Politecnico of Turin

Master's Degree course in Engineering and Management
Academic Year 2023/2024
Session of November/December 2024

Enhancing Driver Safety in the Era of Automation

Exploration of Driver Monitoring Systems and their role in the future through a qualitative research

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Abstract

The automotive industry is rapidly evolving, transitioning from traditional mechanical systems to advanced, automated technologies. As vehicles become increasingly autonomous, the role of the driver is shifting from active control to passive supervision, which introduces new safety challenges. One critical area in ensuring road safety is the development of Driver Monitoring Systems (DMS), which are designed to detect driver states such as fatigue, distraction, and inattention. Despite the progress made in this field, existing DMS technologies still face several limitations, particularly in terms of real-time accuracy, reliability, and privacy concerns related to the collection of sensible data.

This thesis examines the evolution of automotive technologies with a specific focus on Driver Monitoring Systems. It highlights the increasing need for predictive and efficient DMS due to the rise of vehicle automation. The research begins by tracing the historical development of vehicles using the Abernathy-Utterback model, showcasing the transition from the fluid phase to the highly specialized systems of today. Additionally, it explores the technological foundation of DMS, including face and eye-tracking cameras, behavioral and bio-metric sensors, and artificial intelligence (AI) algorithms, which are integral to assessing driver engagement and attention.

Through a series of interviews with potential users, this research investigates current perceptions, benefits, and concerns associated with DMS. Key findings obtained from the thematic analysis used, indicate that while there is a broad acknowledgment of the safety benefits provided by DMS, privacy and data security remain significant barriers to wider adoption. Furthermore, the interviews reveal a desire for systems that are not only more accurate, but also transparent in their operations and data management.

The thesis concludes by discussing the future prospects for DMS, emphasizing the need for innovation in AI-driven prediction models, better integration with vehicle systems, stronger regulatory frameworks to address privacy concerns, and the possibility of implementing comfort features like automatic personalized settings adjustment through face recognition to balance the discomfort created by the previously cited problems.

Suggestions for future development could include enhancing the precision of DMS technologies, exploring non-invasive monitoring methods, improving the public's trust through clearer communication of data usage policies, and integrating safety monitoring functions with features that add tangible value to the driver's experience.

In summary, this thesis underscores the critical role of DMS in the next generation of vehicles, particularly as the industry moves towards higher levels of automation. By addressing the technical challenges and ethical concerns surrounding these systems, DMS can play a pivotal role in enhancing driver and road safety, shaping the future of automotive technologies.

Contents

Chapter 1

Introduction

1.1 From mechanical systems to automotive technologies

The automotive industry has undergone a remarkable transformation over the past century, shifting from simple mechanical systems to highly complex and intelligent technologies. Today, vehicles are not just modes of transportation, but sophisticated machines equipped with advanced electronic and digital systems. As this evolution continues, the integration of automation in driving systems has become a crucial focus, leading to significant developments in areas such as Advanced Driver Assistance Systems (ADAS) and autonomous driving technologies.

1.2 Rise of automation and need of better driver monitoring

One topic that has gained particular importance in recent years is the need for effective Driver Monitoring Systems (DMS). With the rise of automation, drivers often transition between active driving and passive monitoring, increasing the risk of disengagement and inattention. This creates a pressing need for technologies that can accurately assess driver states, including fatigue, distraction, and cognitive load, to ensure safety and mitigate accidents caused by human error.

1.3 Current state of DMS and problems

Despite the advancements in DMS technologies, several challenges remain. Current systems often struggle with providing accurate, real-time assessments of driver behavior and engagement. Moreover, privacy concerns related to the collection and use of bio-metric data pose significant hurdles for the widespread adoption of these systems. This highlights the need for ongoing innovation and the development of more predictive, reliable, and privacy-conscious solutions.

1.4 Need of a predictive survey and survey objective

This thesis aims to explore the evolution of automotive technologies with a specific focus on Driver Monitoring Systems, investigating both the technical challenges and potential future advancements in this field. By conducting a survey and analyzing the perspectives of key stakeholders, this research seeks to identify the key innovation drivers behind DMS, as well as the concerns and expectations of consumers and industry experts. Given these insights, a more comprehensive understanding of the present situation will be achieved, guiding the necessary steps to ensure a broader and successful global implementation of the DMS, enabling a safer and more comfortable driving experience.

