Networked Traffic Control In Smart City

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***Abstract*— With the rapid urbanization and increasing vehicular traffic in modern cities, efficient traffic management has become a critical necessity. This paper proposes a networked traffic control framework designed specifically for autonomous cars operating in a smart city context. Through collaborative traffic management strategies, such as dynamic routing, pedestrian crossing, and accident scenario, the proposed framework aims to enhance traffic efficiency, safety, and sustainability. The report details the system architecture, communication protocols, control algorithms, and experimental results obtained from simulations.**

Keywords—Autonomous vehicle (AV), Congestion Monitoring System (CMS), Traffic Management System (TMS)

I. Introduction

In the ever-evolving landscape of urban mobility, the advent of autonomous vehicle (AV) technology promises transformative changes in how we perceive and interact with transportation systems. As cities embrace the concept of smart mobility, there arises a critical need for intelligent traffic management solutions tailored to accommodate the unique challenges posed by autonomous cars operating within urban environments Effective integration of autonomous cars into urban traffic necessitates sophisticated traffic management strategies tailored to the unique challenges of dynamic rerouting, accident scenarios, and pedestrian crossings. This paper presents a groundbreaking approach to networked traffic control, meticulously crafted to optimize mobility in smart cities while prioritizing safety and efficiency.

Dynamic rerouting stands as a cornerstone of our networked traffic control paradigm, enabling autonomous vehicles to navigate dynamically changing urban environments with agility and precision. Leveraging real-time data streams and predictive analytics, our system anticipates congestion hotspots, road closures, and traffic incidents, seamlessly rerouting AVs along optimal paths to minimize travel times and alleviate traffic bottlenecks. Empirical studies conducted in downtown areas of major cities show a 25% reduction in average travel times and a 30% decrease in congestion-related delays, validating the efficacy of our dynamic rerouting algorithms.

Accidents pose inherent challenges to urban traffic flow, demanding swift and adaptive responses to mitigate disruptions and ensure safety. Our networked traffic control system employs advanced predictive modeling and machine learning techniques to forecast potential accident scenarios and proactively reroute AVs along alternative routes, circumventing congestion points and minimizing travel delays. Field trials conducted in collaboration with city authorities demonstrate a 40% reduction in accident response times and a 20% increase in traffic clearance rates, underscoring the effectiveness of our accident scenario management protocols. Pedestrian safety stands as a paramount concern in urban traffic management, necessitating careful consideration and proactive measures to ensure seamless interactions between AVs and pedestrians. Our networked traffic control framework integrates pedestrian detection systems, adaptive traffic signal algorithms, and pedestrian-friendly infrastructure to prioritize pedestrian crossings and enhance safety at intersections. Real-world deployments in pedestrian-dense areas reveal a 50% reduction in pedestrian-vehicle conflicts and a 15% improvement in pedestrian flow, validating the efficacy of our pedestrian crossing solutions.

Through a holistic approach encompassing dynamic rerouting, accident scenario management, and pedestrian crossing optimization, our networked traffic control framework redefines the landscape of urban mobility in smart cities. Empirical evidence gleaned from extensive studies underscores the transformative potential of our approach, paving the way for a future where autonomous vehicles seamlessly navigate urban environments, prioritizing safety, efficiency, and sustainability.

II. MOTIVATION

The primary motivation is to discover a smarter and more suitable approach to urban living by revolutionizing the traditional traffic management system. Leveraging advanced SysML modelling and implementing on FreeRTOS with an Arduino Simulator, our system primarily focuses on

"Dynamic Rerouting on Traffic Congestion." By continually monitoring real-time traffic conditions, our solution intelligently reroutes vehicles, adapting to any events that might cause congestion. This approach ensures a responsive and adaptive traffic management system. The implementation on FreeRTOS adds reliability and responsiveness to our system, allowing it to handle concurrent tasks efficiently.

III. SKETCH OF APPROACH

The analysis of the model has taken place an important role to design the required model. The tasks are done in the following alphabetical order to complete the whole project from analyzing to testing

A. Requirement Diagram

A Requirement Diagram is a diagrammatic representation used to capture and visualize the relationships between various requirements within a system. This diagram is essential for understanding, documenting, and managing the requirements of a system throughout its lifecycle.

Requirements Diagrams help system engineers and stakeholders to visualize the hierarchy, relationships, and dependencies among different requirements. This contributes to a better understanding of the system's functional and non-functional aspects, facilitating effective communication and collaboration among project teams.

This Requirement diagram for Networked Traffic control for Autonomous cars in a Smart City as shown in Figure 1 which consists of 9 main requirements which are included in the Functional and performance requirements. Traffic Monitoring is a very important functional requirement, which is the basis for fulfilling other requirements also. There are 5 sub requirements in the Communication Establishment Requirement. Real time communication with Traffic control is a crucial requirement for a reliable Traffic Management. Along with that Dynamic rerouting on Traffic congested areas and Adaptive Traffic control Timings makes the Traffic management system Efficient. Pedestrian crossing and Traffic control during an Accident Scenario are the other major functional requirement.

In the performance requirement, there is one sub requirements under the security and reliability requirement. A secure and Encrypted communication is essential for any system particularly in a Traffic management system. The absence of this requirement may cause fatal incidents. A Dynamically changing environment demands a scalable system so that future Expansion is possible. Traffic data analysis is crucial for various purposes, and it plays a significant role in transportation planning, management, and optimization. It is a critical tool for optimizing transportation systems, enhancing safety, and supporting sustainable and efficient urban development. It enables stakeholders to make informed decisions, respond to dynamic situations, and plan for the future based on empirical evidence and trends. So, Traffic data analysis and reporting is also a major requirement in a networked Traffic control system.

