Assignment #3 - Ambiguity and Architectural Questions

Software Systems Architecture

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1 Introduction

This paper explores the process of uncovering ambiguity and formulating architectural questions in the context of a traffic signal control system. The system's goal is to optimize traffic flow while minimizing time, energy, and emissions. We begin by generating probing questions to clarify requirements and expand upon the initial product description. These questions are then organized based on logical groupings and timeframes within the project lifecycle. Finally, five particularly significant questions are identified, highlighting their importance, impact, and implications on the system's architecture and stakeholders.

2 Architectural Questions

Within the architectural domain, we navigate the intricate landscape of our traffic signal control system, probing foundational elements that underpin its design and functionality. These inquiries delve into the core principles guiding the system's structure, encompassing considerations of scope, regulatory compliance, sensor technologies, optimization metrics, control mechanisms, and environmental impacts. By addressing these architectural questions, we lay the groundwork for a robust and adaptable infrastructure that optimizes traffic flow, enhances safety, and minimizes environmental impact.

The following are the architectural questions discussed:

1. What types of sensors will be used to detect oncoming traffic? Are we considering technologies like radar, cameras, or other detection systems?
2. If we used AI, how would we train the model? Is the data provided?
3. How can we test the system?
4. What distance should traffic be detected at?
5. Should the system have any user interface accessed remotely?
6. Should the system provide real-time analytics?
7. Should there be some kind of communication between the vehicles and the traffic signs?
8. Are we going to have software that can predict which traffic lights are going to break down so that we can replace them before that happens?
9. What are the system requirements in terms of hardware, software, and network infrastructure?
10. How will the system integrate with existing traffic management technologies?
11. Are there plans for future upgrades or enhancements to incorporate new technologies?

12. How will the system handle communication and coordination with adjacent jurisdictions or neighboring municipalities to ensure consistent traffic management across borders?
13. Will the system only be applied to new traffic signs, or will modifications be made to existing signs to integrate them with the system?
14. Is integration with Police systems necessary for reporting drivers who violate the law?
15. How should the system react in case of failure?
16. How should the system react when the sensor cannot collect information (because of fog, heavy rain, etc...)?
17. How should the system handle emergency services like ambulances?
18. How should we handle low-volume roads near high-volume roads, should we have a max. time on a green light?
19. How will the system accommodate special events or temporary changes in traffic patterns, such as parades or construction projects?
20. Should we consider cyclists as traffic?
21. Will there be any hierarchy between vehicles (emergency, public transport, cyclists, ...)?
22. How will the system handle situations where there are conflicting traffic patterns or congestion from multiple directions?
23. How will the system handle maintenance and updates to ensure ongoing reliability and performance?
24. Are there any plans for future expansion or integration with emerging technologies like connected vehicles or smart infrastructure?
25. Is it necessary for manual intervention in some situations? If so, how would it affect its scalability?
26. Different places have different ways of handling traffic, so are there plans for expansion beyond the initial deployment area?
27. Can you provide more details about the geographical scope of the traffic signal control system? Are we focusing on a specific city or region, or are there multiple locations involved?
28. Who are the possible stakeholders and their roles in this scenario?
29. What problems are we solving for each stakeholder?
30. How this scenario would scale with traffic signals for pedestrians?

31. How quickly can the system recover from a failure to ensure uninterrupted traffic flow?
32. Are there backup power sources that the system should rely on?
33. How will the system handle sensitive personal information like faces?
34. In case of bad weather conditions and measurement errors, how would, this system, be secure for all stakeholders?
35. How will the system protect against cyber threats such as hacking or unauthorized access?
36. What's the budget of this project?
37. How will the costs of maintenance and operation be distributed among stakeholders?
38. What measures are in place to ensure fairness and equity in traffic signal control?
39. Are there any potential negative impacts on the community, such as increased noise or light pollution?
40. Resolving this problem, would any possible stakeholder be at a disadvantage, like pedestrians waiting to cross the road with a lot of traffic?
41. Are there specific timeframes or deadlines for the implementation and deployment of the traffic signal control system?
42. Are there any intermediate deliveries?

3 Question organization

Effective organization of the myriad inquiries surrounding our traffic signal control system is paramount to gaining clarity and coherence in our design endeavors. Through thoughtful categorization and arrangement, we aim to streamline the process of analysis and decision-making. By grouping questions based on thematic similarities such as system scope, technological aspects, regulatory compliance, and operational considerations, as well as sorting them by urgency, we create a structured framework that facilitates comprehensive exploration and strategic planning. This systematic approach ensures that no aspect of the system's architecture is overlooked and fosters a holistic understanding of its intricacies.

Bearing in mind the set of questions presented above, we divided them into ten different categories:

- **Reliability:** Ensuring the system operates consistently and performs as expected under various conditions.

