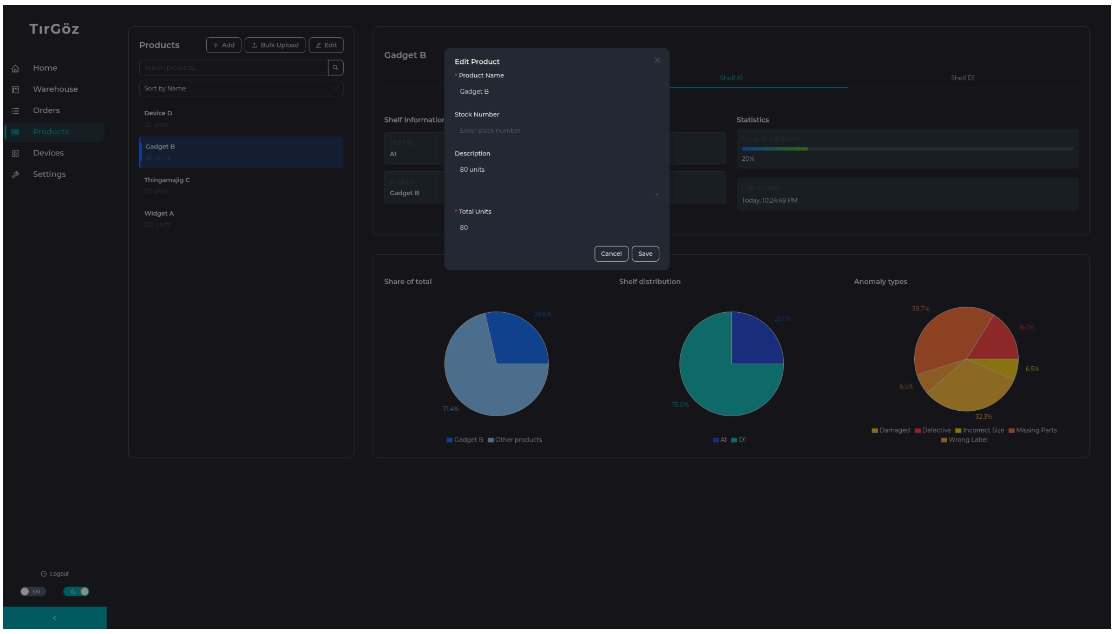

Figure 26: Products Page - Editing Product

Besides adding new products, existing products can be edited by clicking the edit button at the top of the card list again.

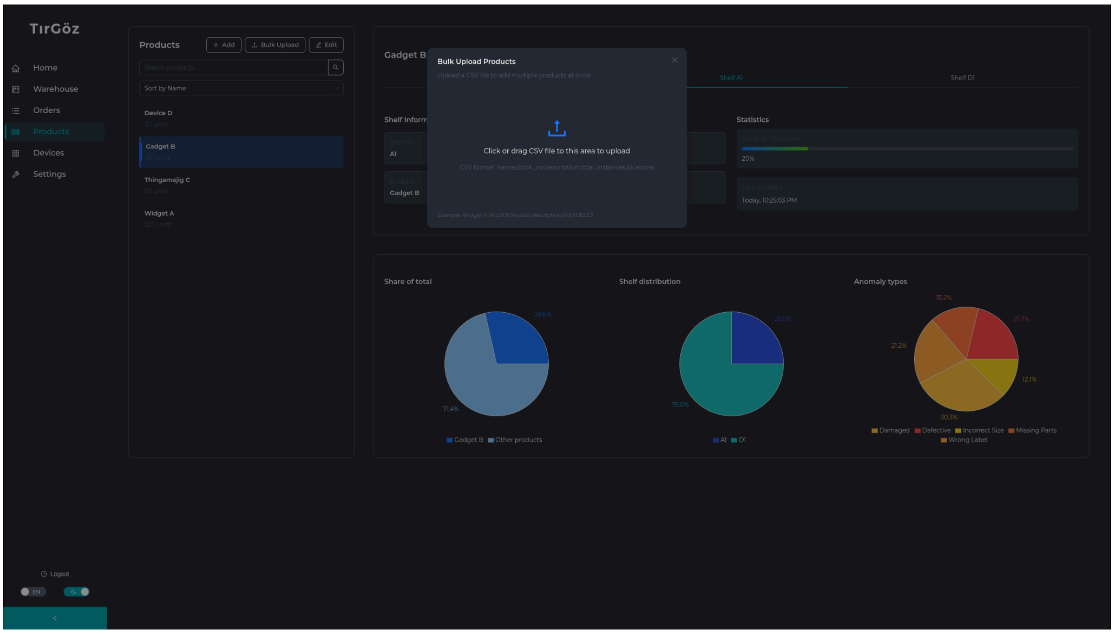

Figure 27: Products Page - Adding Multiple Products Uploading CSV File

If there is an enormous number of products, adding products one by one can be challenging. That's why the app presents a CSV uploader to upload a CSV file containing all products in the requested format.

