Automation Of Public Lighting System Using Model-Based Systems Engineering Approach

Mahalingam. P P[1], *Assistant Professor, Department of Mechanical Engineering,*

Mugesh. S[2], *UG Student, Department of Mechatronics Engineering,*

Siva Santhosh. R. M[3], *UG Student, Department of Mechatronics Engineering,*

[1,2,3] *Dr. Mahalingam College of Engineering and Technology.*

ABSTRACT:

This project presents a Definition & Decomposition phase of System Modeling model and its simulation with the use of Model-Based Systems Engineering approach to support the design and development of a public lighting system for automation. The use of Model-Based Systems Engineering enabled the creation of a comprehensive model of the system, which facilitated the identification of requirements, design decisions, and trade-offs. The model also provided a platform for communication and collaboration among the various stakeholders involved in the project. The paper highlights the benefits of using Model-Based Systems Engineering for the development of complex systems, and how it can contribute to the success of automation projects. The results of the simulation of the systems Model demonstrate the effectiveness of Model-Based Systems Engineering in supporting the design and development of public lighting systems and suggest that it can be applied to other automation projects.

Keywords: MBSE, SysML, Automation

1. INTRODUCTION

Streetlights play a crucial role in ensuring safety and security for road users by illuminating the environment during dark conditions. However, the conventional method of controlling street lighting, which relies on manual operation of each lamp, presents several challenges. This manual approach not only leads to inefficient use of electricity but also results in high maintenance costs due to the need for frequent checks and repairs. Moreover, it fails to adapt to environmental conditions, leading to unnecessary energy consumption and decreased system usability. The shortcomings of the current manual control system have prompted the exploration of automated solutions to improve energy efficiency and optimize resource utilization in public street lighting. Automation offers the promise of automatically switching lights on or off based on predetermined criteria, thereby reducing energy consumption and enhancing system efficiency. In response to these challenges, this project proposes the development of an integrated system for the automation of public street lighting using a Model-Based Systems Engineering (MBSE) approach. By leveraging Model-Based Systems Engineering principles, we aim to design a comprehensive solution that addresses all aspects of street lighting control, from energy efficiency and environmental adaptability to maintenance and system optimization.

1.1 MODEL-BASED SYSTEMS ENGINEERING

Model-Based Systems Engineering is a method of systems engineering that places a strong emphasis on using models for all phases of complex system design, analysis, and management. It is an interdisciplinary field of engineering and engineering management process, that manages the entire lifecycle of complex products. Using graphical models and notations, MBSE offers a disciplined process for creating and documenting system

requirements, architecture, Behaviour, and integration. Generally systems engineering is a V-shaped method or process which is in the below block diagram.

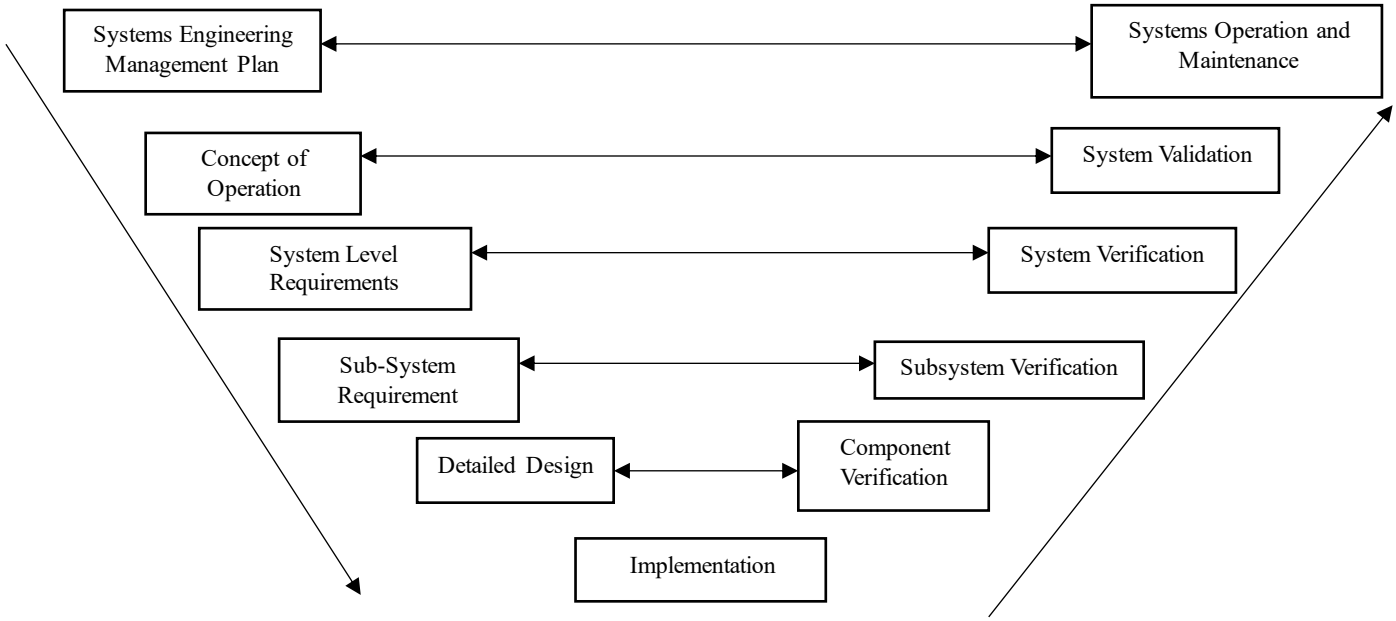

Figure 1: V Model Approach

A system's components, linkages, Behaviour, and interactions are all captured by system models in MBSE. Through the use of these models, stakeholders are better able to comprehend, share, and validate system designs and needs. Modelling languages like Unified Modeling Language (UML), Systems Modeling Language (SysML), or particular domain-specific languages can be used to generate the models.