  - Questions: 15, 16

- **Upgradability:** Ability to seamlessly integrate future enhancements or technological advancements.
  - Questions: 23, 24, 11, 25, 26, 27

- **Usability:** Focuses on specifying different use cases of the system.
  - Questions: 29, 30

- **Technology:** Addresses the technological components and innovations driving the system's functionality.
  - Questions: 1, 2, 3, 4, 5, 6, 7, 8, 9

- **Integration:** Ensures seamless compatibility and interaction with existing infrastructure and technologies.
  - Questions: 10, 12, 13, 14

- **Schedule:** Manages timeframes and deadlines for project implementation and deployment.
  - Questions: 41, 42

- **Ethic:** Considers fairness, equity, and ethical implications in system design and operation.
  - Questions: 38, 39, 40

- **Cost Effectiveness:** Evaluates efficiency in terms of resource allocation and long-term financial sustainability.
  - Questions: 36, 37

- **Security:** Implements measures to protect against cyber threats and unauthorized access.
  - Questions: 33, 34, 35

- **Availability:** Ensures continuous operation and accessibility to meet user demands without interruption.
  - Questions: 31, 32

Moreover, there is a substantial group of questions that do not fit entirely in a theme, therefore they were arranged between those axes. The questions are 16, 17, 18, 19, 20, 21 and 22.

The spiderweb depicted in **figure 1** may be challenging to read. For a clearer understanding, you can navigate to the following **link**.

4 Fundamental Questions

At the heart of our inquiry lie five fundamental questions that serve as the bedrock upon which the architecture of our traffic signal control system is built. These questions encompass pivotal aspects such as the system's geographical scope, regulatory requirements, sensor technologies, optimization metrics, control mechanisms, environmental considerations, and scalability. By delving into these fundamental inquiries, we unearth key insights that inform critical decisions, guiding the development of a resilient, efficient, and future-ready traffic management infrastructure.

4.1 Question 1

What types of sensors will be used to detect oncoming traffic? Are we considering technologies like radar, cameras, or other detection systems?

4.1.1 Why

To achieve a comprehensive representation of the environment for traffic detection, it is feasible to employ and combine various types of sensors. For instance, to visually capture the surroundings, one can choose a LIDAR sensor, capable of providing a three-dimensional representation of the environment, or a conventional camera, offering a two-dimensional view of the world.

Additionally, these sensors will communicate with technology from a higher layer so it is important, before defining the architecture, to comprehend which protocols will be used in this data flow. Understanding the types of sensors employed for detecting oncoming traffic is crucial to establishing the technical foundation of the traffic signal control system. It ensures that the chosen sensors align with the system's objectives and contribute to efficient traffic flow optimization.

4.1.2 Whom

This question will impact the requirements team since each type of sensor has its limitations. It will also influence developers, as there are specific techniques associated with handling the information collected for each type of sensor. Ultimately, it will also affect stakeholders, as the choice of sensors will impact the cost of installing the system in cities and, consequently, its relevance.

4.1.3 When

This question should be asked as early as possible so that developers can familiarize themselves with the technologies employed and so that stakeholders can estimate the costs associated with the type of sensors used.

4.1.4 How

Certain types of sensors can only provide reliable representations of the environment when used in conjunction with other sensors, which may be of the same type or not. The communication between these sensors will impact the architecture, requiring the implementation of secure communication channels. The careful integration of information from multiple sensors is crucial, as there may be failures in some of these sensors.

4.2 Question 2

If we used AI, how would we train the model? Is the data provided?

4.2.1 Why

This question is crucial because it addresses the feasibility and methodology of implementing AI within the traffic signal control system. It directly impacts the system's ability to optimize traffic flow effectively. Understanding the approach to training the AI model is essential for ensuring that the system can learn from and adapt to various traffic scenarios accurately.

4.2.2 Whom

This question impacts the software architects, developers, and data scientists involved in designing and implementing the AI component of the system. Additionally, it affects stakeholders who are concerned with the system's performance and its ability to achieve the desired outcomes of minimizing traffic congestion, fuel consumption, and emissions.

4.2.3 When

This question can be addressed during the early analysis and design phases of the project. It requires careful consideration and planning to determine the data requirements, training methodologies, and algorithms to be used. Addressing it early ensures that the necessary data collection processes and model development can proceed effectively.

4.2.4 How

The answer to this question fundamentally shapes the architecture of the system, particularly in terms of data management, processing pipelines, and integration with AI technologies. It may necessitate the inclusion of data storage systems capable of handling large volumes of traffic data, as well as the implementation of machine learning frameworks for model training and inference. Additionally, the choice of AI algorithms and training methodologies will influence the overall system design and computational requirements. Therefore, the architecture must be flexible and scalable to accommodate the AI components effectively.

4.3 Question 3

What measures are in place to ensure fairness and equity in traffic signal control?