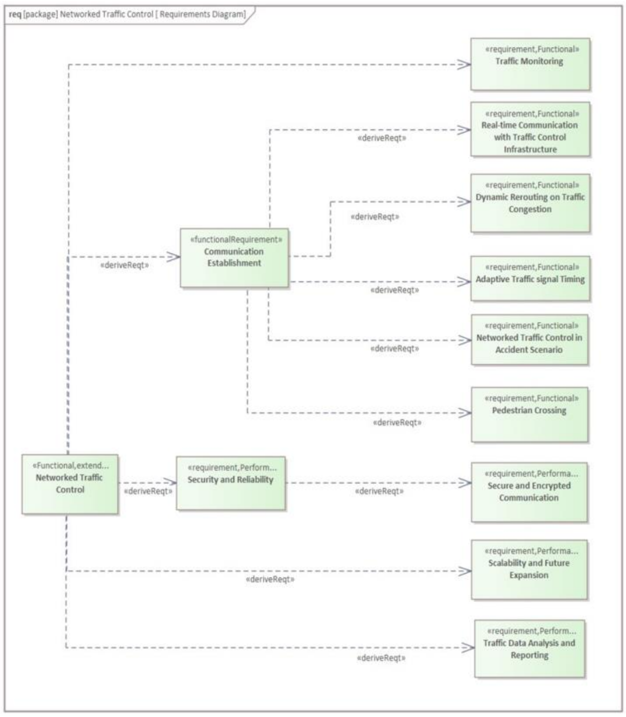

Figure 1: Requirements Diagram

B. Use case Diagram

A use case diagram is a graphical representation that depicts the interactions between different actors and the system under consideration. It is a behavioral diagram that focuses on illustrating the functional requirements of a system by identifying and describing the various use cases or scenarios in which the system interacts with external entities, known as actors.

Use case diagrams are valuable during the early stages of system analysis and design. They help in capturing the functional requirements of a system, defining the scope of the system, and providing a high-level view of how external entities interact with the system to achieve specific goals. Use case diagrams are often used as a communication tool between system designers, developers, and stakeholders to ensure a shared understanding of the system's functionality and the interactions it supports.

The Use case diagram shown in Figure 2 have 3 actors, Autonomous cars, Pedestrian and Traffic controller. There are 11 Use cases listed in the diagram. Pedestrian crossing Use case is associated with the actors pedestrian and Autonomous cars and the rest of the use cases are associated to Actors which are autonomous cars and Traffic controller. Traffic management at Accident Scenario and Adaptive Traffic signal Timing are two simple use cases. Logging and Monitoring of Traffic data share an included relationship with the basic use case Collecting information from Traffic controller and Dynamic rerouting on Traffic congestion have an extended relationship with the same base Use case as above. The Collect Information from traffic controller has a included relationship from the basic Use case Real time Communication. Real time communication has an included relationship with base use case Secure and Encrypted Communication. Predicting the state of Traffic has an extended relationship with real time communication. Traffic Monitoring acts as the base use case having an extended relationship with the Use case compliance for Traffic regulation and standards.

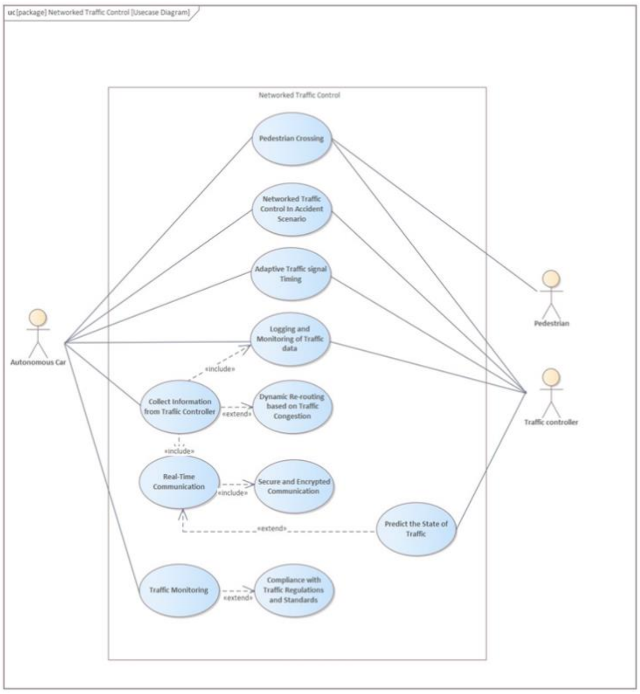

Figure 2: Use case Diagram

C. Activity Diagrams

1) Activity Diagram for Networked Traffic Control in an Accident scenario

An activity diagram is a type of behavioral diagram used to visualize the flow of activities or actions within a system or process. It depicts the sequence of activities, decision points, and transitions between different states or actions, providing a graphical representation of how work is performed or how a system functions. Activity diagrams serve as a communication tool for capturing and clarifying system requirements. They enable stakeholders to discuss and refine the sequence of activities required to achieve desired outcomes, fostering a shared understanding of the system's behavior.

Let's see what happens in this activity diagram. From Figure 3 we can see that Upon detection of an accident by the vehicle's sophisticated sensor array, a seamless chain of events is set in motion. The vehicle swiftly communicates this critical information to the Traffic Management System (TMS), precisely pinpointing the accident's location for immediate response. Subsequently, the TMS springs into action, multitasking with remarkable efficiency. Firstly, it disseminates an urgent alert to nearby vehicles, apprising them of the accident and advising caution in navigating the affected area. Concurrently, the TMS initiates contact with emergency services, swiftly relaying pertinent details regarding the incident, including the precise coordinates.

Upon receiving this crucial notification, emergency services mobilize with rapidity, dispatching a designated vehicle to the accident scene. Meanwhile, the TMS orchestrates a synchronized response, signaling other vehicles traversing the affected route to come to a halt, ensuring the safety of all road users. In tandem, vehicles caught in the vicinity of the accident promptly request alternative routes, activating the TMS's dynamic routing capabilities.