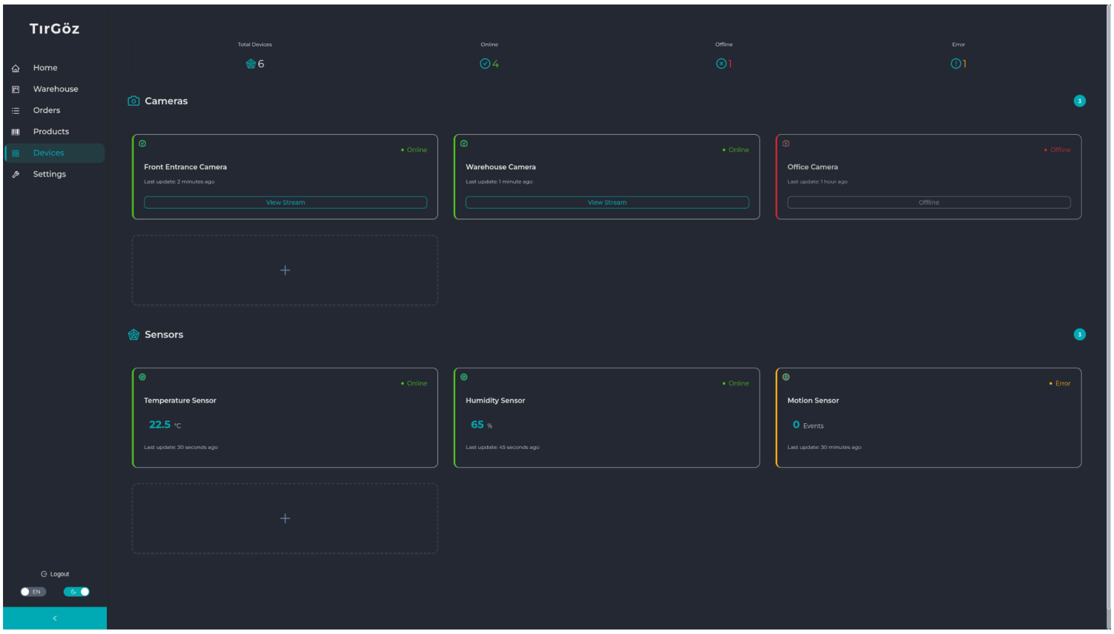

Figure 28: Devices Page

The Devices page displays the main status of all sensors and cameras with their total counts in the warehouse. The user can see whether the looking sensor or camera is active.

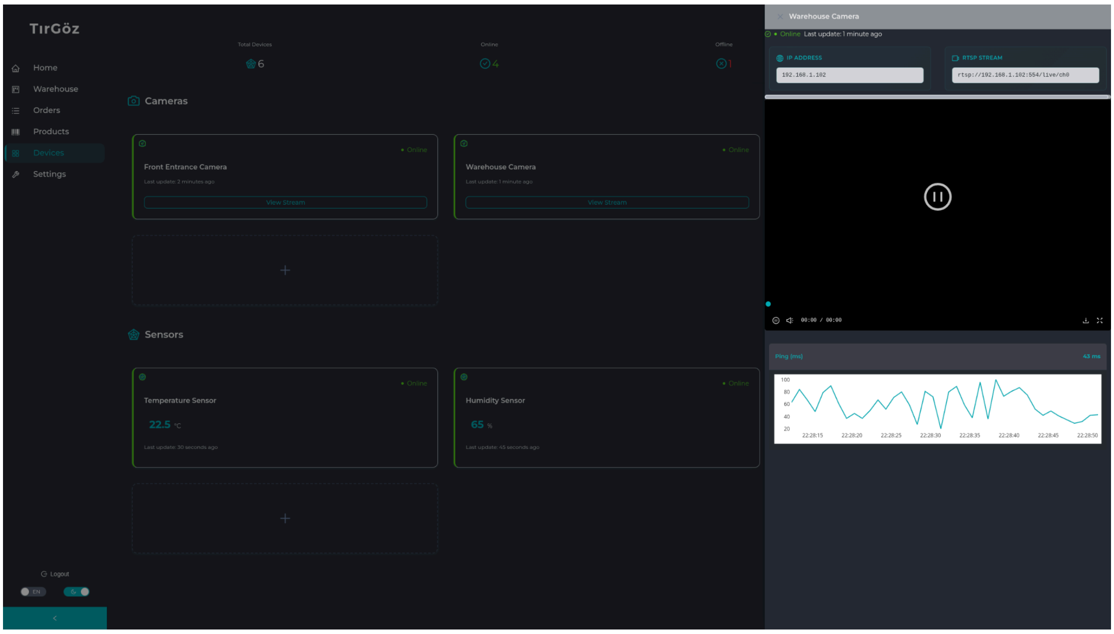

Figure 29: Devices Page - Displaying Stats of the Camera

The camera's details can be viewed by clicking the “View Stream” button, located just below the camera device's card. The details are displayed in a drawer component. The camera's information, including IP address, RTSP stream URL, live ping values, and stream data, can be viewed in this drawer.