1.2 Three Pillars of MBSE:

- Modeling Language (SysML)
- Modeling Method (Abstraction Level)
- Modeling Tool (Gaphor)

1.3 Role of System Modeling Language in MBSE:

Systems modelling language, or System Modeling Language, is a graphical modelling language used for model-based systems engineering (MBSE) applications. With the use of diagram like requirements diagram, use case diagram, block definition diagram, internal block diagram, activity diagram, sequence diagram, state machine diagram, and parametric diagram among others, System Modeling Language diagram, shown in figure 2, offers a standardized method for expressing complicated systems. In Model-Based Systems Engineering, System Modeling Language is essential for creating a system model that encapsulates the needs, Behaviour, structure, and interfaces of the system. System Modeling Language Diagram. Throughout the system's lifecycle, the System Modeling Language model serves as a blueprint for design, analysis, and verification. Particularly, System Modeling Language enhances Model-Based Systems Engineering in the ways listed below:

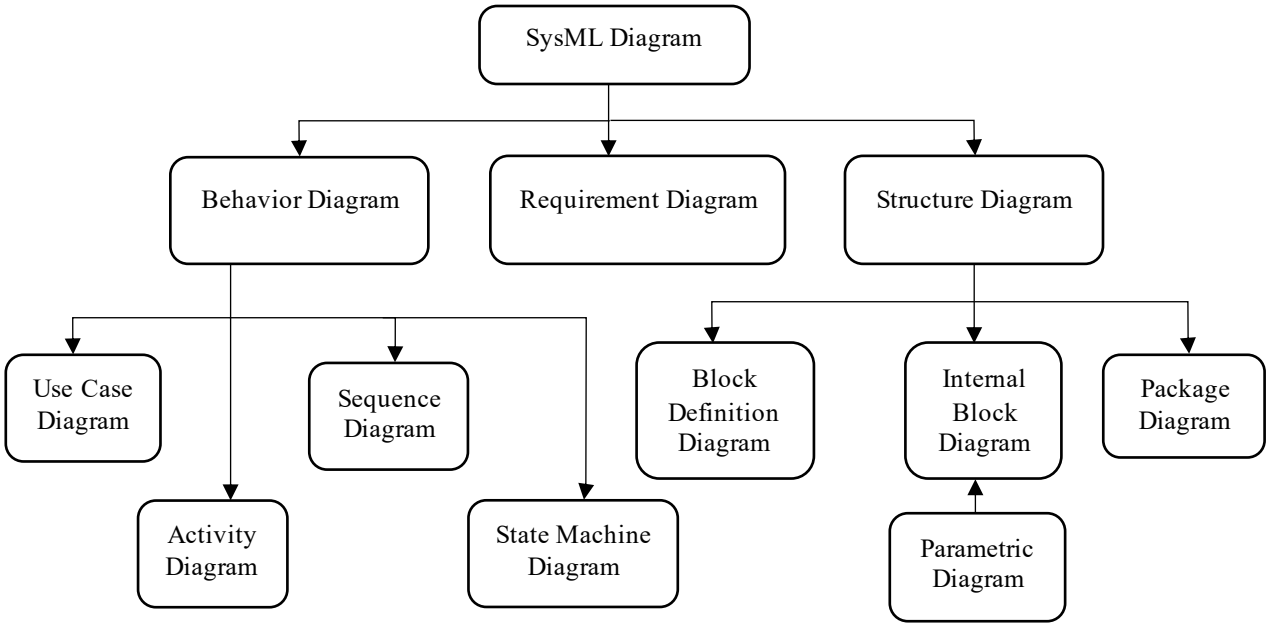

Figure 2: System Modeling Diagram Types

- Standardization: SysML offers a standardized method of expressing systems, fostering uniformity, clarity, and stakeholder communication.
- Modelling adaptability: SysML facilitates the modelling of a system's hardware and software components, allowing for a more thorough system model.
- Management of needs: SysML provides modelling of system requirements, making it easier to connect requirements to design aspects.
- Verification of the design: SysML models can be used to simulate and test the behaviour of the system, assisting in the early detection of design defects.
- Communication and collaboration are made easier by the ability for team members and stakeholders to share SysML models.

In conclusion, SysML is a crucial tool in MBSE because it offers a standardised method for representing complex systems and makes it easier for stakeholders to collaborate and manage needs. The four SysML pillars, which are shown in figure 3, are the fundamental ideas on which the language is built. They are as follows:

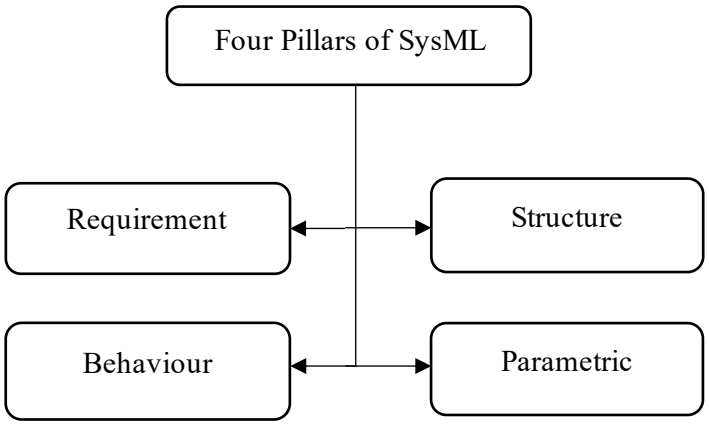

Figure 3: Pillars of SysML

- Structure: Blocks, pieces, ports, and connectors are just a few of the structural ideas offered by SysML to define a system's constituent parts and subsystems.
- Behaviour: Using a range of diagram, including activity diagram, state machine diagram, and sequence diagram, SysML facilitates the modelling of system behaviour.
- Requirements: SysML offers tools for managing and capturing system requirements, including attribution and tracability.
- Parametrics: SysML provides the modelling of system constraints, equations, and other quantitative relationships through the use of parametric diagram, allowing for the analysis and optimisation of system performance.

These four pillars work together to make it possible to build a complete system model that encapsulates a system's structure, behaviour, needs, and parametric relationships. This paradigm helps system stakeholders communicate and work together while acting as a potent tool for system design, analysis, and optimisation.

2. PROBLEM DEFINITION & OBJECTIVE

2.1 Problem Definition

The public lighting system sector faces challenges in maintaining efficient and precise operations due to its reliance on traditional infrastructure and manual processes. To enhance efficiency and accuracy in this domain, there's a growing interest in developing automation solutions using Model-Based Systems Engineering (MBSE) methodologies. However, the complexity of automating public lighting system demands a structured approach for design, development, and implementation. The absence of an effective MBSE approach poses challenges in achieving optimal system efficiency and accuracy. Without a structured and integrated MBSE approach, project teams may encounter difficulties in Requirement Definition, System Design, Verification and Validation, Collaboration and Communication, System Optimization, and Knowledge Transfer and Maintenance.

2.3 Objective of the Project

- To model and implement an Automation of Public Lighting System using MBSE principles.
- To Integrate advanced technologies and smart control strategies to optimize energy efficiency, enhance user experience and contribute to sustainable and intelligent urban environments.

3. METHODOLGY

3.1 Software Requirements

A SysML tool is software for modeling complex systems. It uses the SysML language, which is like a special drawing method for engineers. This tool helps people describe, analyze, and design systems. With SysML, users can specify, plan, and check various types of systems. It's a useful tool for engineers working on complicated projects.

There are several SysML tools available in the market, both commercial and open source. Some popular SysML tools include CATIA MAGIC Enterprise Architect, MagicDraw, Papyrus, Cameo Systems Modeler, Rhapsody, and Modelio, Gaphor.