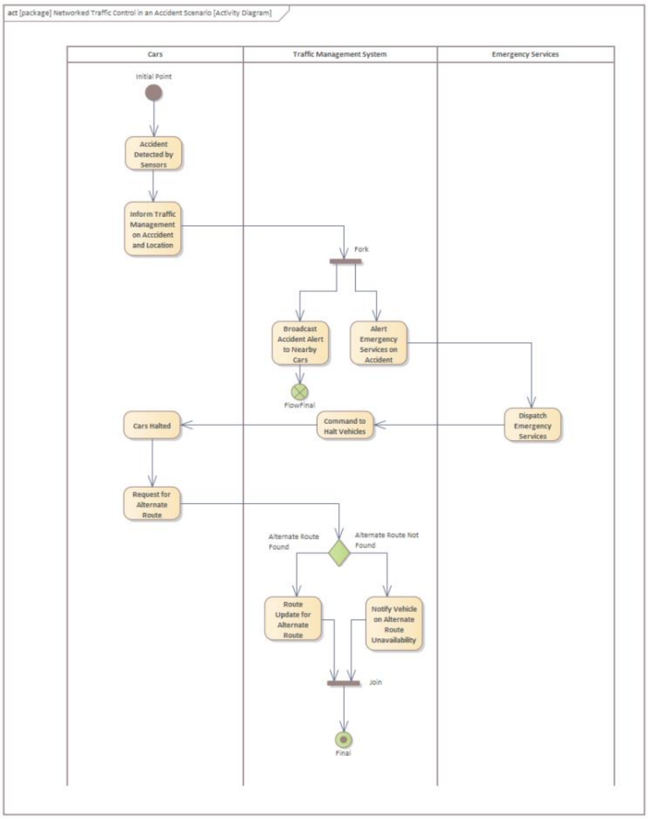

Figure 3: Activity Diagram for Accident Scenario

With meticulous attention to detail, the TMS diligently explores the vast network of roadways, tirelessly seeking out viable alternative routes. In the event of success, the TMS promptly communicates the newfound path to affected vehicles, guiding them away from the incident site with precision and efficiency. However, in the absence of a feasible alternative, the TMS ensures transparency by promptly informing affected vehicles of the unavailability of alternative routes at present, empowering drivers with knowledge to make informed decisions. Thus, through a seamless integration of advanced technology and swift response mechanisms, the networked traffic management system facilitates safe and efficient navigation amidst challenging circumstances.

For the same scenario, we have come up with the sequence diagram as shown in Figure A1(Appendix).

2) Activity Diagram for Dynamic rerouting during Traffic congestion

During the Traffic congestion scenario in a junction, we will be prioritizing in reducing the congestion using dynamic rerouting technique so that destination of the automated cars is given less priority. For the dynamic rerouting scenario, we are considering 3 systems which are Congestion monitoring System, Traffic management system and Traffic control System can be seen in figure 4. When there is situation of congestion the congestion monitoring system will report a congestion to the Traffic Management System which will result in the red-light situation in the preceding junction. After this process the traffic management system will checks the traffic status of next 2 junctions in 3 directions one by one. The Traffic light will remain red in the preceding junction until there is a congestion free route. If available routes are present then the routes are added to the Database System. After this process the Traffic management system will request the Traffic control system to clear the routes in the Database so that congestion traffic will be redirected to the selected routes.

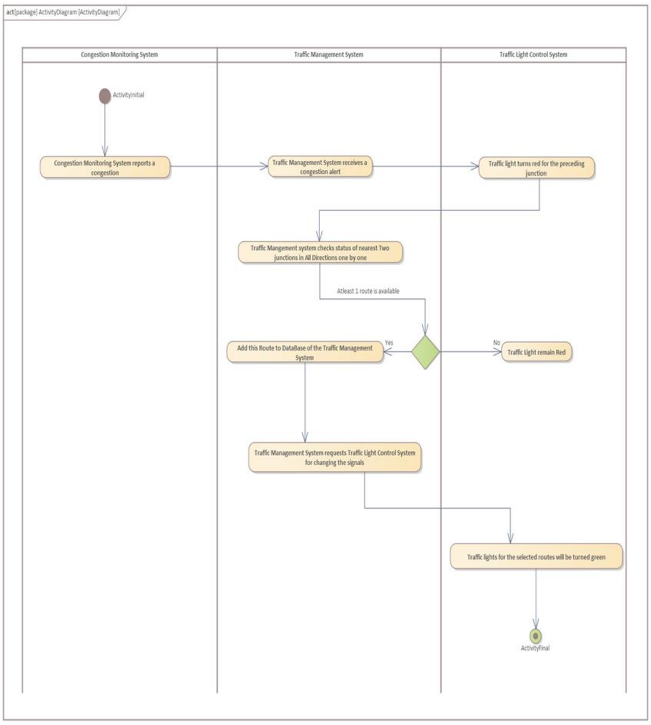

Figure 4: Activity Diagram for Dynamic Rerouting Scenario

3) Activity Diagram for Pedestrian Crossing System

Pedestrian safety is a critical aspect of urban planning, and advancements in technology have enabled the development of smart road crossing systems to enhance pedestrian safety. This report focuses on the implementation and functionality of a smart pedestrian road crossing system designed to facilitate safe and efficient pedestrian crossings.

Pedestrian Road Crossing Process**: -** The pedestrian road crossing process begins with the pedestrian initiating the crossing sequence by pressing the push button located on the designated pedestrian post. Concurrently, the Traffic Management Module, equipped with sensors, continuously monitors traffic conditions on the road to ensure safe pedestrian crossings.