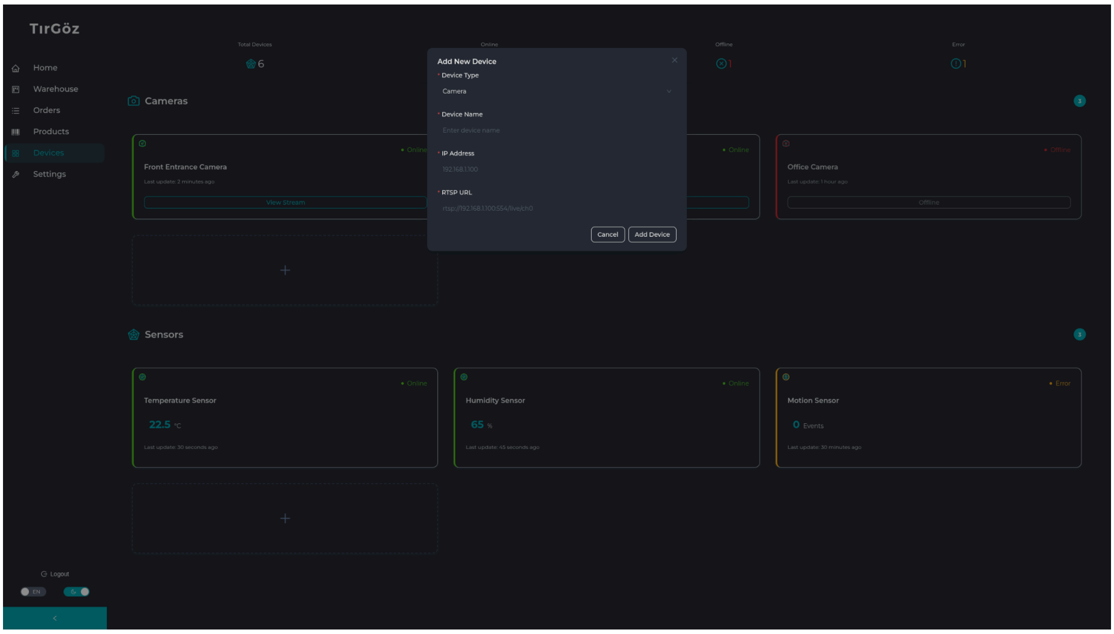

Figure 30: Devices Page - Adding a New Device

The new device can be added by clicking the “+” icons under the existing cards. It opens a modal that requires entering the device type, name, IP addresses, and RTSP URL if it is needed.

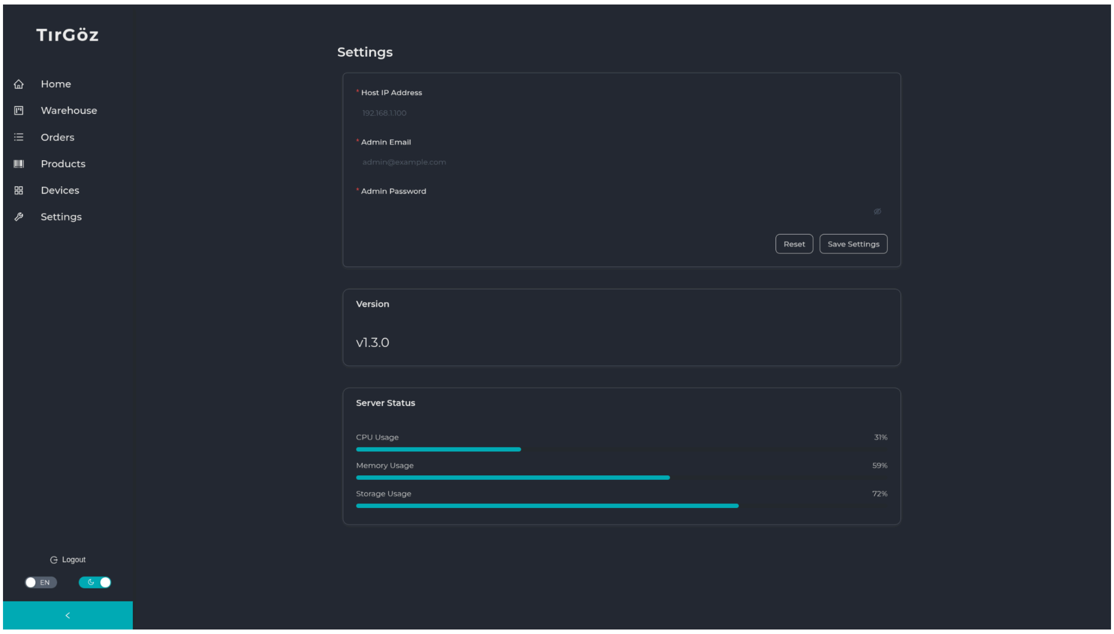

Figure 31: Settings Page

The settings page enables users to adjust their account credentials, basically. Furthermore, the admin user can view the system load by examining CPU, memory, and storage usage.

