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Use Cases Development for Automated Functions in Autonomous Rail Inspection Vehicles

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Introduction

Timely maintenance is crucial for ensuring safe and cost-effective railway operations. Therefore, it is vital to establish structured guidelines for defining both the schedules and routes for inspection activities during the missions of special trains, such as inspection vehicles, which are anticipated to operate as regular trains within mixed traffic in the near future.

This paper presents several use cases for inspection vehicles, as outlined in Work Package 5 of the project R2DATO [1] under the European Rail Joint Undertaking (ERJU) [2] a European partnership dedicated to rail research and innovation as part of the Horizon Europe program (2020-2027) and the successor to the Shift2Rail Joint Undertaking (S2RJU) [3]. In this context, the concept of the Journey Profile (JP) is expanded to support inspection-related operations by incorporating information such as inspection start and end points, sensor deployment and retraction locations, inspection areas, event detection criteria, environmental conditions, and potential safety risks.

These use cases demonstrate how future inspection activities could be more effectively planned and structured within mission definitions, facilitating a smoother integration of inspection trains into regular railway operations. The presented use cases include:

- Elaborate mission and journey profiles including inspection activities;
- Arriving at the starting point of the area to be inspected;
- Finishing the inspection, retract devices, check data and prepare to return.

These use cases assist practitioners in understanding the operational context of future inspection vehicles.

Mission Profile

The Mission Profile (MP) is a structured set of tasks planned by the Railway Undertaking (RU) to be performed during time slots when the train is not in service, based on the paths agreed with Infrastructure Managers (IMs). These tasks can be executed in sequence or in parallel and are solely under the RU's responsibility, ensuring a clear distinction from the IM's duties. Tasks may be linked to a specific journey or be independent, and their initiation can depend on time or location triggers [4].

For each planned journey in the MP, a valid JP with a defined departure time, a defined arrival time and an End of Journey will be sent by IM. The associated Segments Profile (SP) will be extracted from an infrastructure database like illustrated in the figure below:

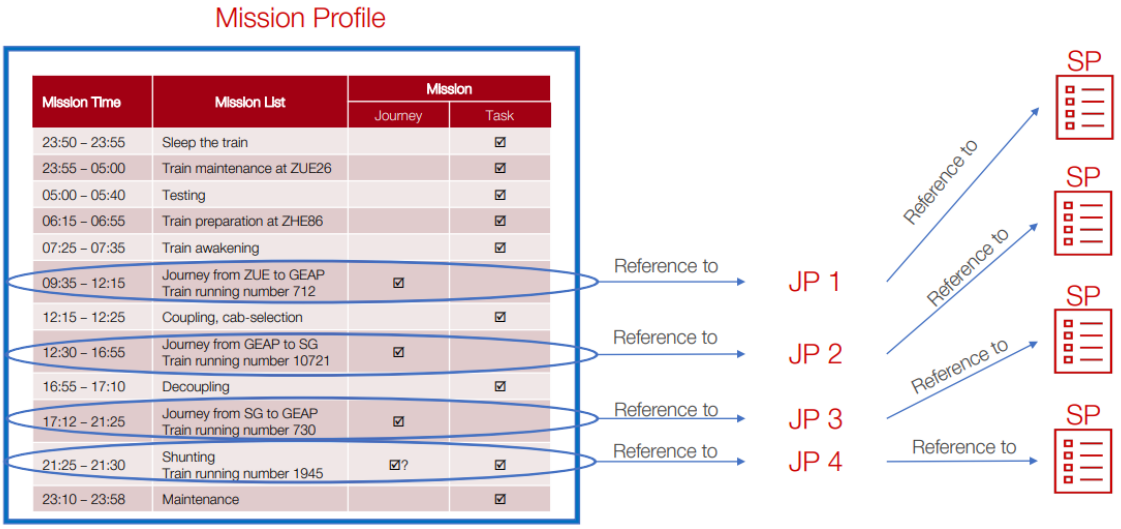

Figure 1: Relationship between Mission Profile (MP), Journey Profile (JP), and Segment Profile (SP). The Journey Profile (JP) defines the train's complete route by listing the Segment Profiles (SPs) to be traversed. Each SP contains the static infrastructure data necessary for safe and efficient operation. The MP coordinates operational tasks in alignment with the JP, ensuring consistency between planned activities and the physical rail network [4].