4.3.1 Why

This question is important because it addresses the need for fairness and equity in traffic signal control, particularly concerning the treatment of different road users and traffic lanes. Ensuring equitable treatment between vehicles and pedestrians crossing the road, as well as between lanes of traffic, is essential for promoting safety, efficiency, and social cohesion on roadways. It helps prevent conflicts and bottlenecks, leading to smoother traffic flow and reduced congestion.

4.3.2 Whom

This question impacts a wide range of stakeholders, including pedestrians, drivers, cyclists, transit users, and local communities. It particularly affects vulnerable road users such as pedestrians and cyclists, who may face greater risks from traffic accidents if not adequately accounted for in signal control. Additionally, it impacts urban planners, traffic engineers, and policymakers responsible for designing and managing transportation infrastructure.

4.3.3 When

While addressing this question early in the design phase allows for proactive integration of equity considerations into the system architecture, it can also be revisited and refined throughout the project lifecycle. For example, specific measures to ensure fairness and equity may be further developed and implemented during the system testing and deployment phases based on feedback from stakeholders or real-world observations.

4.3.4 How

The answer to this question impacts the architecture of the system by influencing the design of signal timing algorithms, sensor placement, and prioritization strategies. Measures to ensure equity between vehicles and pedestrians may involve implementing pedestrian countdown timers, signal phases dedicated to pedestrian crossing, and pedestrian detection sensors at intersections. Similarly, equity between lanes of traffic may involve dynamic signal timing adjustments based on traffic volume and lane utilization, as well as prioritizing public transportation lanes during peak hours. Therefore, the architecture must include features that prioritize safety, efficiency, and equity for all road users and traffic lanes.

4.4 Question 4

How should the system react when the sensor cannot collect information (because of fog, heavy rain, etc...)?

4.4.1 Why

To ensure the reliable and robust operation of the system, it is crucial to understand its response to sensor limitations induced by adverse weather conditions. This consideration aligns with the necessity of maintaining effective traffic signal control, even in challenging environmental scenarios, thereby supporting the primary goal of optimizing traffic flow and enhancing safety.

4.4.2 Whom

This question will affect the team dedicated to the requirements engineering phase, as well as the team responsible for deciding on the hardware to be used in the traffic lights. Ultimately, this decision will also impact developers and stakeholders, as the project may become more expensive.

4.4.3 When

To be able to incorporate solutions that address sensor limitations in challenging conditions into the system design and improve overall system effectiveness, this question should be addressed early in the requirements definition process.

4.4.4 How

The answer to this question influences the architectural design by guiding the incorporation of adaptive mechanisms, such as redundant sensors, predictive algorithms, etc. These considerations aim to enhance the system's capability to respond to challenges brought on by adverse weather conditions and ensure continuous traffic flow optimization.

4.5 Question 5

Are there any plans for future expansion or integration with emerging technologies like connected vehicles or smart infrastructure?

4.5.1 Why

To guarantee the traffic signal management system's flexibility and ongoing relevance over time, it is essential to comprehend the strategic vision for future growth and integration with new technologies. This aligns with developing a system that can evolve alongside advancements in connected vehicles and smart infrastructure.

4.5.2 Whom

The architecture design team will be impacted by this choice because the architecture will need to be modified to accommodate upcoming expansions and the incorporation of new technologies. Stakeholders will also be impacted because the response to this query will indicate how relevant the project is going forward.

4.5.3 When

This question should be tackled in the initial phases of system design. It will be easier to accommodate future expansions and integrate emerging technologies if the team adopts the mindset that the system architecture needs to be upgradable.

4.5.4 How

When designing the system architecture, it is crucial to incorporate an approach that allows for the independent addition or updating of specific components. Additionally, the architecture must be carefully planned to be compatible with the technologies and practices adopted in smart infrastructures. An essential consideration in this process is a focus on security, especially when connecting our system to the smart infrastructure network, as it implies potential exposure to risks. Therefore, ensuring robust security measures becomes a priority to mitigate possible vulnerabilities and ensure the integrity and reliability of our system within the context of smart infrastructures.

5 Conclusion

In conclusion, our comprehensive exploration of ambiguity and formulation of architectural questions for the traffic signal control system has yielded a structured framework essential for informed decision-making and strategic planning. By categorizing and organizing inquiries based on thematic similarities and urgency, we've ensured a comprehensive understanding of the system's intricacies, leaving no aspect of its architecture overlooked. The fundamental questions highlighted serve as the bedrock upon which the system's architecture is built, addressing pivotal aspects such as sensor technologies, AI integration, fairness and equity, resilience in adverse conditions, and future expansion. These inquiries not only clarify requirements but also guide the development of a resilient, efficient, and future-ready traffic management infrastructure.

This systematic approach underscores the importance of thorough inquiry in designing complex software systems, particularly in the domain of traffic management. By engaging in a structured exploration of ambiguity and strategic formulation of architectural questions, we lay the foundation for success, ensuring that the traffic signal control system meets the needs of stakeholders, adapts to emerging technologies, and contributes to the advancement of transportation infrastructure.

Figure 1: Spiderweb