3 Other Analysis Elements

3.1 Consideration of Various Factors in Engineering Design

3.1.1 Constraints

3.1.1.1 Implementation Constraints

Technology and Platform Constraints: The system's architecture and development workflow are shaped by its dependency on RTSP-compatible security cameras, which limit input sources to devices capable of delivering real-time video streams. This requirement influences hardware selection and ensures compliance with streaming standards. The Computer Vision pipeline must also rely on real-time inference frameworks, such as YOLO variants, that support video decoding and low-latency execution [1]. On the backend, a containerized deployment using Docker is required, and the frontend must rely on cross-platform web technologies, thereby preventing the use of UI toolkits that are specific to a particular platform.

Real Time Processing Constraints: The Computer Vision module, including decoding, detection, and event generation, must operate within a latency of 1,000 ms. Any computationally heavy approaches that exceed this limit cannot be used. Continuous real-time streaming is required; paused or delayed frames are unacceptable because operators must react instantly to operational issues. The Route Optimization module must also compute updated routes within a tight time budget as warehouse and truck states change. Since vehicle routing is NP-hard, exact solvers (e.g., full linear or integer programming) are not feasible for real-time use, making heuristic or approximation algorithms mandatory [2][3].

Integration Constraints: All modules must communicate through standardized REST/HTTP interfaces to retain consistency across components. Data must be stored in the designated storage layers: a relational database for structured truck, warehouse, and configuration data; Redis for cached real-time states and temporary results; and object storage for videos and images [4] . This separation prevents ad hoc storage patterns and ensures predictable access. The Computer Vision module must also adhere to a predefined event logging schema to maintain traceability and ensure that event data is consumable by other services.

Resource Constraints: The entire pipeline must be optimized for efficient memory and compute use. Video parameters, including clip duration, resolution, compression, bitrate, and FPS, must be controlled to avoid unnecessary storage consumption. The Route Optimization module must also utilize algorithms that remain efficient as the problem size increases, since memory usage in distance matrices, cost tables, and constraint sets grows rapidly. As a result, industry-standard optimization techniques are required.

Security and Compliance Constraints: All communication, both video streams and API traffic, must use secure protocols such as HTTPS/TLS. GDPR and KVKK regulations impose strict retention limits on video clips, event logs, and operational records, mandating the implementation of automatic deletion mechanisms [5]. Role-based authentication and authorization ensure that each user type (operators, security staff, administrators) only accesses data and functions appropriate to their responsibilities.

Testing and Deployment Constraints: Because live camera access is not always available during development, the system must support testing with recorded videos to enable repeatable evaluations. Testing primarily focuses on modular validation, controlled simulations, and small-scale experiments, rather than full industrial deployment scenarios.

3.1.1.2. Economic Constraints

Economic limitations restrict choices for hardware, software, and infrastructure. Since the project must operate without enterprise-grade resources, such as GPU servers, specialized networking systems, or high-resolution cameras. All components must run on standard workstations and low-cost development servers. This limits model complexity and prevents the use of computationally expensive solvers. To control long-term operational costs, the system cannot rely on paid cloud services, commercial APIs, or licensed optimization software; instead, it must utilize open-source libraries and cost-efficient storage solutions. Video storage must be managed through clip duration limits, compression, and automated retention policies. Camera acquisition is also constrained to affordable RTSP-compatible devices already deployed in warehouses.

3.1.1.3. Ethical Constraints

TırGöz must comply with ethical standards related to privacy, transparency, and appropriate use of surveillance technologies. Video processing must remain strictly limited to logistics-related tasks, and the system must avoid collecting or storing unnecessary personal data. The Computer Vision module must not be repurposed for employee monitoring beyond project scope. Ethical design also requires transparency regarding detections and recommendations: operators should understand why alerts are generated, allowing the system to support rather than replace their decisions. Automated outputs must be clear, interpretable, and aligned with responsible use guidelines.

3.1.1 Standards

3.1.1.1 Modeling Standards

UML 2.5.1: Used for all modeling artifacts (use case, class, sequence, state, activity diagrams)[6]. Ensures a consistent and standardized representation of system structure and behavior.

3.1.1.2 Requirements & Documentation Standards

IEEE 29148: Defines structure and quality criteria for functional and non-functional requirements, ensuring clarity, correctness, and traceability[7].

IEEE 1058: Provides guidelines for project management documentation such as work packages, schedules, team roles, and deliverables.

IEEE 1016: Specifies how software design descriptions should be structured, supporting architectural clarity, interface definitions, and design documentation.

3.1.1.3 Lifecycle & System Engineering Standards

ISO/IEC/IEEE 12207: Defines the software lifecycle processes across planning, development, testing, deployment, and maintenance[8].

ISO/IEC/IEEE 15288: Covers system level lifecycle processes, including stakeholder interactions, architectural definition, and integration across services.

3.1.1.4 Security Standards

ISO/IEC 27001: Guides information security practices, including access control, secure storage, authentication, authorization, and logging, ensuring confidentiality, integrity, and availability.

OWASP ASVS: Used informally to strengthen backend and API security through guidelines on input validation, authentication, session handling, and protection against common vulnerabilities.

3.1.1.5 Testing & Quality Standards

ISO/IEC/IEEE 29119: Provides a structured approach to testing, including test planning, test design, execution, and reporting.

IEEE 829: Used conceptually to structure test cases and test documentation.