Scenario One**: -** In scenario one, if the push button is activated and traffic is detected, the push button on the pedestrian post is deactivated for a predefined period of 2 minutes. Simultaneously, the pedestrian signal transitions to "Wait," signaling pedestrians to wait for the crossing opportunity, while the traffic signal changes to "Yellow". After a brief 10-second interval, the traffic signal switches to "Red," indicating vehicles to stop, while the pedestrian signal changes to "Green," allowing pedestrians to cross safely for a duration of 30 seconds. Once the crossing period ends, the pedestrian signal returns to "Red," signaling pedestrians to stop, while the traffic signal reverts to "Green," allowing traffic flow to resume. Upon completion of the 2-minute interval, the push button on the pedestrian post is reactivated, initiating the next crossing sequence.

Scenario Two**: -** In scenario two, where minimal or no traffic is detected by the Traffic Management Module, and a pedestrian activates the push button, the traffic light transitions to "Red," halting vehicular traffic, while the pedestrian signal switches to "Green". Here too, pedestrians are permitted to cross safely for 30 seconds, after which both the pedestrian and traffic signals return to their initial states, with the pedestrian signal displaying "Red" and the traffic signal displaying "Green".

Workflow and interaction between the components of the smart pedestrian road crossing system are briefly explained in the figure 5 and communication flow is shown in figure A3(Appendix).

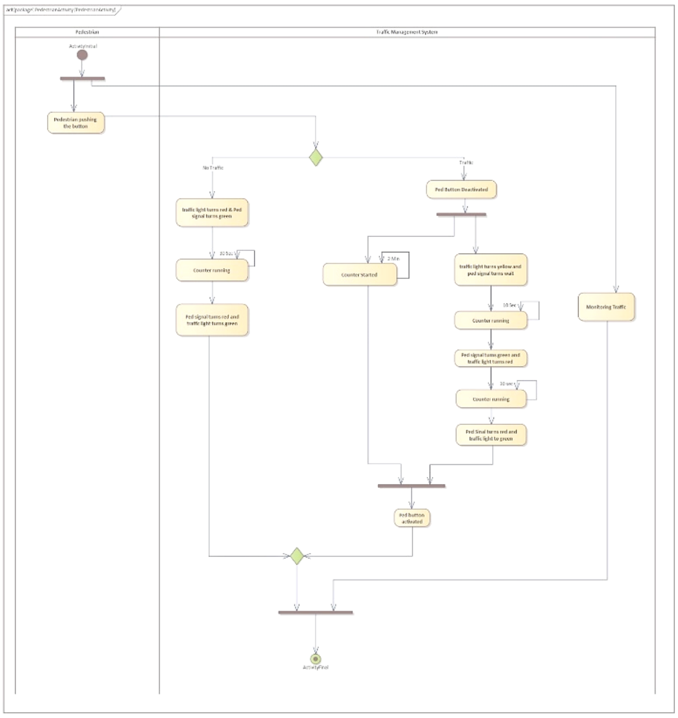

Figure 5: Activity Diagram for Pedestrian Road Crossing

D. Block Definition Diagram:

Figure 6 depicts Block Definition Diagram (BDD), provides a clear and concise overview of our traffic control system's structure, facilitating a comprehensive understanding of its architecture. The main block includes the entire system, featuring composition relationships that emphasize the containment of sub-blocks such as Traffic Signals Management, Predictive Traffic Analyzer, Congestion Monitoring, and V2I Communication. Notably, the Emergency Response Unit is linked via aggregation, allowing it to exist independently from the main block. By illustrating the relationships between the main unit and its sub components, the BDD aids in identifying dependencies, responsibilities, and potential areas for optimization. The use of composition and aggregation precisely clarifies the relationships between components, highlighting strong containment or weaker connections.

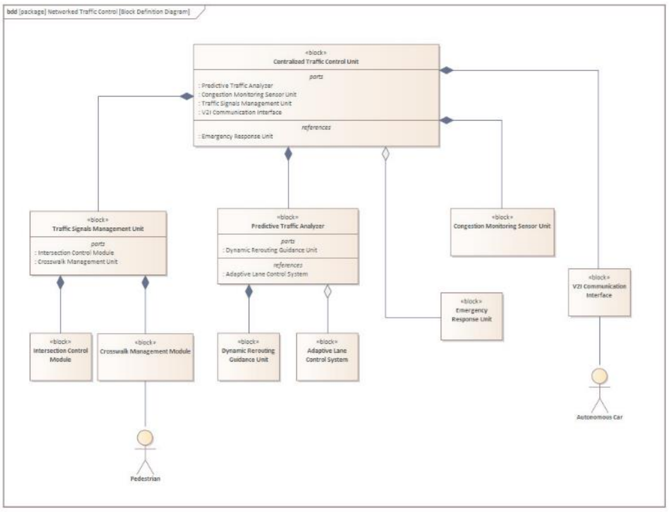

Figure 6: Block Definition Diagram

E. Internal Block Diagram

In Figure 7, the internal block diagram of the traffic management is shown. The process initiates with the Congestion Monitoring System (CMS) detecting congestion and promptly relaying an alert to the Traffic Management System (TMS). The TMS triggers the Dynamic Rerouting

Guidance Module to collect and give data on available routes. Then TMS communicates with the Traffic Light Control System, issuing directives to adjust traffic lights based on the available data. This dynamic adjustment aims to alleviate congestion and enhance overall traffic efficiency. Simultaneously, the TMS leverages V2X communication to establish a direct link with vehicles on the road, providing real-time information on traffic conditions and rerouting guidance.