1.5 Thesis structure

The thesis develops the previously cited contents as follows: Chapter 2 delves into the historical evolution of the vehicle, examining its development through various technological phases occurring during time and analyzing the technologies of Electrical/Electronic Architecture (EEA) and Advanced Driver Assistance Systems (ADAS), which are fundamentals for vehicle's present and future. Chapter 3 focuses on the current state of DMS, exploring its technologies, challenges, and future perspectives. Chapter 4 presents a thematic analysis of interviews conducted to gain insights into the perceptions and concerns regarding DMS' present and future. Finally, Chapter 5 concludes with recommendations and potential future directions for improving DMS, favoring its widespread and enhancing driver and road safety.

Chapter 2

Evolution of the vehicle and of automotive technologies

The evolution of automotive technologies has fundamentally reshaped the way vehicles are designed, manufactured, and operated. From the earliest mechanical systems to the sophisticated, computer-driven architectures of today, the modern automobile has undergone a radical transformation. This chapter explores the historical progression of vehicle development, focusing on the rise of advanced electronic systems and their implications for safety, efficiency, and driver experience.
Central to this evolution is the shift from isolated mechanical components to integrated Electrical and Electronic Architectures (E/E Architecture), which have enabled the proliferation of intelligent vehicle systems. These systems, such as Advanced Driver Assistance Systems (ADAS), are critical steppingstones toward fully autonomous vehicles. However, as these systems evolve, they introduce new challenges in monitoring and ensuring driver engagement, which is where Driver Monitoring Systems (DMS) come into play.
In order to comprehensively examine these factors, it is essential to first delve into the historical evolution of the vehicle as a whole, with particular emphasis on the implementation of its automotive technologies, an evolution which has seen alternating periods of innovation, decline, and resurgence on the part of its various protagonists.
The origins of the vehicle can be traced back to the early 19th century, coinciding with the initial conceptualization and construction of the first automobiles.

2.1 History of the vehicle through the Abernathy-Utterback model

To conduct a comprehensive and precise analysis of the evolution of vehicles, the Abernathy-Utterback model will be employed. This framework illustrates the dynamic patterns of industrial innovation through the lenses of performance, sales, number of firms and the rate of innovation, all examined as a function of time. The model is typically delineated into three principal phases:

- The Fluid Phase
- The Transitional Phase
- The Specific Phase

To ensure a thorough exploration and to construct a more cohesive narrative, each phase will be systematically deconstructed and analyzed independently. Each phase is marked by distinct characteristics and unfolds within different historical contexts. This approach will facilitate a deeper understanding of the present situation and elucidate the processes that have led to the current state of affairs, enabling a more nuanced and informed analysis.

2.1.1 The Fluid Phase

The initial fluid phase is marked by the invention of new technology, which remains in an immature state throughout all the duration of this period, undergoing numerous trial-and-error processes aimed at identifying the final set of characteristics that will later define the dominant design.

When applying this framework to the automotive industry, one can argue that the journey of what we now recognize as the modern car began in 1886 with Carl Benz's development of the first gasoline-powered automobile. This era also witnessed the advent of the first electric vehicles, as the electric motor had already been invented at the beginning of the 19th century.

As previously mentioned, this phase represents the industry's embryonic stage, where a dominant design has yet to emerge. During this period, numerous inventors and firms engage in experimentation with various propulsion systems and designs, each striving to discover the optimal configuration.