3.1.1.6 API & Data Standards

REST Principles & JSON Schema Standards: Define how microservices communicate, specifying consistent request/response structures and data validation rules.

3.2 Risks and Alternatives

3.2.1 Misuse of Video Streams and Privacy Violations

● **Risk:**

Since TırGöz continuously processes video streams from security cameras, there is a risk that these recordings could be misused for purposes beyond logistics monitoring, such as personnel surveillance. Additionally, improper handling of video data may violate GDPR/KVKK data protection rules and create legal and ethical issues.

● **Alternative:**

Restrict access to video streams and recorded clips using strict role-based access control, allowing only authorized logistics and security operators to view relevant footage. Apply data minimization by storing only the segments necessary for anomaly evidence. Define and enforce clear retention policies that automatically delete video clips and logs after a specified period, in line with GDPR/KVKK regulations. Moreover, clearly communicate to stakeholders that the system is designed solely for monitoring goods and operations, not employees, and document these limitations.

3.2.2 Real Time Streaming and Inference Latency

● **Risk:**

The system must maintain latency under 1,000 milliseconds for live streaming and computer vision inference. If network delays or inefficient video processing pipelines cause latency to exceed this limit, operators may see outdated frames, resulting in delayed reactions to anomalies and reduced trust in the system's alerts.

● **Alternative:**

Optimize the pipeline by using efficient video codecs, adaptive frame rates, and lightweight detection models that satisfy the latency constraint. Implement asynchronous processing and buffering strategies in the streaming gateway to separate decoding, inference, and visualization, allowing them to be tuned independently.

3.2.3 Inaccurate Detection and Anomaly Recognition

● **Risk:**

Computer vision models may produce false positives (e.g., flagging undamaged items as damaged) or false negatives (missing damaged or misplaced items). Such inaccuracies can erode trust in the system, lead to unnecessary manual checks, or, in the worst case, allow genuine issues (incorrect loading, damage) to go unnoticed.

● **Alternative:**

Train and validate detection models on representative warehouse data that covers different conditions, item types, patterns, and camera angles. Utilize a configurable confidence threshold and post-processing rules to filter out low-confidence predictions. Provide operators with short event clips and visualization overlays to quickly verify alerts, allowing for a human decision in critical situations.

3.2.4 Route Optimization Quality and Scalability

● **Risk:**

If the route optimization module cannot scale to complex constraints (time windows, capacities, updated loads), it may produce suboptimal routes or require excessive computation time [2,3]. Inaccurate or outdated occupancy information from the detection module can further compromise planning quality, resulting in inefficient routes, delayed deliveries, and increased operational costs.

● **Alternative:**

Use heuristic algorithms designed for dynamic vehicle routing that can produce near optimal solutions within strict time limits, even as the number of trucks and warehouses grows. Integrate the optimizer with updated occupancy data and implement periodic reoptimization when significant changes occur. Conduct evaluations with simulations using realistic scenarios to validate that the chosen algorithms deliver acceptable solution quality and performance.

3.2.5 Storage Overload and Data Loss for Video and Metadata

● **Risk:**

Continuous recording, combined with a numbers of cameras, may exhaust storage capacity or degrade performance. Additionally, hardware failures or configuration errors may result in the loss of video clips, detection logs, or routing history, thereby limiting the ability to audit operations.

● **Alternative:**

Apply strict retention and compression policies for video clips, such as retaining only the last N minutes of continuous footage and storing long-term only for anomaly-related segments. Monitor storage usage and define quotas to prevent uncontrolled growth. Use cloud solutions that support redundancy and automatic replication. Implement regular automated backups for databases and critical metadata, and periodically test restoration procedures to ensure that data can be recovered after failures.

3.3 Project Plan

Table 1: Factors that can affect analysis and design.

	Effect level (1-10)	Effect
Public health	7	Incorrect routing decisions or delays may cause HSE violations, increasing the risk of injury.

Public safety	8	Safety may be affected when damaged items are loaded, truck capacity is exceeded, and as result of other operational safety hazards. The system directly aims at detecting these scenarios.
Public welfare	5	Improving logistics efficiency reduces delivery errors and delays, indirectly improving service reliability for customers.
Global factors	4	Not directly applicable. The system utilises globally adopted technologies in warehouse systems hence it is not geopolitically constrained.
Cultural factors	3	Warehouse practices and HSE may differ based on region, so may require minimal reconfigurations.
Social factors	6	Continuous video monitoring can cause concerns within employees. Ethical design and transparency is required to ensure acceptance.
Environmental factors	6	Optimised routing reduces fuel consumption and emissions. Digital documentation and workflows reduce paper usage in logistics processes.
Economic factors	8	Limited budgeting restricts the use of specialised software and hardware. The project's main aim is addressing this issue.