Use Cases

The subsequent section delineates three use cases that exemplify the incorporation of inspection activities into railway operations through the systematic application of MP and JP. These use cases furnish a comprehensive overview of the operational sequence associated with inspection missions, encompassing the planning and specification of inspection-related data, the preparation of the vehicle at the commencement of the inspection area, and the procedures to be executed upon the completion of the inspection. Collectively, they provide a conceptual framework for comprehending the potential operation of inspection trains within future mixed-traffic scenarios.

Elaborate mission and journey profiles including inspection activities

This use case extends the framework from "UC 13.2.1 – Elaborate Mission and Journey Profiles" [4] by incorporating inspection-related operations requirements. It aims to integrate special-purpose inspection trains into regular railway operations alongside passenger and freight services. The inclusion of inspection activities in mission and journey profiles advances operational efficiency, improving upon traditional manual processes. By incorporating inspection parameters in MP and JP, railways can coordinate these missions with broader network activities, enhancing safety and resource utilization. The extended profiles provide structured embedding of inspection-related information, including timeframes, locations, and operational considerations. While detailed technical configurations remain outside scope, this high-level information enables automated execution and monitoring. The use case assumes a scheduled inspection mission requiring integration into planning frameworks, resulting in profiles enriched with inspection information for operational execution. Figures 1 and 2 provide an overview of processes for this use case. Figure 1 details the initialization sequence for the inspection vehicle database, including device registration and mission parameters. These figures demonstrate how planning data and system components enable automated inspection missions in railway operations. Figure 2 shows the relationships between MP, JP, and SP, illustrating route configuration and operational tasks for trains.