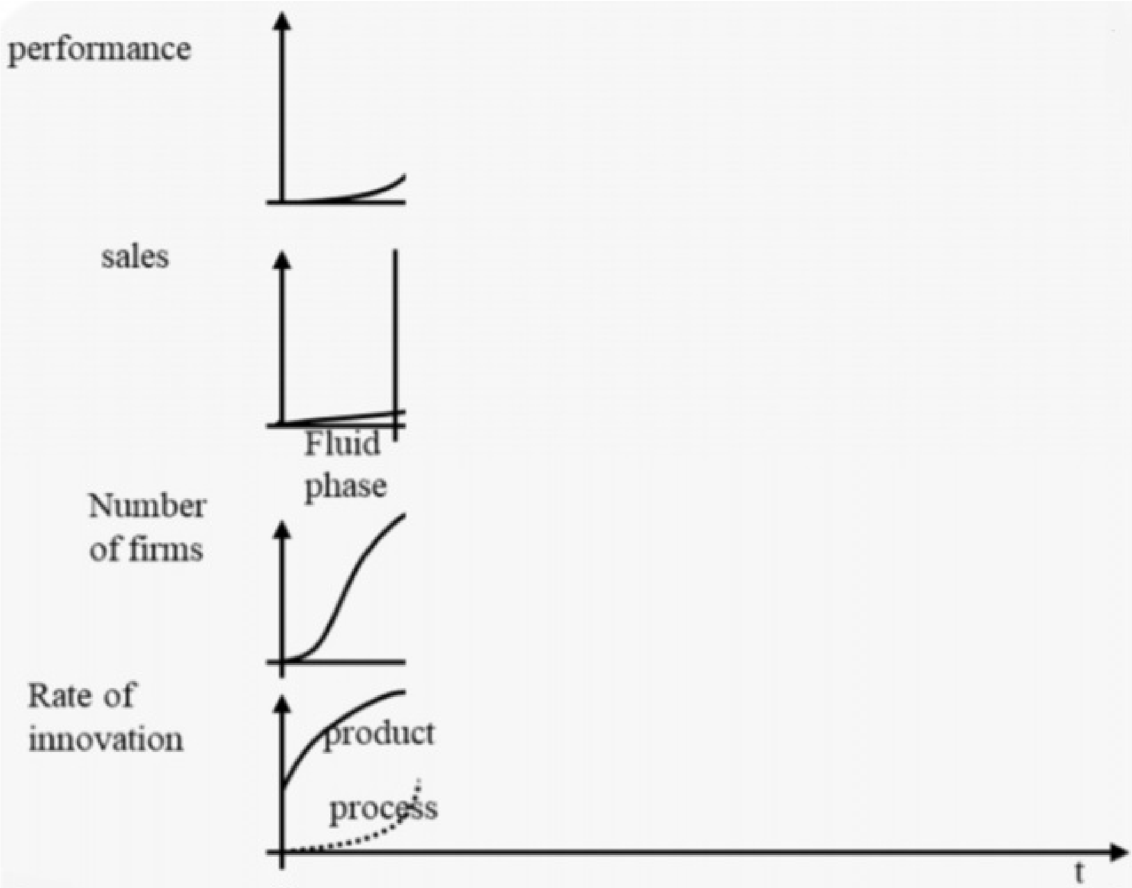


Figure 1: Fluid phase

As illustrated in the image above, the performance of the technology during this phase is notably sub-optimal, which is characteristic of its nascent state; it requires further refinement and development to reach maturity.

Consequently, sales remain minimal, as only a small number of vehicles are produced, precluding the achievement of economies of scale. These early automobiles are far from perfect and are not intended for the general public, being accessible only to technology fanatics or few selected wealthy individuals who acquire them as status symbols.

Conversely, the number of firms is relatively high due to the absence of a dominant design. This lack of a standard allows many entrants to participate in the nascent market, enticed by the relatively low barriers to entry and the promise of potential discovery and profit.

The rate of innovation follows a rising trajectory in both product and process development. However, this innovation is not uniform, nor does it result in substantial progress. Innovation occurs rapidly but along divergent paths, with firms experimenting with different solutions to achieve similar technological goals. This dispersion of efforts inhibits the formation of learning effects and impedes the sharing of

knowledge that might otherwise accelerate collective advancements.
During this period, the role of electrical and electronic components was minimal, as vehicles were largely mechanical. However, early electric systems began to appear, including basic lighting, ignition systems, and batteries. The appearance of these components in the early 20th century laid the groundwork for the more advanced Electrical/Electronic Architecture systems that would be developed in later decades. Although primitive by today's standards, the fluid phase saw also the development of early mechanical assistance systems. Devices such as mechanical odometers and early fuel indicators provided rudimentary information to drivers. These early innovations hinted at the potential for more advanced driver assistance technologies in the future.

2.1.2 The Transitional Phase

As the product becomes increasingly complex and functionally sophisticated, the industry enters the transitional phase. This phase is characterized by the gradual reduction of uncertainty as a dominant design begins to emerge. The establishment of this design leads to a shakeout in the number of firms, driven by the increasing need for capital to finance production facilities, labor and management, as well as to build sustainable business operations-challenges that not all firms can successfully navigate.
In the automotive industry, this phase coincides with the dominance of the internal combustion engine (ICE) vehicle and the decline of alternative propulsion systems. Simultaneously, the introduction of the assembly line by Henry Ford in 1908 marked a pivotal shift in production methods.
The emergence of a dominant design does not necessarily imply that the chosen technology is objectively superior. Rather, it reflects a selection process shaped by technical, economic, and sociopolitical factors. In the early 20th century, the internal combustion engine aligned more closely with the selection criteria of the time. Automobiles were still primarily luxury items for wealthy men, whose desires to display their affluence and masculinity found resonance in the loud and dynamic performance of the internal combustion engine.
Complementary assets also play a critical role in solidifying a dominant design. For example, the internal combustion engine required gasoline or diesel to function, both of which are produced by refining petroleum. The petroleum refining process also generates byproducts used to create asphalt, which in turn facilitated the construction of roads, thereby enhancing the circulation of vehicles within and between cities. This symbiotic relationship between internal combustion vehicles and as-