3.1.2 GAPHOR

Gaphor is a modeling app made in Python for UML and SysML. It's made to be simple yet strong. It follows the UML 2 data model completely, going beyond just drawing pictures. Gaphor lets us visualize various parts of a system fast and make detailed, intricate models easily.

Gaphor Architect supports the four pillars of SysML, enabling the modeling of system

Figure 4 Gaphor Open-Source Software

structure, Behaviour, requirements, and parametric relationships. The tool offers a wide range of graphical modeling capabilities, including block diagram, internal block diagram, activity diagram, sequence diagram, state machine diagram, and parametric diagram. Gaphor Architect's salient characteristics are:

- Hierarchical modeling: Using Gaphor Architect, complex systems can be modelled hierarchically, including the division of system components into smaller parts and the assignment of requirements and restrictions to different system elements.
- Management of system requirements: Gaphor Architect supports managing system requirements, including managing requirement modifications and tracing requirements to system components.
- Collaboration: Collaboration is supported by Gaphor Architect, which enables system stakeholders to share system models and data as well as track changes and comments.

Overall, Gaphor Architect is an effective tool for MBSE utilizing SysML that enables the development of detailed system models that accurately depict the structure, behaviour, specifications, and parametric linkages of complex systems of systems.

3.2 Methodology

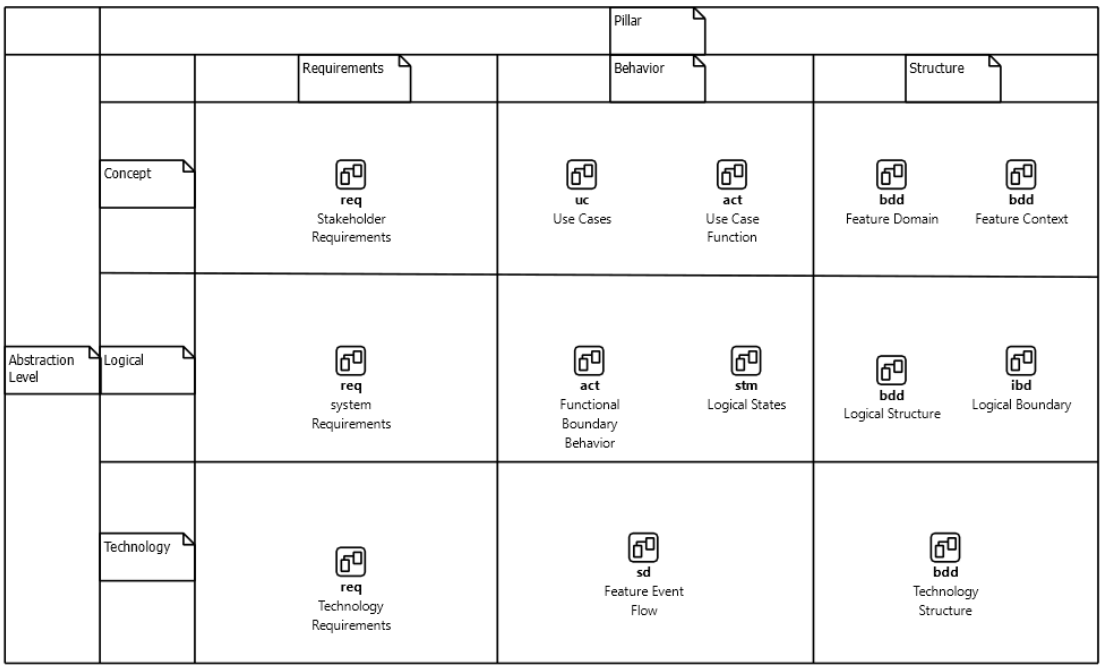

Figure 5 Model Navigation

Abstraction Level

By concentrating on the most crucial aspects and disregarding the rest, abstraction helps to simplify complex systems. In order to focus on the problem that has to be solved, it is a method of simplifying systems by eliminating superfluous elements and emphasizing their essential components. It is essential for a thorough investigation of a system. Consider an artwork in order to comprehend abstraction. A painting represents something to us when we look at it; it could be a person, a scene, or an item. The real environment has been reduced by the artist to a collection of colours, forms, and lines that capture the key elements of the work. Similar to how ants help us understand complex systems, systems engineers utilise abstraction to depict complex systems by dissecting them into their most crucial parts and emphasising the most significant features. A system can be represented at many levels of detail, which are referred to as abstraction levels. Complex systems can be divided into smaller, easier-to-manage components that can be examined and improved using these levels. Stated differently, abstraction levels organise parts of a design that address comparable kinds of queries. In systems engineering, there are three common degrees of abstraction, and the SysML template uses these three levels:

i. Concept Level: Occasionally referred to as Conceptual Level. defines the issue that has to be resolved. At this stage, the system's overall purpose, objectives, and functions are explained, representing the highest level of abstraction. At this stage, comprehending the needs of the system and how it will work with other systems is the main priority.
ii. Logical Level: Specifies a solution apart from technology. At this intermediate level of abstraction, the structure and behaviour of the system are explained. The arrangement and communication between the system's components are the main points of interest at this stage.
iii. Technology level: Also known as physical level in some cases. outlines the precise technical fix. The system is explained at this lowest level of abstraction by describing its individual parts and their characteristics. The implementation details of the system are the main focus at this point.

Different perspectives on the system are offered by each abstraction level, and many facets of system design and analysis depend on the significance of each level. As an illustration, the conceptual level is crucial for comprehending the system's overarching objectives and requirements, but the physical level is crucial for comprehending the system's construction and interaction with its surroundings. The concrete-built system, or the Implementation Level, is the fourth abstraction level that is not modeled. As seen in picture 6, at the upper left corner of Gaphor,

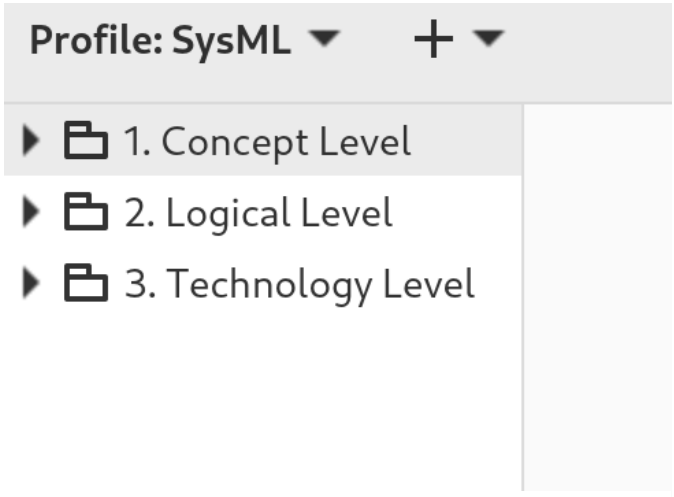

Figure 6 Levels of Abstraction in Gaphor

These three abstraction layers are represented by the three top level packages that Model Browser displays.