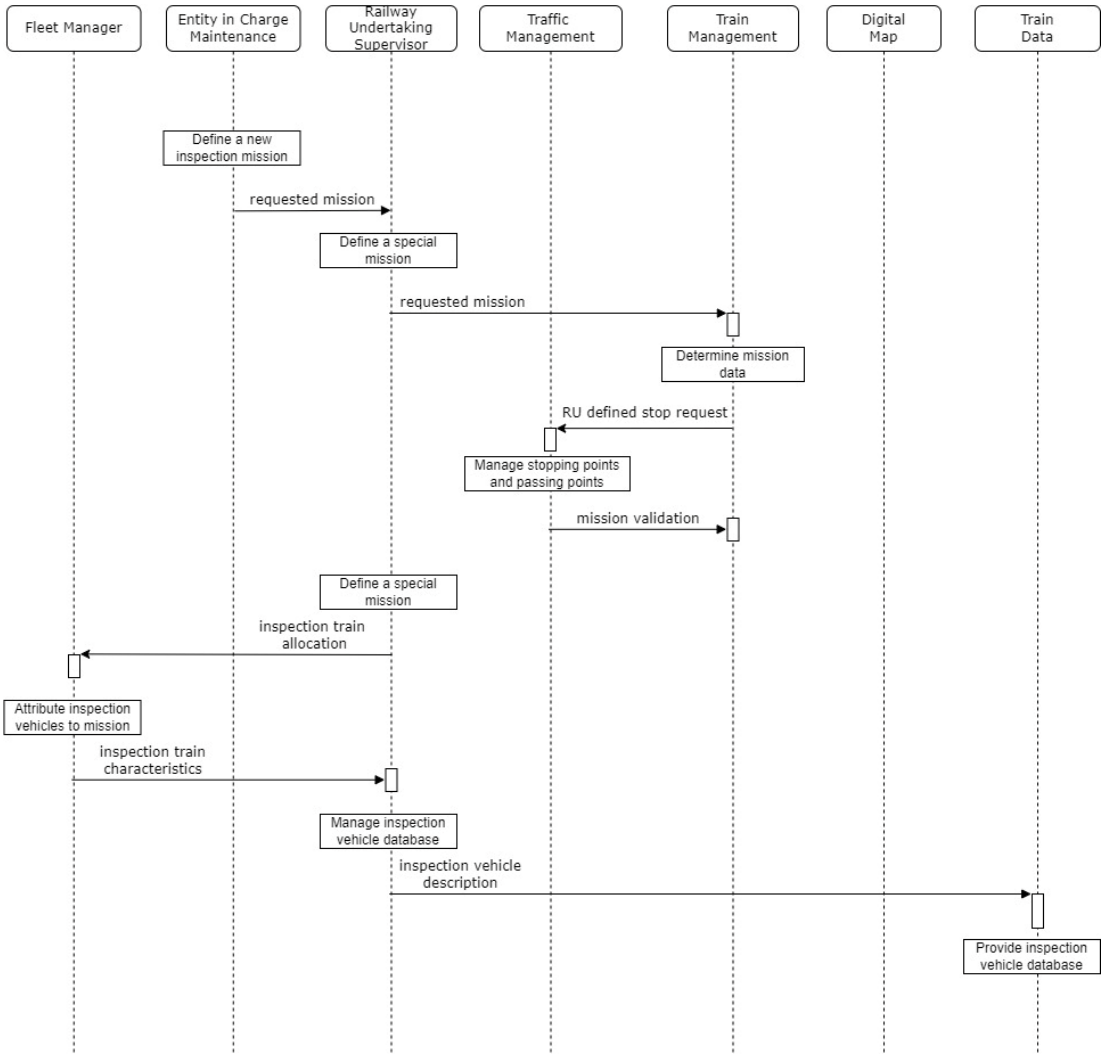

Figure 2: Sequence diagram illustrating the preparation process of the inspection vehicle database.