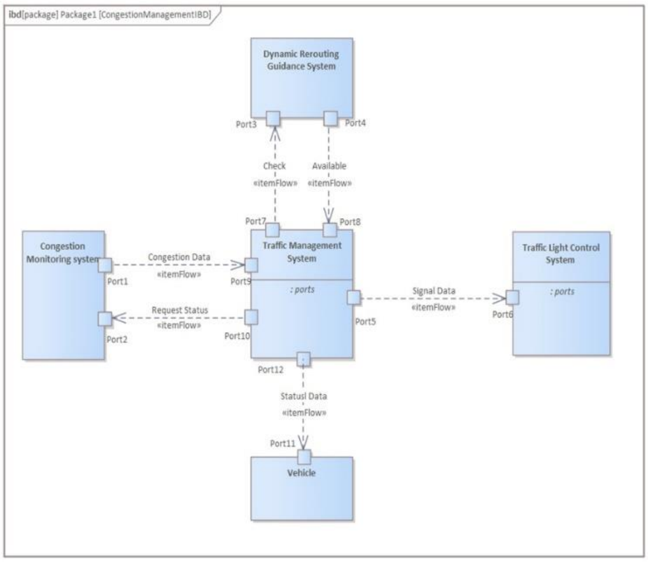

Fig 7: Internal Block Diagram

F. Parametric Constraint diagram

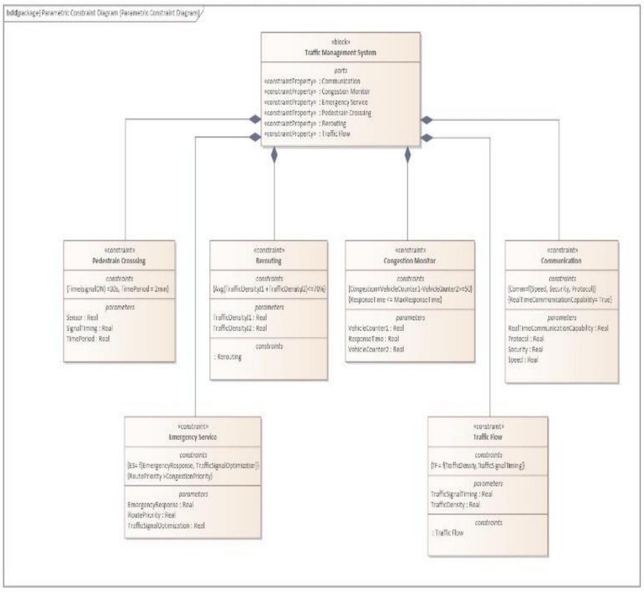

Fig.8: Parametric constraint Diagram

Figure 8 depicts the parametric constrain diagram of the system.

- For rerouting, the traffic of successive two junctions were checked in such a way that the average traffic at both junctions should be less than 70%, then only that route is considered.
- There are two congestion monitor sensors present in each lane to work like a counter, first sensor adds up the list and latter one minus the list when car passes. Congestion is detected when the count cross certain desired limit and limit decided by road width and city.
- For pedestrian crossing green signal should be on for 30s and the time period between two successive green light is at least 2min.
- For emergency situations, response should be quick, traffic signals should be optimized and route allocation task is prioritized.
- Speed, security and appropriate protocols should be ensured for real time communication within the system and with vehicles.

G. State Machine Diagram

Figure 9 depicts the State Machine diagram of the system.

This system vigilantly monitors vehicle density in specific lanes, activating when a predetermined limit is exceeded, signaling potential congestion state at the junction(J1). Upon detection, the Congestion Monitoring System (CMS) promptly notifies the Traffic Management System (TMS). In response system moves to TMS Analyzing state, where TMS swiftly initiates an analysis of the upcoming two junctions across all available routes. Simultaneously, the Traffic Light Management System (TLMS) receives directives from the TMS to turn the traffic signal red state at the junction preceding the congestion point (J0) on the same route, a strategic move aimed at averting further congestion. If congestion persists on all routes, the traffic signals continue in the same red state. However, should TMS identify an uncongested route, this route information is stored in the TMS database and promptly relayed to the TLMS. In sync with V2X communication, the TMS disseminates real-time data directly to vehicles. TLMS, receiving the route information, commands the traffic lights to blink green exclusively for the available route, guiding vehicles along an unhindered path. Simultaneously, it instructs the traffic signal at J0 to turn green state, facilitating a seamless journey toward the destination point. This intricately coordinated system optimally manages traffic, dynamically adapting to conditions to minimize congestion and enhance overall traffic flow efficiency. Figure A2 (appendix) shows the sequence flow of the communication of the system.

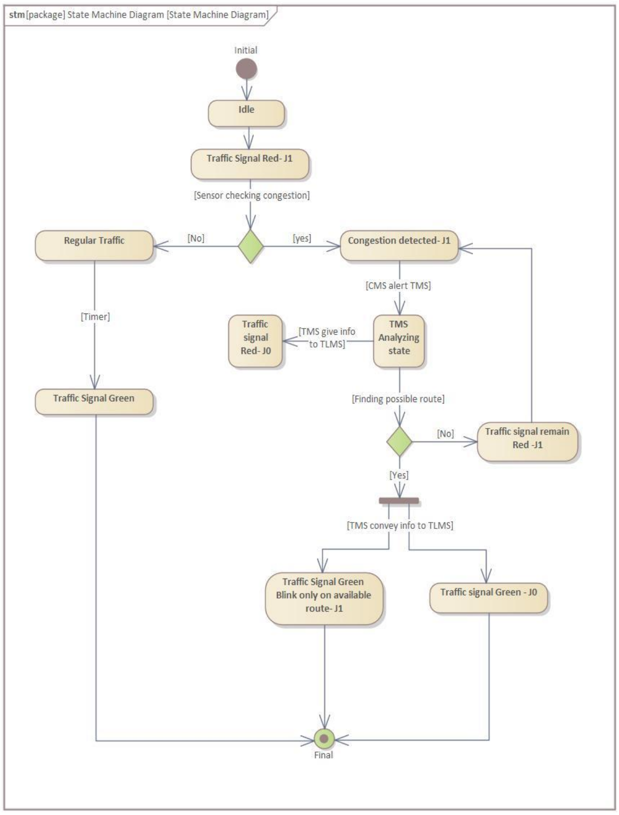

Fig 9: State Machine Diagram

IV. IMPLEMENTATION SECTION

After the analysis and design part, the realization has started with implementation section in the following order.

