# Self-Driving Car System

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# Scenario

AutoDrive, a globally recognized leader in the automotive industry, is at the forefront of innovation in autonomous driving technology. In response to the growing demands for safer, more efficient, and environmentally-friendly transportation solutions, the company is developing a cutting-edge fully autonomous driving system (ADS) aimed at transforming the future of personal and commercial transportation.

With road safety being a critical issue, AutoDrive seeks to address the fact that human error is responsible for the vast majority of traffic accidents globally. The ADS aims to significantly reduce these incidents by eliminating common human mistakes such as distracted driving, speeding, and improper decision-making in high-pressure situations. Furthermore, AutoDrive's system is designed to alleviate the increasing congestion in urban areas, which not only causes significant delays but also contributes to environmental pollution due to excessive fuel consumption.

By leveraging a combination of advanced sensors (LIDAR, cameras, and radar), artificial intelligence (AI), and machine learning, AutoDrive's ADS will enable vehicles to navigate complex road scenarios autonomously. This includes interactions with other vehicles, pedestrians, cyclists, and infrastructure in real-time. The system will operate efficiently in various driving environments such as congested city streets, open highways, suburban roads, and parking lots, offering drivers a seamless and convenient experience.

# Problem and Vision Statement

## Problem Statement

AutoDrive, a leading car manufacturer, is facing growing pressure to address critical issues related to road safety, traffic congestion, and environmental impact.

According to the research of Zhang, Y. et al. (2019), human error accounting for the vast majority of traffic accidents, the demand for safer and more efficient transportation systems is at an all-time high. In urban areas, congestion leads to significant delays, increased fuel consumption, and higher levels of pollution, while individuals with mobility challenges struggle to find reliable transportation options. Although autonomous driving technology holds the potential to address these challenges, existing solutions often lack the sophistication needed to handle complex road conditions, such as unpredictable traffic patterns and adverse weather. This situation highlights the need for a fully autonomous driving system that can provide safe, efficient, and environmentally-friendly transportation across diverse environments, ensuring accessibility and convenience for all users.

## Vision statement

For urban commuters, delivery services, and individuals with mobility challenges who seek a safer, more efficient, and convenient transportation solution, AutoDrive's fully autonomous driving system offers real-time navigation and control in diverse driving environments, from city streets to highways. Unlike other autonomous systems, AutoDrive leverages advanced AI, LIDAR, and radar technology to ensure optimal safety, adaptability, and environmental sustainability, providing users with a seamless and reliable driving experience.

# Challenges of Standard Requirement Analysis Techniques

Self-driving systems are complex, dynamic, and require advanced capabilities that go beyond traditional software development. Standard requirement analysis techniques, such as interviews, use cases, and data flow diagrams, often focus on well-defined, static systems where the functional and non-functional requirements are relatively clear and predictable. However, these techniques face several limitations when applied to self-driving systems:

## Dynamic and Unpredictable Environments

Traditional techniques are often based on predefined scenarios and rules. Self-driving systems, however, must operate in unpredictable, real-world environments, which can change rapidly (e.g., traffic conditions, weather, human behavior). Standard requirement techniques do not capture the full range of dynamic behaviors required for safe and reliable operation. According to the study of Wilkins et.al in 2007, An autonomous vehicle should consider the overall environment and dynamically adjust its control mechanism to balance performance and safety.

## Handling Uncertainty and Ambiguity

Self-driving systems deal with uncertainties such as unexpected obstacles, erratic behavior from other drivers, and varying traffic laws. Standard requirement techniques struggle to accommodate such ambiguity and tend to focus on clear, well-defined functional requirements.

## Complex Interactions and Dependencies

Self-driving systems involve a high degree of interaction between sensors, decision-making algorithms, and control mechanisms. Base on the study of HoBbach, Phillip Maxim in 2019, these systems must process vast amounts of data in real-time and make split-second decisions. Standard techniques do not easily capture the complexity and interdependencies of such systems.

## Emergent and Evolving Behaviors

In self-driving systems, behaviors emerge from interactions between components (e.g., sensor data, AI algorithms). These behaviors are difficult to predict in advance, making traditional methods insufficient for capturing all potential scenarios and responses.

# Proposed Technique

To address the shortcomings of standard requirement techniques, alternative approaches can be used to supplement the requirement specification of self-driving systems. These approaches are more suited to capturing complex, dynamic, and evolving system requirements.