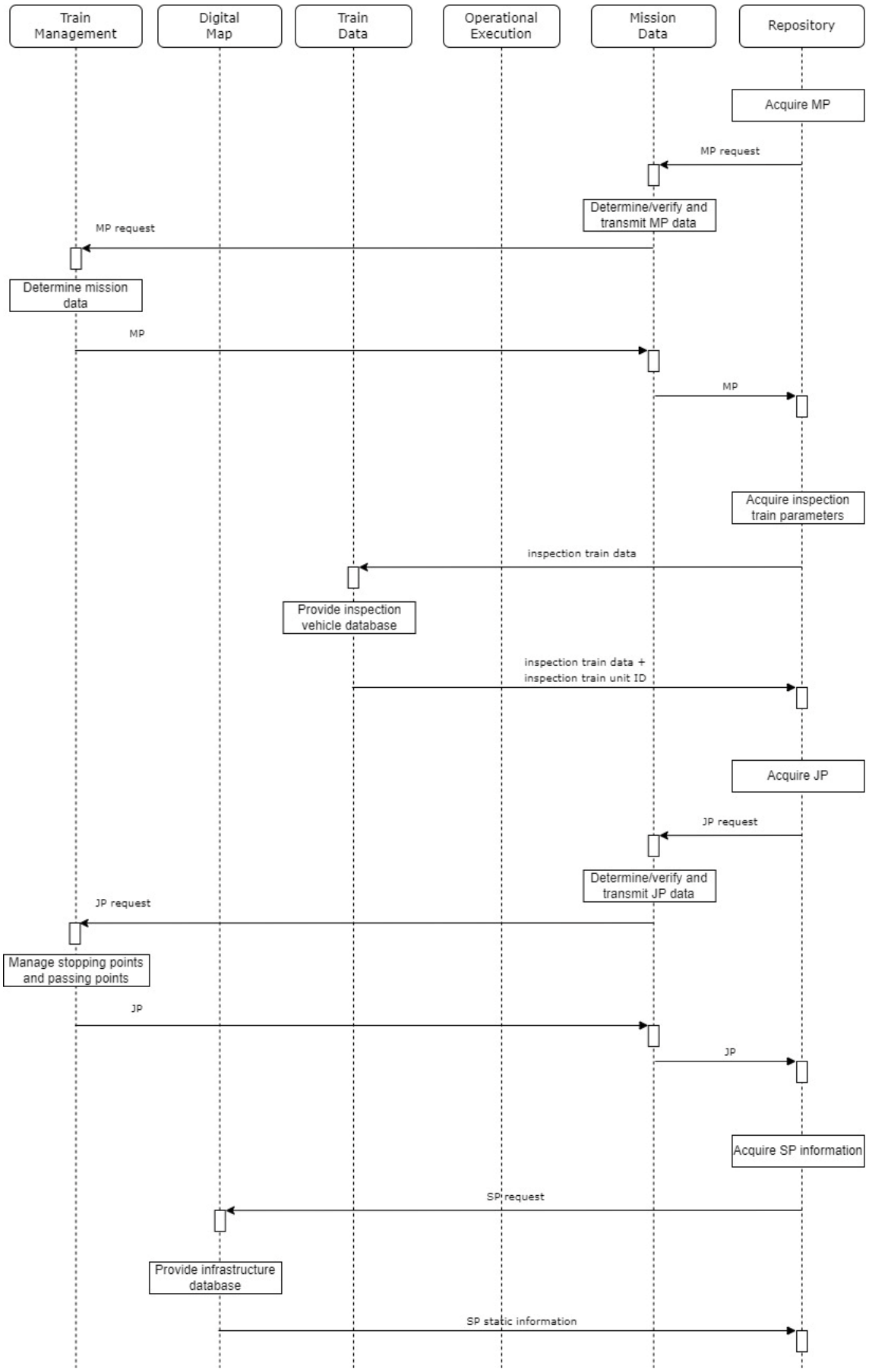

Figure 3: Sequence diagram illustrating the process of requesting Mission, Journey, and Segment Profiles, along with train parameters, for an inspection activity.

Arriving at the starting point of the area to be inspected

This use case outlines the steps when an inspection vehicle reaches the inspection area's starting point specified in the Journey Profile (JP), marking the shift from autonomous navigation to inspection tasks. The mission comprises two phases: autonomous vehicle movement to/from the inspection area (GoA3/4), and inspection execution. Upon reaching the starting point, the train must stop and deploy required onboard inspection systems, including mechanical components and sensor arrays. System checks verify operational readiness before data collection begins. The Journey Profile must contain inspection coordinates and equipment information. Success requires accurate stopping, proper device deployment, and completed system checks before inspection. This use case connects to UC 13.4.7 regarding stopping point determination and aligns with system testing efforts, including sensor verification under TAURO framework.