Pillars

Based on what they represent, four SysML pillars can be used to categorize different sorts of diagrams:

- Behavior: The way a system works Structure: The arrangement of components and links that make up a system
- Parametric: Applys mathematical rules consistently across system values.
- Requirements: Written declarations that impose constraints on the system.

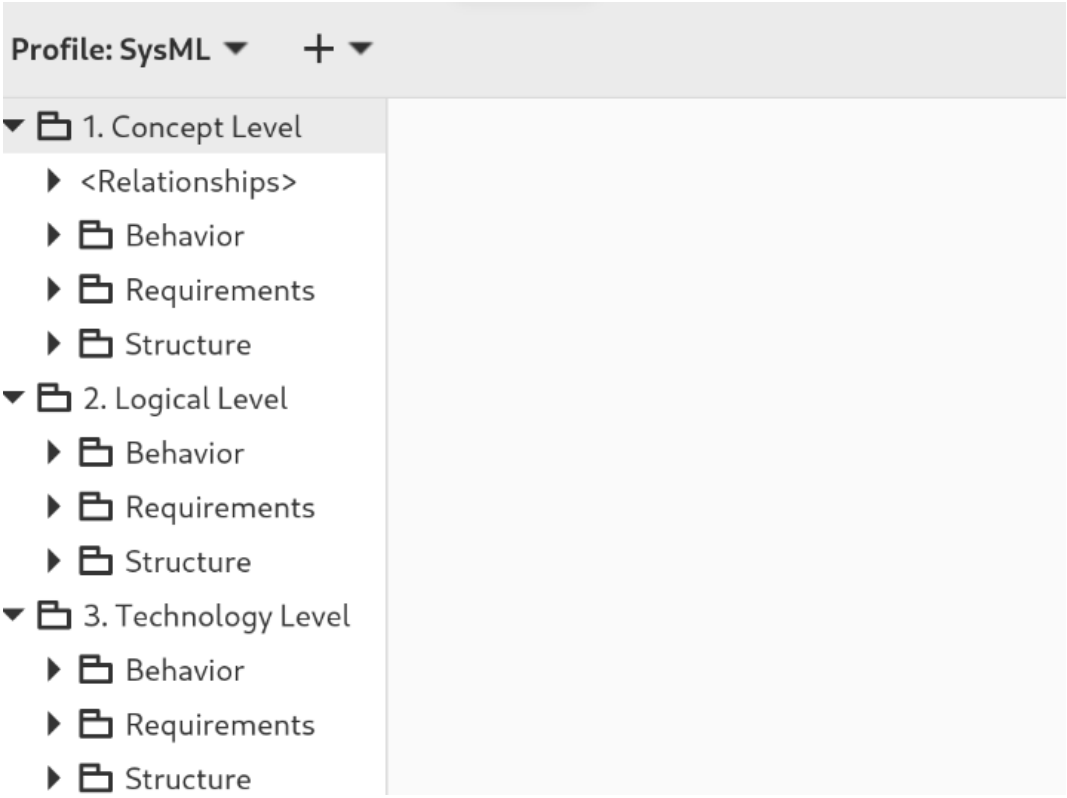

Figure 7 Levels of Pillars in Abstraction

We will limit our discussion to the first three parametric diagrams because they are among the least common types of diagrams in SysML. Creating connections between these three pillars is where SysML's power lies. For instance, by designating a behavior, such as an activity, to a block or other structural component. The Model Browser depicted in Figure 3's top-level Abstraction Level packages can be expanded to reveal three additional packages, one for each pillar. These packages will be where we begin to develop the lighting system's design.

4. SYSML IMPLEMENTATION

4.1 Concept Level

4.1.1 Requirement Diagram

Diagrams that display sets of requirements and their relationships are known as requirement diagrams. A system must fulfil a need to fulfil a function or meet a condition. An example of a text-based requirement is the requirement stereotype, which has text and id attributes. To enable them to be linked to other model elements that satisfy them and test

cases that verify them, requirement diagrams are used to express both functional and non-functional requirements within the model.

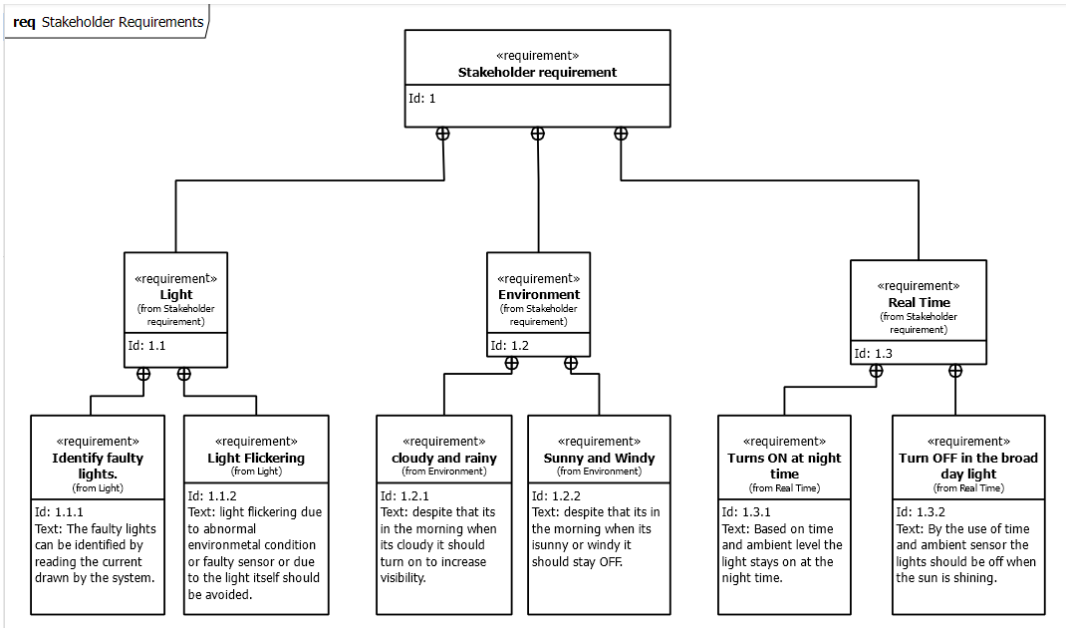

Figure 8 Stakeholder Requirements

4.1.2 Use Case Diagram

An external system user with whom a use case (syntax: oval/ellipse) represents a system transaction is called an actor (stick figure). Use cases are sometimes seen as high-level functional specifications.