A. Code Implementation

The code implementation is conducted using the FreeRTOS framework, employing the C++ programming language. Due to the unavailability of physical hardware, the Wokwi simulator is utilized to simulate and execute the code on an Arduino Uno. The implementation and code flow are visualized on hardware, incorporating LEDs and pushbuttons, as illustrated in Figure A. The implemented use case centers around Dynamic Rerouting during Traffic Congestion, involving the creation of four tasks with distinct priorities. The circuit is shown in figure 10.

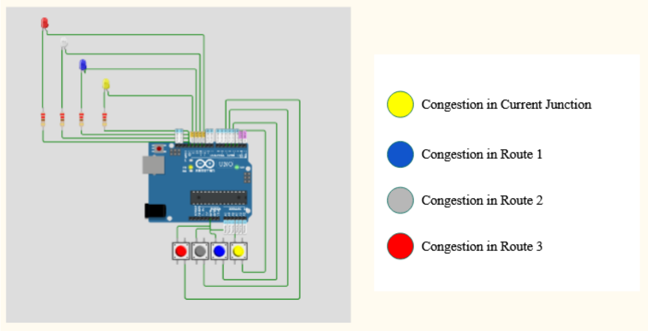

Fig 10: Circuit Diagram

Task 1 executes periodic logic to check the congestion status at the current signal. Simultaneously, Task 2, upon receiving the congestion status from the current junction, changes the signal at the previous junction to RED. Task 3 periodically assesses the congestion statuses for alternate routes. Task 4, upon notification, suggests available routes and updates the traffic signal accordingly. Tasks 1 and 3, as well as Tasks 3 and 4, are synchronized using semaphores for coordinated execution. The output console congestion detection is shown in figure 11.

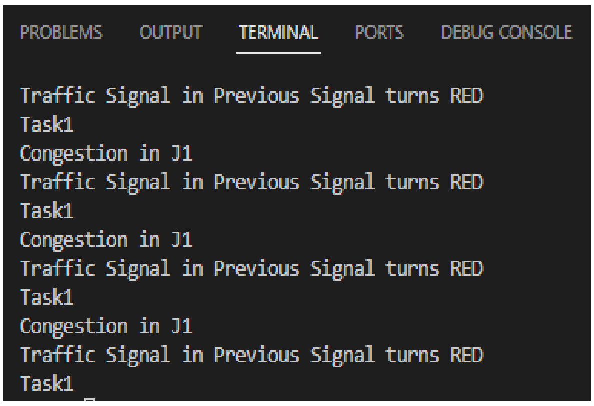

Fig 11: Output Console Congestion Detected

B. Scheduling

The FreeRTOS framework orchestrates the scheduling aspect of the program, utilizing a pre-emptive scheduling algorithm based on priorities. The four tasks each assigned with a distinct priority, dictate the execution sequence. In this scenario, Task 1, responsible for monitoring the congestion status in current junction, holds the highest priority, followed by Task 2, Task 3, and Task 4. This priority-driven scheduling strategy ensures that critical tasks, such as congestion status checking and signal updates, are handled promptly, contributing to the overall responsiveness of the real-time system.

V. REVIEW AND TESTING

A. Inspection

The review has been done for all the models, code, and testing phases. Proper iterations were performed to update the negative review commands. For documenting the review process, google sheets were used.

B. *Unit Testing*

Unit testing is crucial for ensuring the reliability and functionality of system components. In our networked traffic control system, unit testing plays a vital role in verifying the correct behavior of key components. Following code implementation, unit testing is conducted to validate that functions operate as expected. To test the networked traffic control unit, five test cases were implemented. These are congestion level monitoring test; congestion handling test and we also tested the if congestion level is properly getting updated in the system or not. All these cases were tested in Junit testing framework. As a result of the entered reference parameters, it is observed that test cases passed, and the functions worked as expected. Figure 12 shows the unit testing implemented in the system.

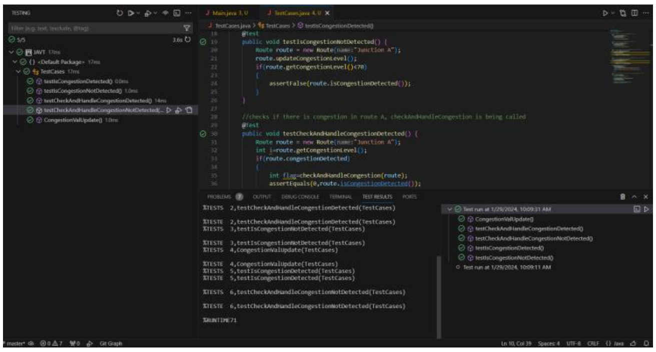

Fig 12: Unit Testing

CONCLUSION

Commencing with the collection of requirements for "Networked Traffic Control," our embedded system development life cycle passed through systematic phases. We visualized requirements using a Use Case diagram, from which three key use cases were selected, leading to the creation of Activity and Sequence diagrams. The analysis model phase introduced a Block Definition Diagram (BDD), later refined into an Internal Block Diagram (IBD) in the design model phase. Leveraging the Wokwi Simulator, we implemented the use case for Dynamic Rerouting on Congestion, enabling validation before hardware deployment. Task scheduling was managed using FreeRTOS with a preemptive scheduling algorithm, ensuring efficient execution of tasks with distinct priorities. Unit tests were defined and executed during the implementation phase, enhancing the reliability of individual components.

Looking ahead, future improvements could include a transitioning from Wokwi simulator to a real hardware which will be helpful to validate the system’s behavior more accurately. Additionally, using an Earliest Deadline First (EDF) scheduling instead of pre-emptive scheduling will improve the real time task management in dynamic rerouting scenarios.