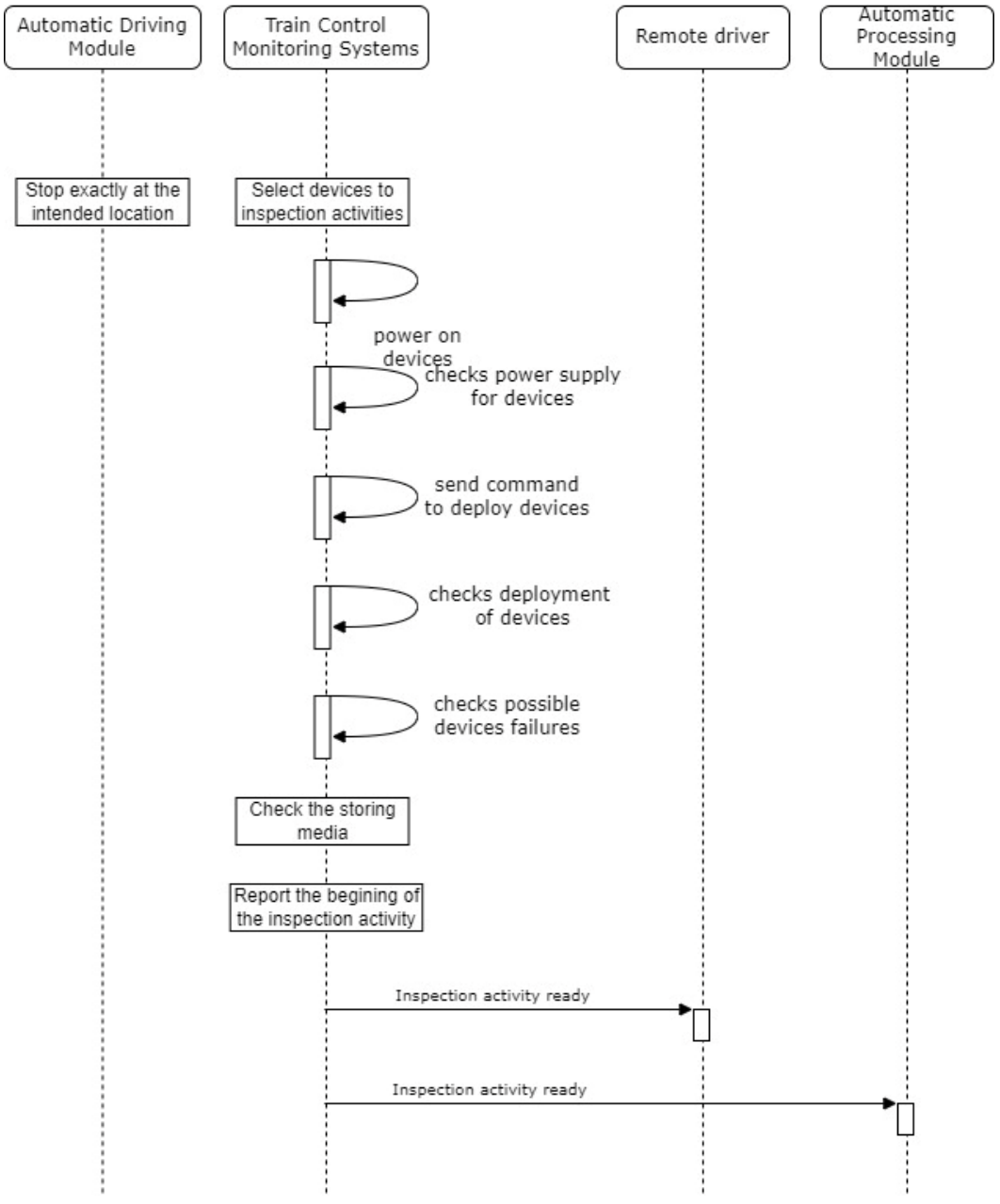

Figure 4: Sequence diagram illustrating the process of arriving at the starting point of the area to be inspected.

Finishing the inspection, retract devices, check data and prepare to return

This use case outlines the actions when an inspection vehicle reaches the end of its designated inspection area after completing assigned activities. It marks the mission's conclusion and transition to normal operations. Inspection missions have two segments: autonomous navigation to/from the inspection area (per GoA3/4), and the inspection specified in the Journey Profile. Upon completing inspection, the train must stop and retract equipment used for infrastructure analysis. Equipment may include supporting frames, robotic arms, or sensors. The retraction process requires verification of proper device stowage and communication integrity, along with confirmation of data collection. The Journey Profile must contain essential information about inspection activity, including stopping points and device deployment details. Success requires completing inspection activities, retracting equipment, validating data integrity, and preparing for return journey. This use case relates to UC 13.4.7 for determining train stopping points and PST1 testing of on-board systems under TAURO. This formalization helps integrate automated special-purpose operations into rail traffic, improving consistency and safety.