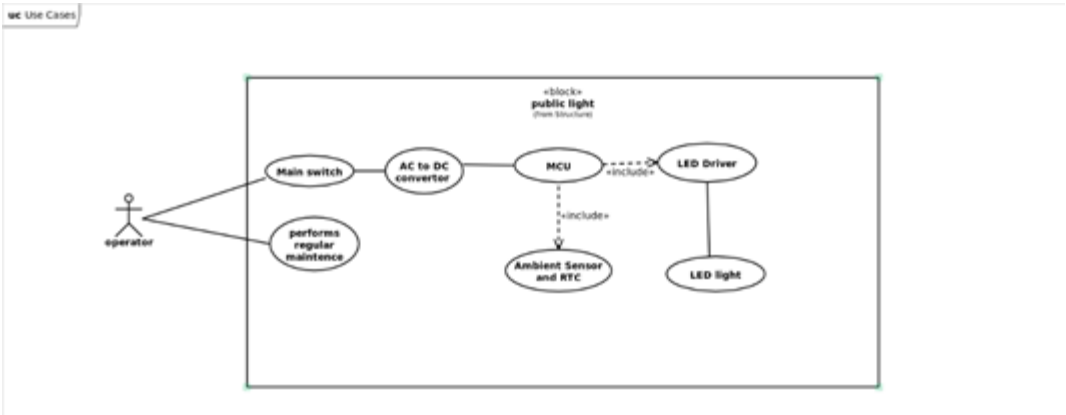

Figure 9 Use Cases

4.1.3 Use Case Function in Activity Diagram

A Use Case Function in an Activity Diagram represents a specific function or Behaviour that a system performs in response to a particular stimulus or event. It is used to depict the high-level functionalities or actions that the system needs to perform to achieve its intended objectives as described by the associated use case.

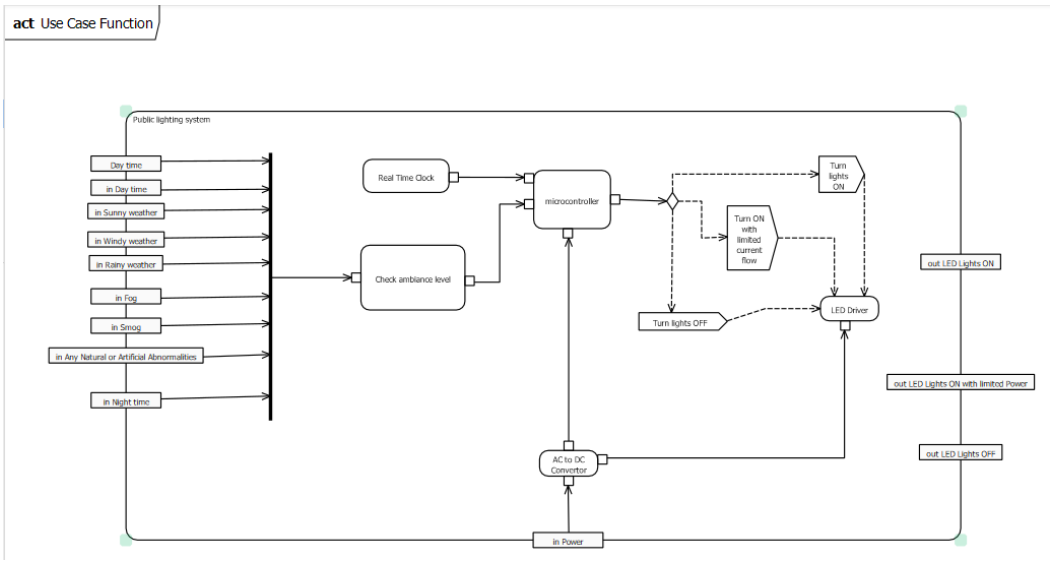

Figure 10 Use Case Function

4.1.4 Domain Diagram (Block Definition Diagram)

An illustration of the ideas, vocabulary, and connections inside a particular domain is called a domain diagram. The essential components and connections inside the domain of the lighting system at a coffee shop could be shown in a domain diagram. A domain diagram that expands on the context diagram by adding new blocks is as follows:

- Public Light
- Public People
- Operator
- Power Source

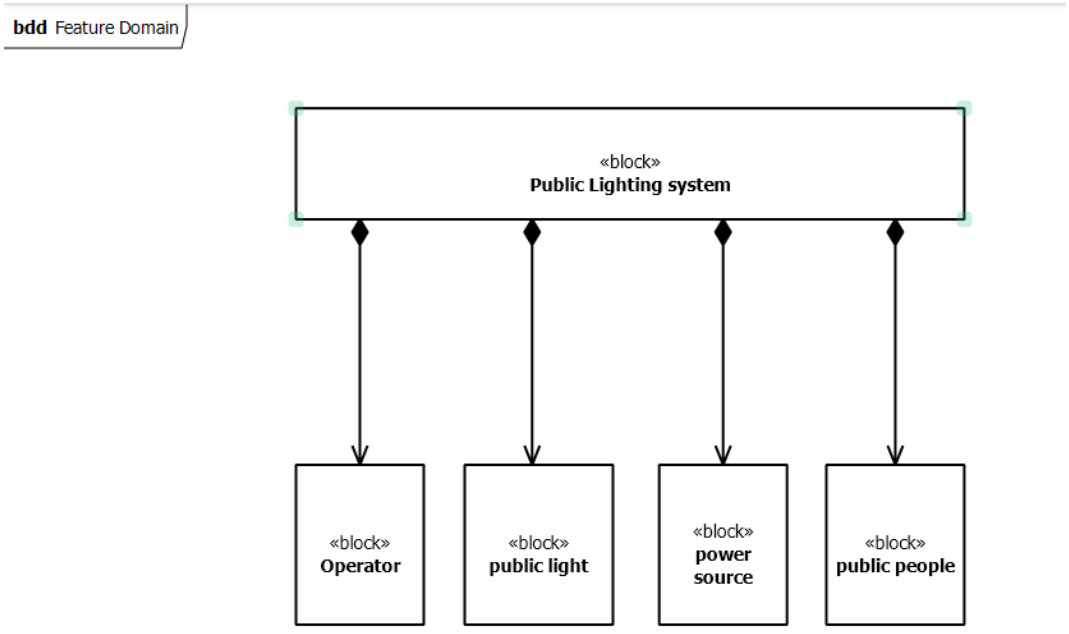

Figure 11 Conceptual Structure

4.1.5 Context Diagram (Block Definition Diagram)

The A high-level representation of the system, the context diagram illustrates how it interacts with outside entities. When it comes to coffee makers, a context diagram offers a succinct and understandable depiction of the system and how it interacts with the outside world.