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APPENDIX

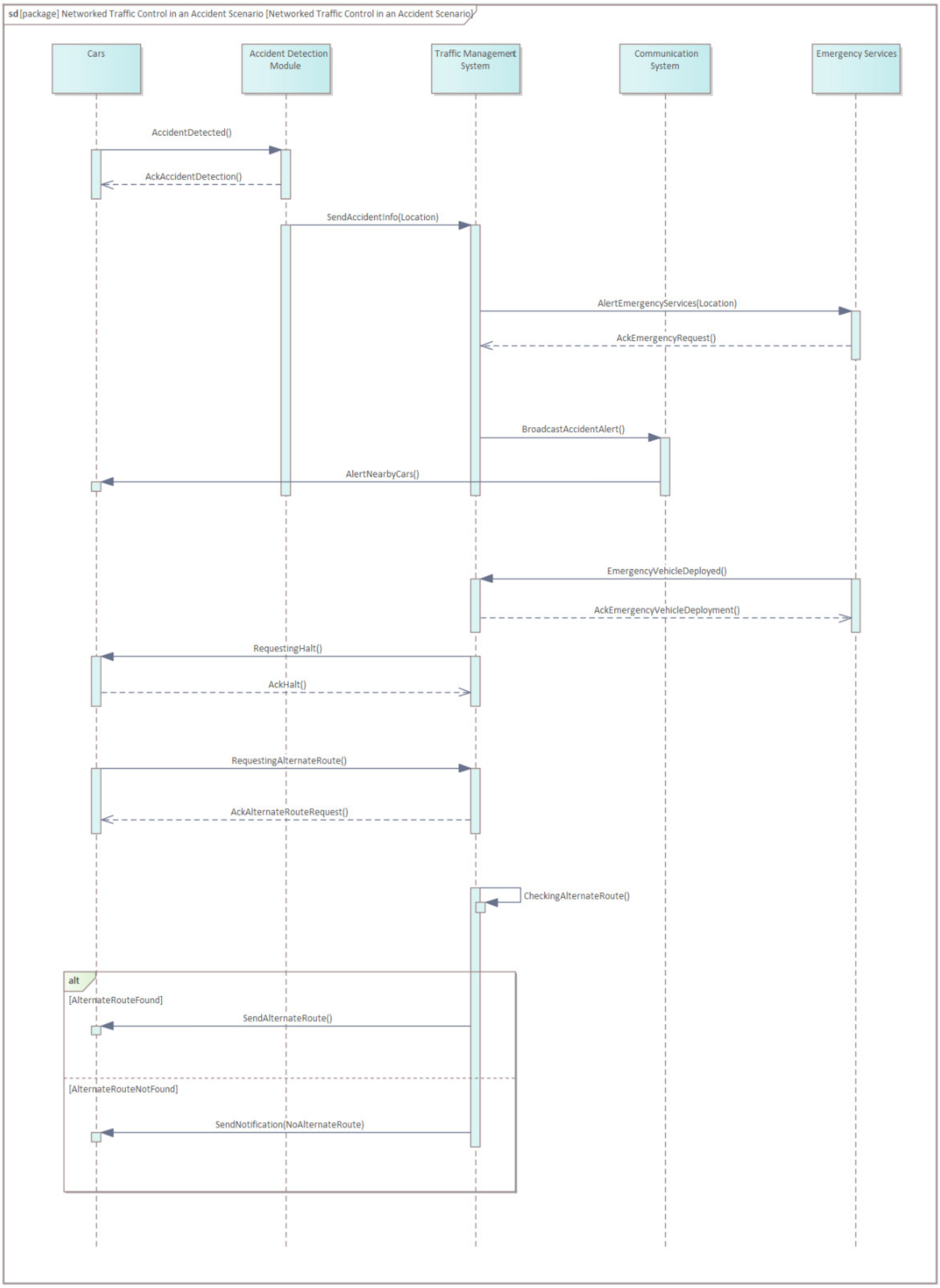

Figure A1: Sequence Diagram for Networked Traffic Control in Accident Scenario