Table 2: List of work packages

WP#	Work package title	Leader	Members involved
WP1	Requirements and System Models (CS 491/2 Deliverables)	*Burak Baştuğ*	*Arda Öztürk, Umut Başar Demir, Burak Baştuğ, Berin Su İyici,* Berkin Kağan Ateş
WP2	Streaming & Frontend	Berkin Kağan Ateş	*Arda Öztürk, Umut Başar Demir, Burak Baştuğ*

WP3	Synthetic Data Generation Pipeline	Berin Su İyici	*Arda Öztürk, Umut Başar Demir, Burak Baştuğ, Berkin Kağan Ateş*
WP4	Computer Vision Model Training	Berin Su İyici	*Arda Öztürk, Umut Başar Demir, Burak Baştuğ, Berkin Kağan Ateş*
WP5	Computer Vision Inference & Event Generation	Arda Öztürk	*Burak Baştuğ, Umut Başar Demir, Berin Su İyici, Berkin Kağan Ateş*
WP6	Core Backend Services & Integration	*Berkin Kağan Ateş*	*Arda Öztürk, Umut Başar Demir, Berin Su İyici, Burak Baştuğ*
WP7	Route Planning & Dynamic Optimisation	Umut Başar Demir	*Burak Baştuğ, Arda Öztürk, Berin Su İyici, Berkin Kağan Ateş*
WP8	Testing, QA & Deployment	Burak Baştuğ	*Berkin Kağan Ateş, Umut Başar Demir, Arda Öztürk, Berin Su İyici*

Table 3: Work Package 1 - *Requirements and System Models (CS491/2 Deliverables)*

WP 1: *Requirements and System Models (CS491/2 Deliverables)*			
Start date: *Oct, 2025* **End date:** *May 2026*			
Leader:	Burak Baştuğ	**Members involved:**	*Arda Öztürk, Umut Başar Demir, Burak Baştuğ, Berin Su İyici*
Objectives: The goal of this work package is to get all the key project documents in order. Documents include Specification Report and the Analysis & Requirements Report defining the scope, requirements and key components of the project.			
Tasks: ***Task 1.1 Specification Report*:** Functional, non-functional requirements, scope, key modules and constraints are defined.			

Task 1.2 Analysis & Requirements Report **:** Analysis of system architecture, design and use-case scenarios are detailed. On top of that UML diagrams such as use-case, class and sequence diagrams are given to make the flow and structure clearer. ***Task 1.3 Documenting*****:** Clear documentation of the source code is needed.
Deliverables ***D1.1:*** *Specification Report* ***D1.2:*** *Analysis & Requirements Report*

Table 4: Work Package 2 - Streaming & Frontend

WP 2: Streaming & Frontend			
Start date: *Early December, 2025* **End date:** *Late March, 2025*			
Leader:	Berkin Kağan Ateş	**Members involved:**	*Arda Öztürk, Umut Başar Demir, Burak Baştuğ*
Objectives: *Provide real-time visualisation of the warehouse and events present, and also define the interaction capabilities of the users with such events. The task includes converting camera streams into formats that are compatible with browsers, with constraints such as latency and intuitiveness for the UI. The UI will allow users to operate with live streams, review detected anomalies, inspect system status, and trigger route calculations.*			
Tasks: ***Task 2.1 Camera to Web Streaming Pipeline*****:** *Implement the streaming gateway that converts the camera stream into a supported format.* ***Task 2.2 Frontend Application Development*** **:** *Develop web-based application.* ***Task 2.3 Authentication and Role Based Views:*** *Integrate authentication with backend service and implement role-based access control.*			
Deliverables ***D2.1:*** *Streaming Gateway Service Source Code* ***D2.2:*** *Web Application Source Code* ***D2.3:*** *User Documentations*			

Table 5: Work Package 3 - Synthetic Data Generation Pipeline

WP 3: Synthetic Data Generation Pipeline			
Start date: *Late December, 2025* **End date:** *Late January, 2026*			
Leader:	*Berin Su İyici*	**Members involved:**	*Arda Öztürk, Umut Başar Demir, Burak Baştuğ, Berkin Kağan Ateş*
Objectives: Building a synthetic data generation pipeline such that it can be configured based on different warehouse settings, such as camera angles and lighting, to generate labelled warehouse and truck loading scenes for CV training and validations. This pipeline can later be used to fine-tune the model based on customer requests when no footage is available from the customer.			
Tasks: ***Task 3.1 Environment Templates***: *Truck interior, warehouse shelf layouts, and other blueprint items are generated.* ***Task 3.2 Augmentation of Scenery for Real Life Scenarios***: *Real life occlusions, lighting changes, noise in the camera stream, textures, and human and machinery movement are modeled.* ***Task 3.3 Annotation Export and Dataset Structuring***: *Bounding boxes, segmentation, tracking IDs, and anomaly labels are exported and structured into a dataset.*			
Deliverables ***D3.1:*** *Synthetic Data Generator Code* ***D3.2:*** *Environment Template Configs* ***D3.3:*** *Documentation of Code* ***D3.4:*** *Dataset Export Documentation and Config Parameter Documentation*			

Table 6: Work Package 4 - Computer Vision Model Training

WP 4: Computer Vision Model Training			
Start date: *Late January, 2026* **End date:** *Early May, 2026*			
Leader:	Berin Su İyici	**Members involved:**	*Arda Öztürk, Umut Başar Demir, Burak*