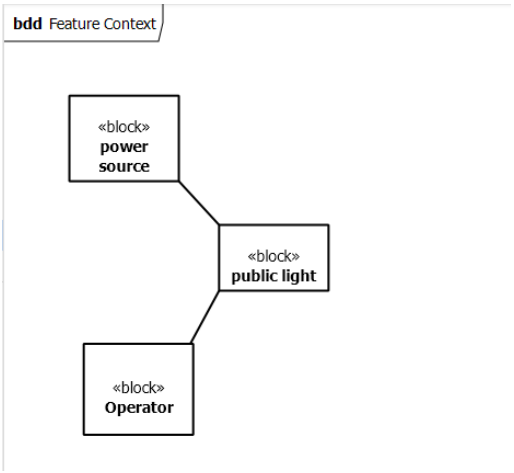

Figure 12 Conceptual Context

4.2 Logical Level

4.2.1 System Requirement:

High-level functionalities and specifications known as logical requirements outline the goals of a system or product without going into detail about how it will be put into practice. Rather than concentrating on the precise technological specifics, these requirements emphasise the intended results and the system's behaviour.

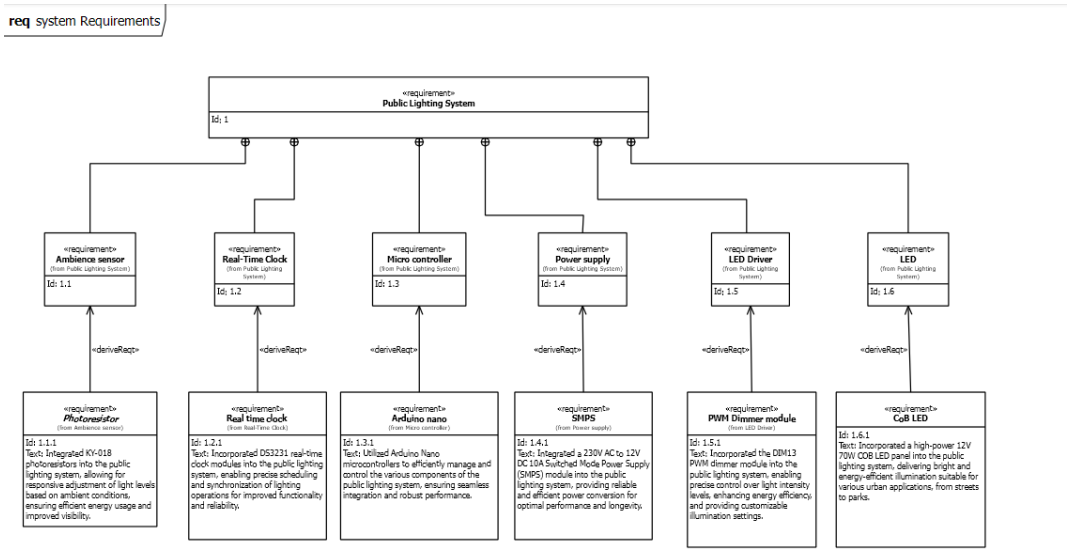

Figure 13 Logical Requirements

4.2.2 Functional Boundary Behaviour (Activity Diagram)

One sort of SysML activity diagram that is used to illustrate the relationships between various logical blocks is the functional boundary behaviour diagram. The swim lanes provide divisions in the diagram, with each area signifying a distinct functional block or element.

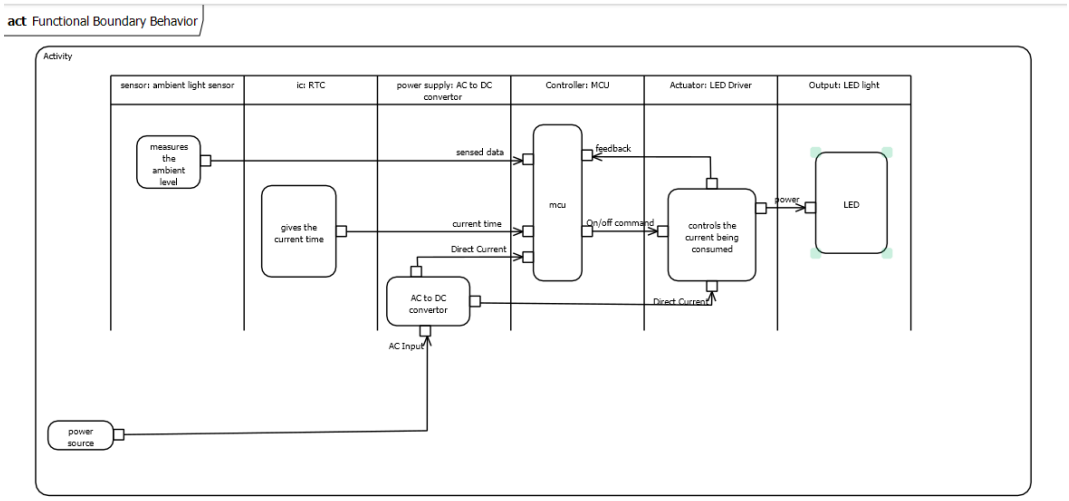

Figure 14 Logical Activity Diagram

4.2.3 Logical State Machine Diagram

A graphical representation of a system's or a component's dynamic behaviour is called a state machine diagram. The different states that an object can be in and how those states change in response to circumstances or occurrences are described.