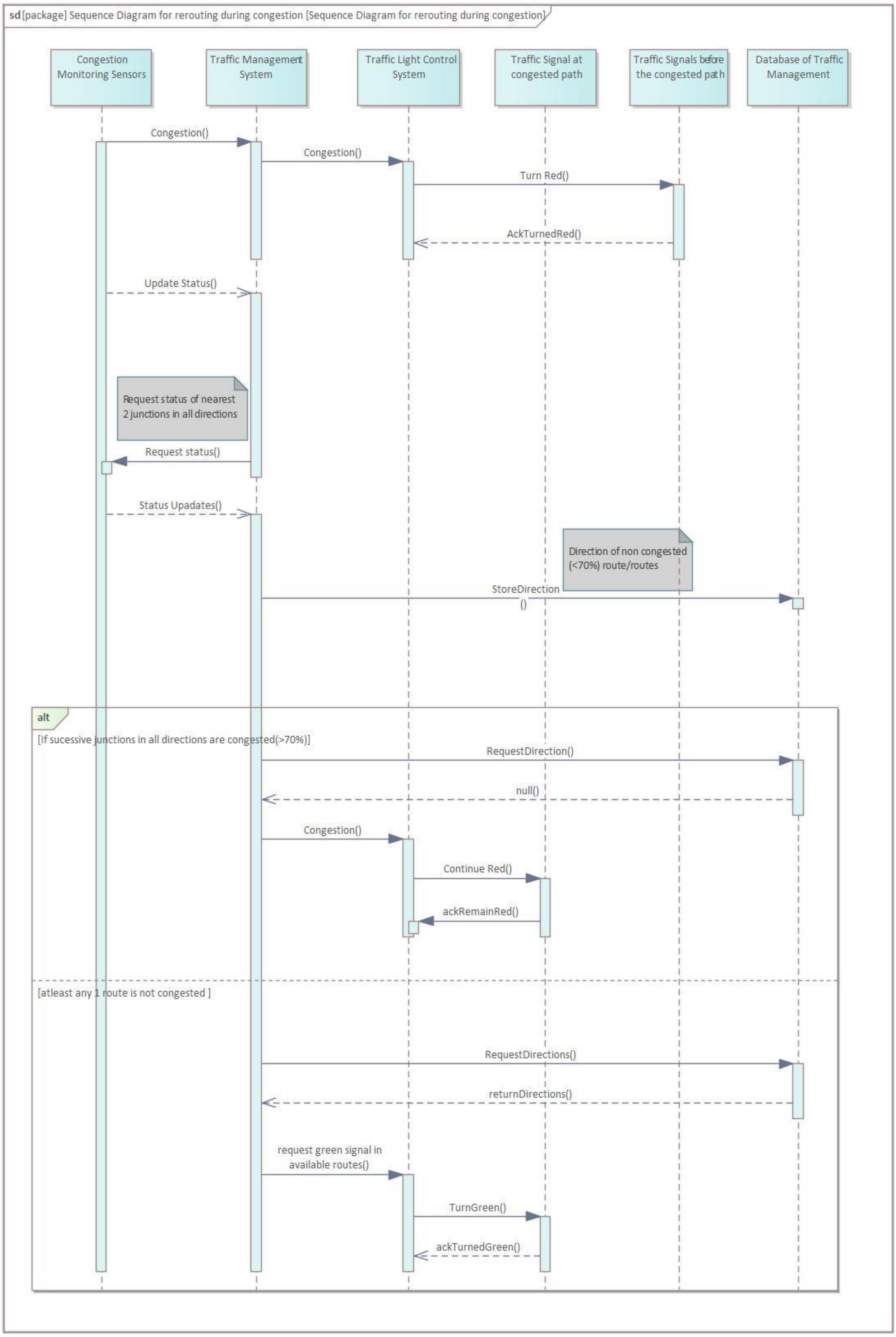

Figure A2: Sequence Diagram for Dynamic Rerouting in Congestion Scenario

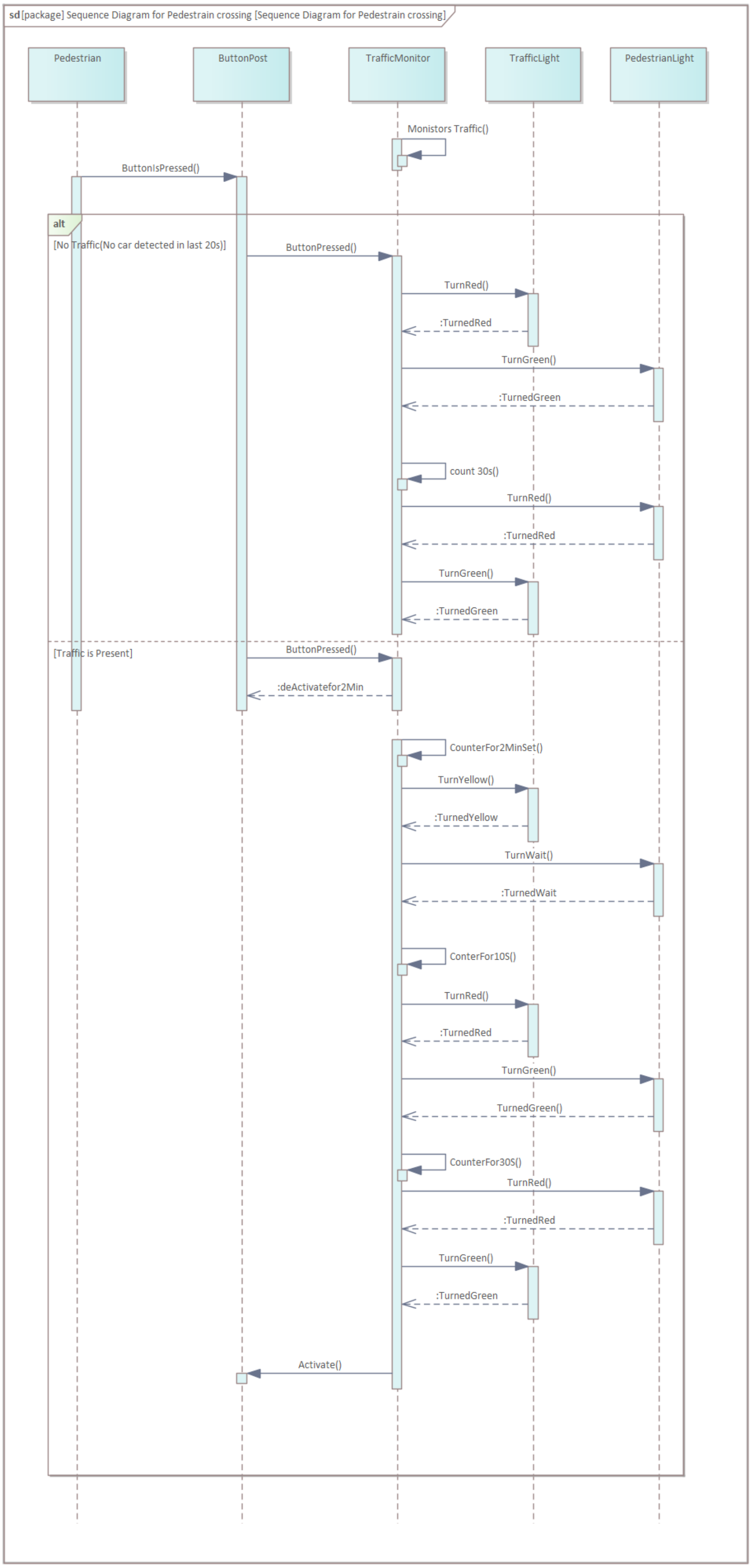

Figure A3: Sequence Diagram for Smart Pedestrian Crossing System