			Baştuğ, Berkin Kağan Ateş
Objectives: *Train and validate ML models used by the CV Subsystem with synthetic data generated from and recorded streams, when available. The selected model must pertain to both accuracy constraints and near real time constraints.*			
Tasks: ***Task 4.1 Dataset Assembly & Labeling*****:** *Merge synthetic and collected data when available. Define class taxonomy, annotation rules and splits* ***Task 4.2 Training Pipeline*** **:** *Reproducibility focused training code, configs, experiment tracking and checkpoint loggers.* ***Task 4.3 Evaluation*** **:** *Metrics defined and scenario based stress tests similar to real life situations are created, taking into account factors such as occlusion, low light and motion blur.* ***Task 4.4 Model Selection Under Latency Constraints & Model Packaging*** **:** *Models are exported and tested under project pipeline. A project that meets <= 1000 ms in the context of the project pipeline is selected.*			
Deliverables ***D4.1:*** *Training Pipeline Source Code and Configs* ***D4.2:*** *Evaluation Logs* ***D4.3:*** *Versioned Model Artifacts Ready for Deployment*			

Table 7: Work Package 5 - Computer Vision Model Training

WP 5: Computer Vision Inference & Event Generation			
Start date: *Early February, 2026* **End date:** *Mid May 2026*			
Leader:	Arda Öztürk	**Members involved:**	*Burak Baştuğ, Umut Başar Demir, Berin Su İyici, Berkin Kağan Ateş*
Objectives: *Providing the system with a subsystem that converts camera footage into operationally meaningful metadata such as item counts and placement, occupancy estimation and anomalies. Outputs must meet the latency target unless it is not mission critical information (Such as the clip of the anomalies that are not always needed in the moment it is detected). Outputs must match the expected inputs for the backend.*			

Tasks: ***Task 5.1 Inference Pipeline*** **:** *Backbone of the pipeline is implemented which streamlines the input and outputs and the inner working of the CV subsystem.* ***Task 5.2 Occupancy Estimation*** **:** *Convert detections into occupancy information, free space estimation and item category counts per zone.* ***Task 5.3 Anomaly Detection*** **:** *Damage classifier, item-truck match checks, idle loading and unauthorised removal behaviour detection and other anomalies.* ***Task 5.4 Business Rules & Deterministic Rules Layer*** **:** *Model outputs are evaluated in this layer to obtain meaningful results. Purpose of this layer can be exemplified as: keep the model from reflagging the same event, cross-service consistency, confidence thresholding etc.* ***Task 5.5 Event Schema and Publishing to Backend*****:** *Creation of the event based on the anomaly taxonomy. Each event has defined metadata including event type, timestamps, affected object ids etc.*
Deliverables ***D5.1:*** *CV Inference Source Code* ***D5.2:*** *Backend Integration Source Code*

Table 8: Work Package 6 - Core Backend Services & Integration

<table>
<tr><td colspan="4">WP 6: Core Backend Services & Integration</td></tr>
<tr><td colspan="4">Start date: mid-January 2026 End date: early May 2026</td></tr>
<tr><td>Leader:</td><td>Berkin Kağan Ateş</td><td>Members involved:</td><td>Arda Öztürk, Umut Başar Demir, Berin Su İyici, Burak Baştuğ</td></tr>
<tr><td colspan="4">Objectives: Implement backbone of the application that powers the UI and routing decisions. These include authentication, authorization, even ingestion, storage, caching, analytics, API endpoints.</td></tr>
<tr><td colspan="4">Tasks:
Task 6.1 Authentication Service : Roles, access permissions, tokens and session management.
Task 6.2 Analysis Service APIs : Dashboards, anomaly lists, clip links, device status and other relevant endpoints.
Task 6.3 Data Layer Integration : Integrate backend services with the application data layer, ensuring consistency and efficiency of caching, db access etc.</td></tr>
</table>

***Task 6.4 Event Integration**: Accepting events generated by CV subsystem, creation of history logs, updating current state.*
Deliverables ***D6.1:** Authentication and Analysis source code* ***D6.2:** Database and migration scripts* ***D6.3:** API documentation*

Table 9: Work Package 7 - Route Planning & Dynamic Optimisation

WP 7: Route Planning & Dynamic Optimisation			
Start date: *Late December 2025* **End date:** *Late April*			
Leader:	Umut Başar Demir	**Members involved:**	*Burak Baştuğ, Arda Öztürk, Berin Su İyici, Berkin Kağan Ateş*
Objectives: *Dynamic Route Optimisation is implemented such that it consumes data in real time and generates near-optimal routes under constraints such as capacity, time windows, time and fuel cost.*			
Tasks: ***Task 7.1 Problem Definition** : Vehicle Routing Problem type is formalised with the constraints of the project.* ***Task 7.2 Baseline Heuristic**: A baseline for fast routing decisions based on greedy and local search.* ***Task 7.3 Dynamic Updates**: Re-optimisation triggers such as occupancy changes, new or withdrawn orders, delays and their implications on the routing are defined.* ***Task 7.4 Integration API**: Endpoints to calculate route, recalculate, get current plan etc are implemented.* ***Task 7.5 Evaluation**: Test scenarios are simulated. Such scenarios may include capacity drops, new orders etc.*			
Deliverables ***D7.1:** Route Optimisation Subsystem Source Code* ***D7.2:** Demo Scenarios with Expected Outputs* ***D7.3:** Evaluation of the model*			