## Scenario-Based Analysis

Scenario-Based Analysis (SBA) is a powerful method for identifying and classifying risks by simulating real-world situations that a system may face, particularly in Dynamic and Unpredictable environments for self-driving vehicles. According to Kazman et al. (1996), scenarios and use cases were broadened to cover a wide range of real-world situations that a self-driving system might encounter, including pedestrians crossing, adverse weather conditions, and sudden road changes. Once risks are identified, they are classified by evaluating their severity, likelihood, and detectability. According to Liu et al. in 2013, a scenario where a sensor fails to detect an obstacle in heavy fog might be classified as high severity and moderate likelihood, depending on system performance in similar conditions. By analyzing a wide range of possible real-world situations, SBA provides a structured framework to uncover and prioritize risks, helping developers mitigate critical issues before real-world deployment. This ensures the system can operate safely in diverse and unpredictable environments while addressing technological and ethical challenges.
By provides detailed context for how the system behaves in specific, real-world situations, helps identify edge cases and unusual conditions that may not be covered by traditional analysis. However, Scenario-Based Analysis (SBA) can be challenging to define every possible scenario, and some edge cases may still be missed. This method can lead to an overwhelming number of scenarios, making it difficult to manage all cases effectively.

## Prototyping and Simulation

Prototyping and simulation are valuable techniques for addressing uncertainty and ambiguity in system development, particularly in complex environments like self-driving systems. By creating prototypes or utilizing simulation environments, developers can model the system's behavior under various conditions, including those that are unpredictable or difficult to define. In 2018 Zeigler et al stated that simulations can be used to expose the system to rare or extreme events, such as sudden pedestrian crossings or unexpected weather changes, allowing developers to assess how the system responds to ambiguous situations. These iterative tests help refine the system’s capabilities by identifying weaknesses or gaps in its handling of uncertainty. Moreover, according to the study of Pittman in 1993, prototypes allow for real-time experimentation, where developers can modify components and observe outcomes, improving the clarity of ambiguous requirements through continuous feedback. This approach not only reduces risks but also ensures that the system evolves to manage uncertainties inherent in dynamic environments, providing insights that might not be captured through static requirement analysis alone.

Prototyping and simulation allow for iterative testing and refinement of system behavior. Simulations can expose system weaknesses in handling unexpected events, helping to refine requirements. However, creating detailed, realistic simulations is expensive and resource-intensive. Prototypes may not perfectly reflect real-world scenarios, limiting their effectiveness in gathering complete requirements.

## Model-Based Systems Engineering (MBSE)

Model-Based Systems Engineering (MBSE) is an effective approach for managing emergent and evolving behaviors in complex systems, such as self-driving vehicles. In 1993, Wayne Wymore stated that by using formal models like SysML or UML, provides a structured framework for MBSE to capture the system's architecture, behavior, and interactions across components. This enables developers to trace requirements from high-level objectives down to system implementation, ensuring that the system can adapt as behaviors evolve. According to the study of Friedenthal et al in 2015, emergent behaviors, like those that arise from interactions between system components that can be challenging to predict, but MBSE helps by simulating various scenarios and interactions to reveal these dynamics. As system requirements change over time, MBSE facilitates updating models in a consistent and traceable way, ensuring that the system design adapts to new requirements without losing its integrity. However, despite these advantages, capturing emergent behaviors in real-world environments can still be difficult due to the complexity of modeling all possible interactions. Nonetheless, MBSE provides an essential foundation for managing the evolving nature of modern, complex systems.

Even though Model-Based Systems Engineering (MBSE) provides a clear and structured way to visualize the system and supports traceability from high-level requirements to system design and implementation, it requires specialized expertise in modelling languages and tools. Additionally, building and maintaining comprehensive models can be time-consuming and resource-intensive. According to the study of Zeigler et al in 2018, capturing emergent behaviors in real-world environments can still be difficult due to the complexity of modeling all possible interactions.

# Requirements Specification

## Requirement 1

**Requirement**: The system must maintain the vehicle within its designated lane at all times, ensuring smooth lane transitions when necessary.

**Rationale**: Lane-keeping is crucial for the safe operation of autonomous vehicles. By maintaining the vehicle within its lane, the system minimizes the risk of accidents caused by veering into adjacent lanes or off the road. Ensuring lane discipline also contributes to the flow of traffic and overall road safety. A failure to reliably maintain lane position could result in traffic violations, collisions, or other dangerous situations.