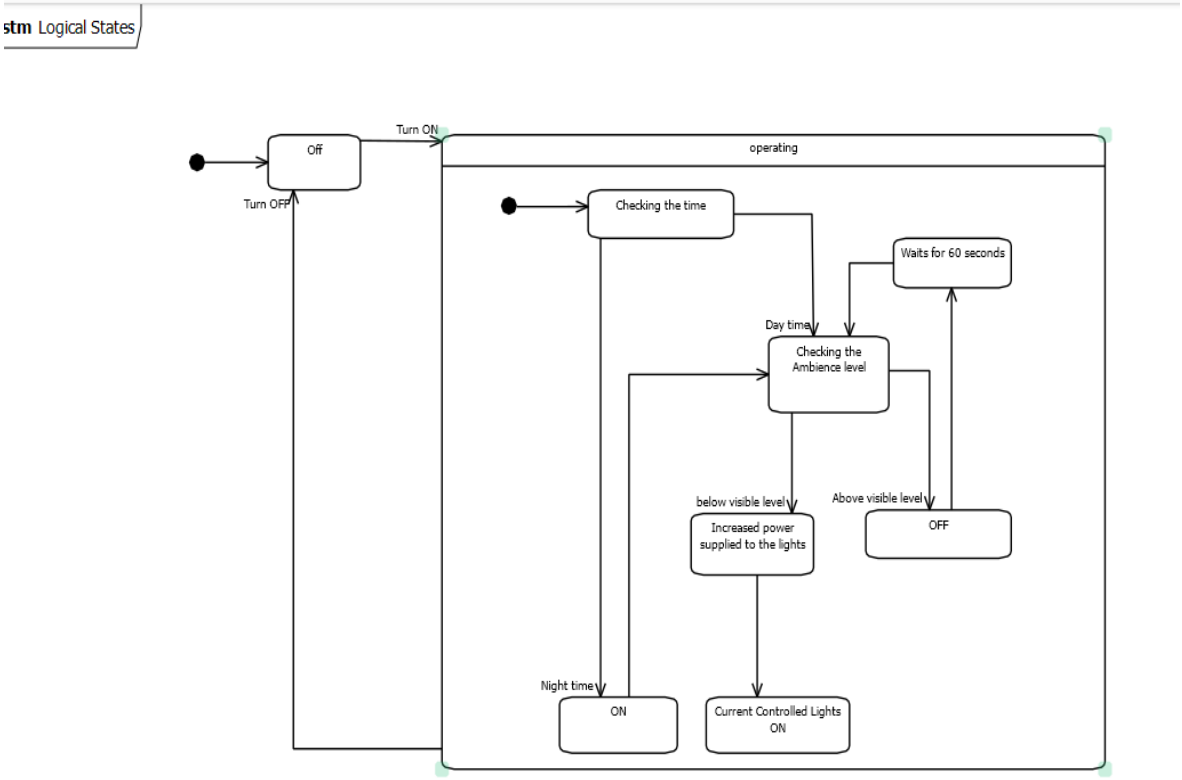

Figure 15 Logical States

4.2.4 Logical Block Definition Diagram

An illustration used to specify the structural features of a system or a component inside a system is called a Block Definition Diagram (BDD). By displaying the individual system blocks and their connections, it offers a high-level perspective of the system's architecture.

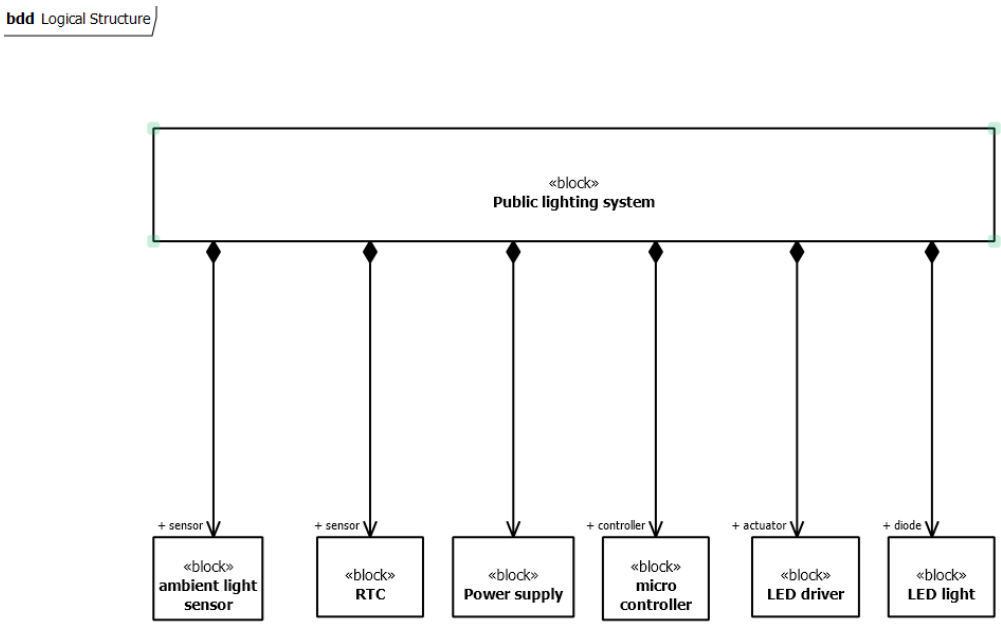

Figure 16 Logical Structure

4.2.4 Internal Block Diagram

An Internal Block Diagram type called the Logical Boundary shows the relationships between a system's internal blocks, or components, and depicts the internal structure of the system. It is beneficial to see how these blocks communicate and interact with one another inside the system.

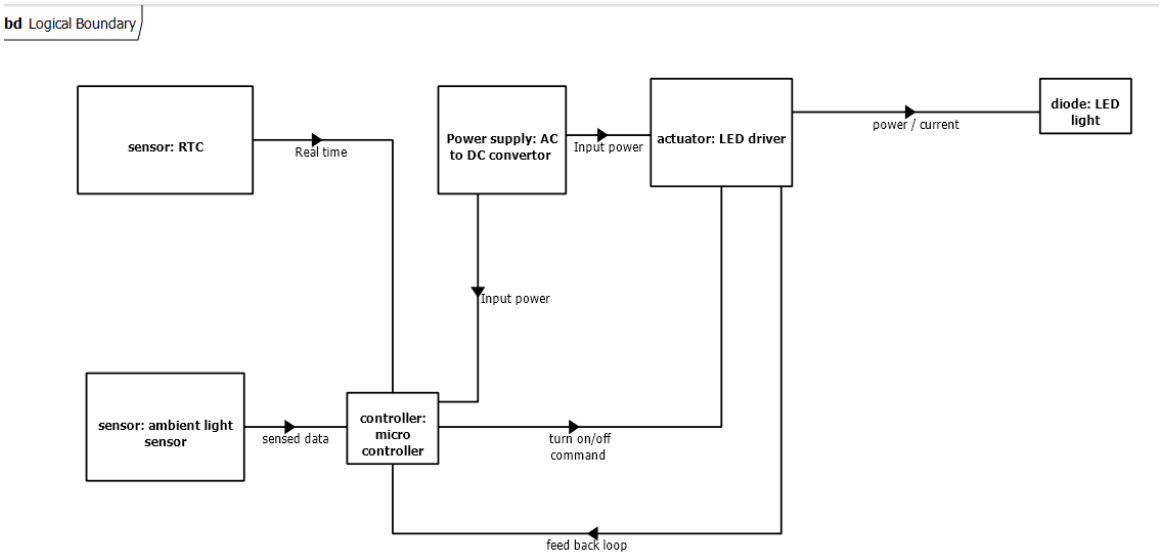

Figure 17 Internal Block Diagram

4.3 Technology Level

The Technology Level design uses a very similar approach as the Logical Level. Work on the Behaviour, structure, and then the requirements.