Table 10: Work Package 8 - Testing, QA & Deployment

<table>
<tr><td colspan="4">WP 8: Testing, QA & Deployment</td></tr>
<tr><td colspan="4">Start date: Late January 2026 End date: Mid May 2026</td></tr>
<tr><td>Leader:</td><td>Burak Baştuğ</td><td>Members involved:</td><td>Berkin Kağan Ateş, Umut Başar Demir, Arda Öztürk, Berin Su İyici</td></tr>
<tr><td colspan="4">Objectives: Ensure the application meets functional and non-functional requirements under real life scenarios. Provide a reproducible, dockerised deployment and test strategy.</td></tr>
<tr><td colspan="4">Tasks:
Task 8.1 Docker Compose Stack : Gateway, streaming, CV, backend, route, DB and other systems.
Task 8.2 Testing with Pre-recorded Streams : Test streaming, inference, anomaly detection, anomaly detection, and event generation using recorded video streams to ensure reproducible evaluations.
Task 8.3 Integration Tests : Validate data flow across services to ensure correctness.
Task 8.4 Performance Tests : Measure latency, throughput and other system behaviour under different loads or other real time constraints.
Task 8.5 Security Tests : Verify authentication, authorisation, secure network communication.</td></tr>
<tr><td colspan="4">Deliverables
D8.1: Dockerised Deployment Environment
D8.2: Overall Test Results</td></tr>
</table>

3.4 Ensuring Proper Teamwork

To ensure the successful delivery of the project, the team will adopt a structured collaborative framework centered on clear communication. We will utilize Jira as our primary project management tool to maintain an organized backlog, track individual tasks, and monitor overall progress through our project plan [9]. This systematic approach will allow the team to visualize workflows, identify potential bottlenecks early, and ensure that all project requirements are met on schedule. Regular team and mentor meetings will complement these tools, providing a forum for team members to align on objectives and resolve any emergent challenges.

Technical collaboration will be managed through GitHub to ensure a disciplined and transparent development environment. By utilizing a central repository, the team will maintain version control integrity, enabling multiple members to contribute simultaneously without compromising the project's stability. We will implement a structured branching strategy, ensuring that every contribution is reviewed thoroughly.

3.5 Ethics and Professional Responsibilities

A core ethical concern of this system will be the protection of privacy and the autonomy of warehouse personnel. The platform will be strictly prohibited from being used for personnel surveillance, and data collection will be limited exclusively to what is necessary for logistics operations. No personal information will be stored unless it is legally required, and users will be clearly informed regarding the specific capabilities and limitations of the detection technology. Furthermore, the project will strictly adhere to international and local data protection regulations, such as GDPR and KVKK, ensuring that all stored footage is automatically deleted once the defined retention period expires.

To ensure fairness and operational integrity, the team will actively work to identify and mitigate technical bias within the automated detection models. Since warehouse environments often feature varying lighting conditions and diverse worker activities, the detection models will be tested against a wide range of data sets to prevent inaccuracies such as incorrect item counts or false alerts. The team will maintain transparency in evaluating model performance and will proactively adjust training data if any unintended biases are discovered. Finally, all integrations with third-party tools or external interfaces will be managed to respect licensing requirements and intellectual property rights.

3.6 Planning for New Knowledge and Learning Strategies

The successful implementation of this project requires a proactive approach to mastering emerging technologies in computer vision and automated logistics. To bridge the gap between current expertise and project requirements, the team will engage in a structured knowledge acquisition phase focusing on state-of-the-art video analytics and real-time data processing. We will prioritize hands-on learning through specialized technical documentation and online learning programs.

In addition, to align with the architecture of the project, the team will prioritize deepening our collective understanding of microservices, which serves as the foundational framework for ensuring modularity and component independence. We will implement a dual-stream learning strategy that merges internal expertise with high-quality external resources. Team members with previous experience in this architecture will provide technical mentorship and leadership during the development phase, while the rest of the team will utilize specialized technical blogs, industry-standard articles, and comprehensive video courses to address any remaining knowledge gaps.

4 Glossary

Term	Definition
RTSP	A networking protocol used for streaming video from security cameras.
CCTV	Also called Closed Circuit Television. A type of surveillance camera.
YOLO	A deep learning model for object detection
Ad hoc	A temporary solution that does not meet the standards of the system
Anomaly Detection	Detecting unusual events and abnormal patterns.
Occupancy Estimation	Process of approximating how full a space is, in our case warehouse and truck load.
Heuristic Algorithms	Fast and rule-based solutions that determine good solutions. Used in our case because route optimisation is computationally expensive.
Meta-Heuristic Algorithms	Problem agnostic frameworks that guide and improve heuristic rules.
Vehicle Routing Problem	An NP-hard optimisation in the field of logistics. The goal is to find optimal sets of routes for a fleet.

Dynamic Routing	Real-time adjustments of delivery routes based on new information such as load delays, traffic.

5 References

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