## Requirement 2

**Requirement**: The system must detect obstacles and take appropriate action (e.g., stop, slow down, or maneuver around) to avoid collisions.
**Rationale**: Detecting and responding to obstacles is essential for the safety of passengers and other road users. Without this capability, the autonomous vehicle could collide with objects, pedestrians, or other vehicles, leading to accidents. Accurate obstacle detection will allow the system to take preventive action, thereby avoiding incidents and maintaining a high level of trust from users and regulators.

## Requirement 3

**Requirement**: The system must autonomously plan and follow optimal navigation routes using real-time traffic data.

**Rationale**: Efficient route planning reduces travel time and fuel consumption, contributing to both user convenience and environmental sustainability. By leveraging real-time data, the system can avoid traffic congestion, accidents, and road closures, ensuring that the user reaches their destination in the shortest possible time. Failure to optimize routes could result in inefficient travel, user frustration, and increased environmental impact.

## Requirement 4

**Requirement**: The system must identify and avoid pedestrians in or near the vehicle's path to prevent accidents.

**Rationale**: Pedestrian safety is a critical concern for autonomous vehicles. By detecting pedestrians and responding accordingly, the system helps reduce the risk of accidents involving pedestrians, which can result in injury or death. Ensuring this capability will also contribute to compliance with legal and ethical standards for road safety, especially in urban environments.

## Requirement 5

**Requirement**: The system must autonomously park the vehicle in available parking spots, including parallel parking.

**Rationale**: Parking is a key aspect of driving, and automating this task enhances user convenience while ensuring efficient use of space in busy urban areas. By autonomously handling parking, the system will eliminate the potential for human error during parking maneuvers, such as collisions or misjudging space. This also improves accessibility for users with limited mobility.

## Requirement 6

**Requirement**: The system must adapt its driving behavior in response to changing weather conditions, such as rain, snow, or fog.

**Rationale**: Adverse weather conditions can significantly affect driving safety. By adjusting the vehicle's speed, braking, and lane-keeping behavior, the system will minimize risks associated with reduced visibility or slippery roads. Failure to do so could lead to dangerous situations, such as hydroplaning or collisions, which would undermine the system's reliability and user trust.

## Requirement 7

**Requirement**: The system must prioritize the minimization of harm in situations where a collision is unavoidable, based on predefined ethical guidelines.

**Rationale**: Ethical decision-making in unavoidable accidents is one of the most challenging aspects of autonomous vehicle design. By integrating ethical frameworks, the system will be able to make decisions that minimize overall harm to passengers, pedestrians, and other road users. This feature is essential to ensuring public trust and acceptance of autonomous vehicles, as well as for regulatory compliance.

## Requirement 8

**Requirement**: The system must protect user data by adhering to relevant data protection laws, such as GDPR.

**Rationale**: Autonomous vehicles collect significant amounts of data, including user preferences, routes, and personal information. Ensuring the privacy and security of this data is essential for compliance with global regulations and for maintaining user trust. Data breaches or misuse could result in legal consequences and loss of customer confidence in the system.

## Requirement 9

**Requirement**: The system must detect and respond to vehicle malfunctions or external accidents by bringing the vehicle to a safe stop.

**Rationale**: Detecting emergencies is critical for maintaining safety in autonomous vehicles. Whether due to internal system failures or external accidents, the system must be able to recognize danger and respond appropriately. Bringing the vehicle to a safe stop will prevent further damage or harm and ensure passenger safety. Failure to do so could lead to catastrophic results, both for the vehicle's occupants and other road users.

## Requirement 10

**Requirement**: The system must comply with local, national, and international regulations governing the operation of autonomous vehicles.

**Rationale**: Legal compliance is mandatory for the deployment of autonomous vehicles. Without adhering to traffic laws and regulations, the system cannot be legally deployed on public roads. This includes compliance with speed limits, signalling, and right-of-way rules. Regulatory violations could result in penalties, legal challenges, and delays in adoption.

### Requirement 11

**Requirement**: The system must communicate with other autonomous vehicles to share real-time information about traffic, hazards, and road conditions.

**Rationale**: Vehicle-to-vehicle communication enhances safety and efficiency by allowing autonomous cars to share critical information about their surroundings. This collaboration can prevent accidents, reduce traffic congestion, and optimize route planning. A failure to implement this feature could result in missed opportunities for efficiency and increased risk of collisions or traffic delays.

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