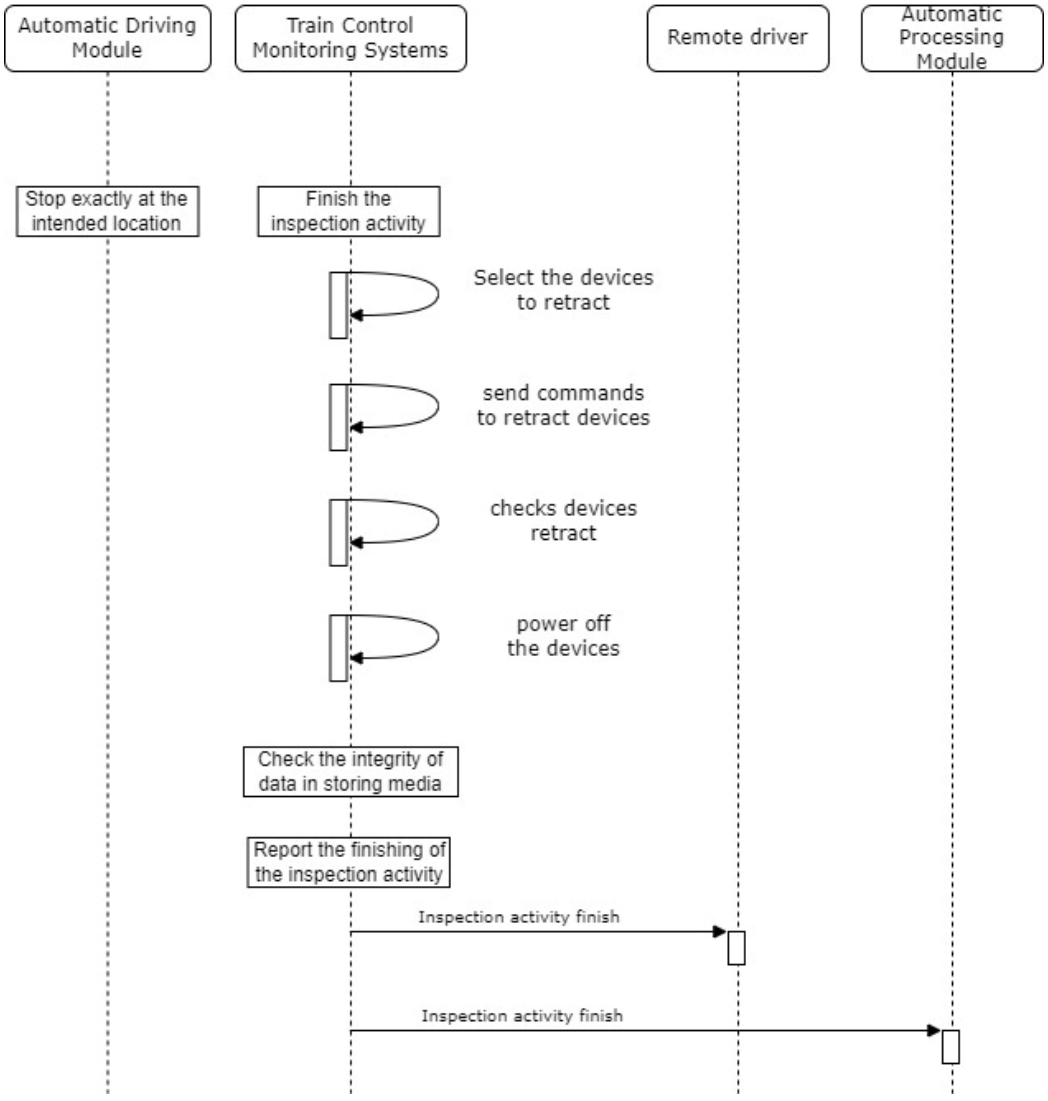

Figure 5: Sequence diagram illustrating the process of finishing the inspection, retract devices, check data and prepare to return.

Conclusions

This study investigates the integration of inspection activities into routine railway operations through the application of structured planning elements, specifically Mission Profiles (MP) and Journey Profiles (JP). By expanding these existing frameworks to encompass general information pertinent to inspection tasks, it becomes feasible to synchronize the execution of inspection missions with standard traffic, thereby enhancing coordination and operational efficiency. The presented use cases provide a comprehensive overview of the management of inspection vehicles within prospective automated railway environments. They delineate the entire process, from the planning of inspection activities to the preparation of the train at the commencement and conclusion of the inspection area. This structured methodology facilitates a clearer definition of roles, enhances planning transparency, and promotes integration with existing railway processes.

References

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