4.3.1 Requirements

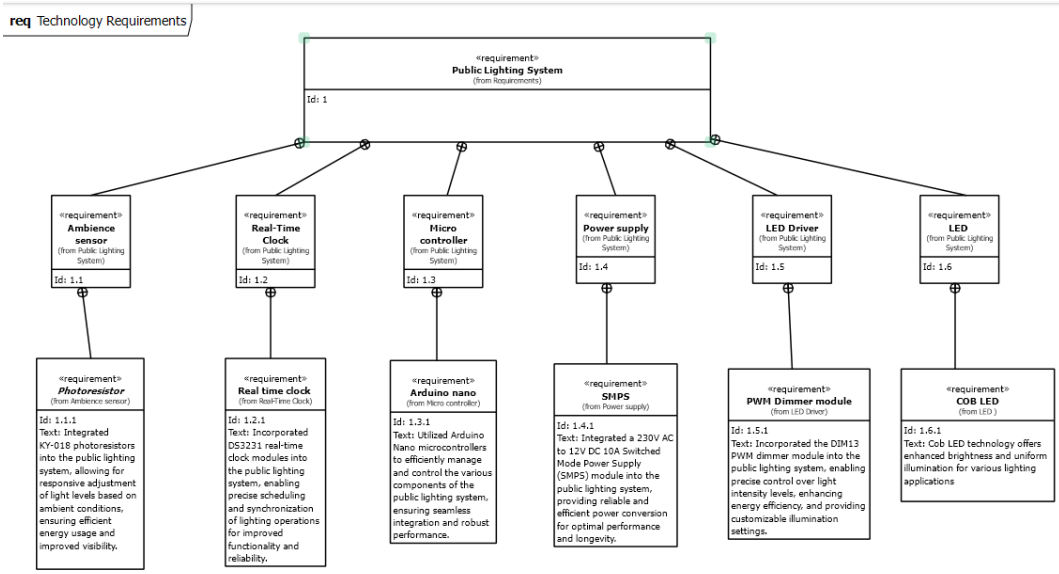

Figure 18 Technology Requirement

4.3.2 Lighting System Event Flow (Sequence Diagram)

Sequence Diagram depicts the chronological sequence of events and interactions between various components within a lighting system. This diagram illustrates how different parts of the system communicate and collaborate to achieve specific functions or Behaviours related to lighting control.

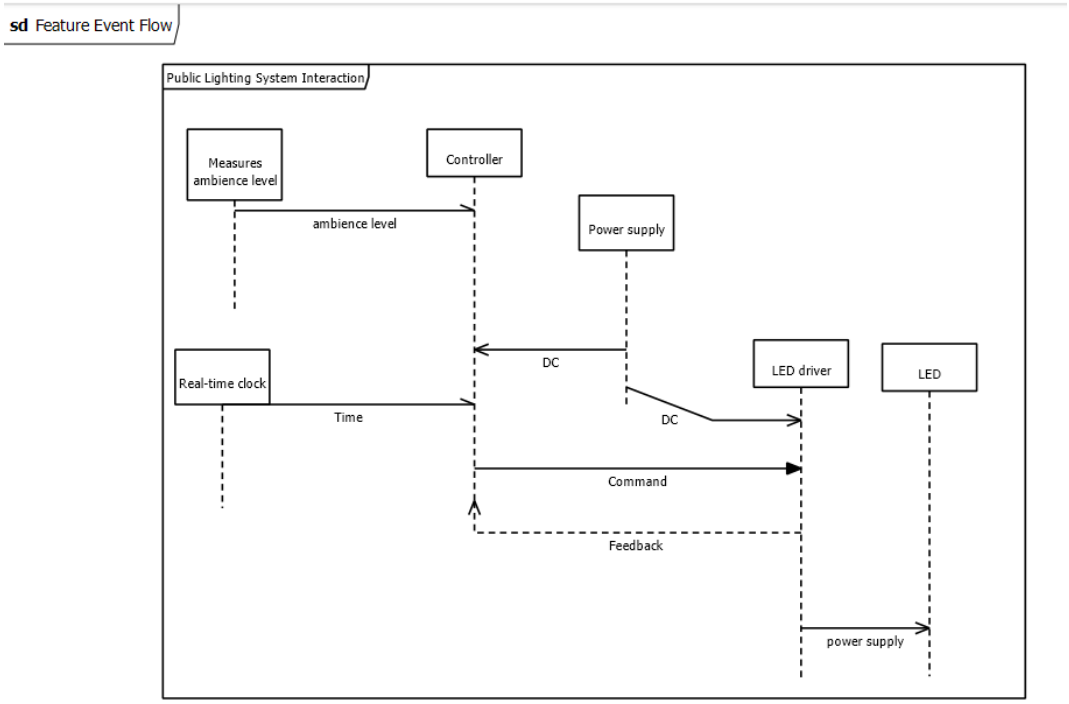

Figure 19 Sequence Diagram

5. RESULT

Each of these diagrams provides a different perspective on your system, helping to ensure a comprehensive understanding and effective communication among stakeholders involved in the project.

1. Requirements Diagram:

Identify and organize requirements for the system, such as functional requirements (e.g., automatically adjust brightness based on ambient light level) and non-functional requirements (e.g., reliability, power efficiency).

2. Use Case Diagram:

Illustrate the interactions between actors (e.g., operator, sensors) and the system, showing various use cases such as "System Initialization," "Automatic Brightness Adjustment."

3. Block Definition Diagram:

Determine the system's primary parts and their connections, such as the photoresistor, real-time clock module, Arduino Nano, LED dimmer module, LED light, and power supply.

4. Internal Block Diagram:

Detail the internal structure of each block/component, showing how they are connected and interact within the system. For example, how the photoresistor interfaces with the Arduino Nano, or how the LED dimmer module controls the brightness of the LED light.

5. Sequence Diagram:

Show the sequence of interactions between different components or actors in the system over time, such as how the system responds to changes in ambient light levels.

6. State Machine Diagram:

Showcase the system's various states and how it switches between them. For example, the system might transition between states like "Day Mode" and "Night Mode."

7. Activity Diagram:

Describe the flow of activities within the system, such as the steps involved in initializing the system, adjusting brightness levels.

8. Parametric Diagram:

Specify the relationships between system parameters, such as the relationship between ambient light level and LED brightness, or the power consumption of the system under different operating conditions.

6. CONCLUSION

In conclusion, the development of a public lighting system integrating an Arduino Nano microcontroller, RTC DS3231, photoresistor KY-018, PWM dimmer module DIM13, COB-LED panel, and SMPS unit represents a significant advancement in the realm of intelligent lighting solutions. By leveraging the capabilities of these components, the system achieves efficient and adaptive illumination while minimizing energy consumption and maximizing user control. The seamless integration of scheduling, ambient light sensing, and brightness modulation functionalities ensures optimal performance in diverse environmental conditions, thereby enhancing safety, comfort, and sustainability in public spaces. Moving forward, further refinements and optimizations could be explored to enhance the scalability, reliability, and functionality of the system, paving the way for broader deployment and adoption of smart lighting technologies in urban environments.

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