phalted roads reinforced the internal combustion engine's position as the dominant design. Improved road infrastructure, travel distances increased, the ease of refueling and greater storage capacity gave the internal combustion engine a decisive advantage over competing technologies.
In this competitive environment, the electric vehicle faltered. Its inability to cover long distances and the difficulty of recharging its battery made it a less viable alternative. The technology was simply not ready to compete, leading to the temporary disappearance of electric vehicles from the market.

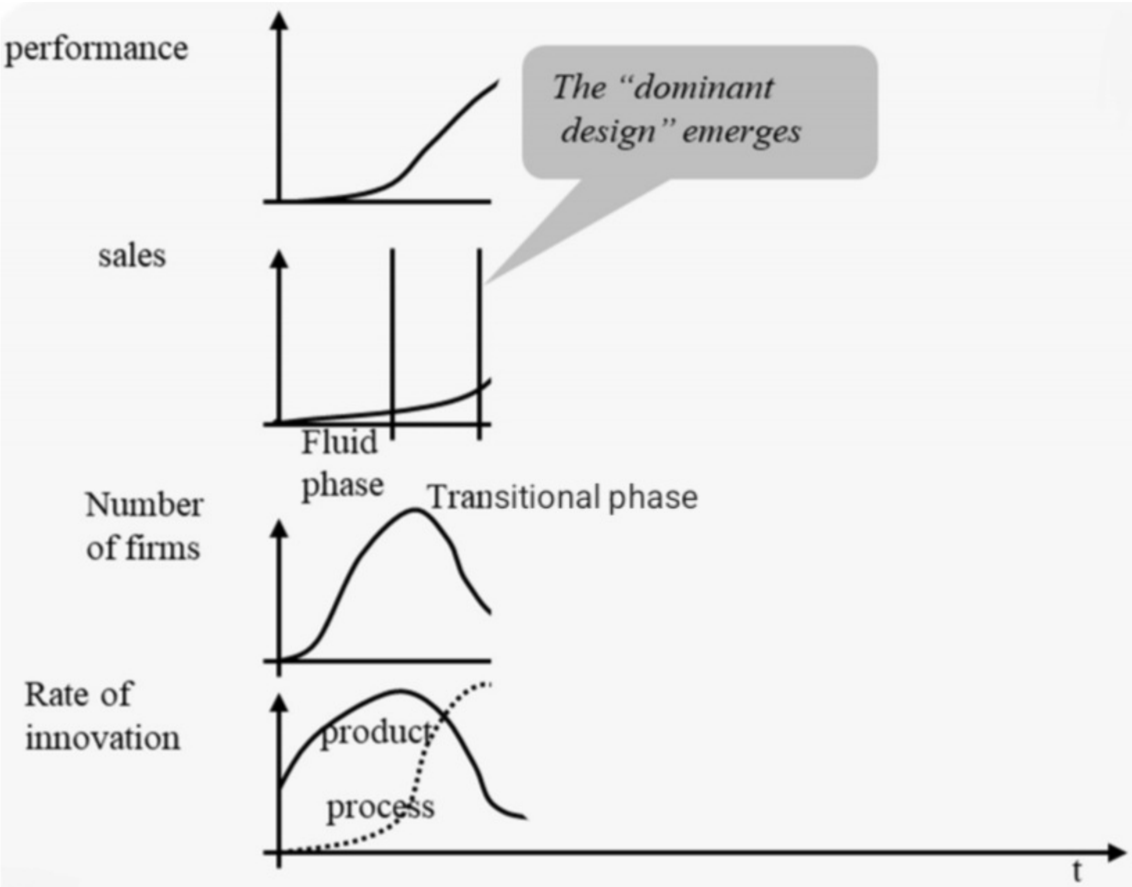


Figure 2: Transitional phase

As depicted in the image above, the transition from the fluid phase to the transitional phase is marked by significant changes in industry dynamics. The rise of the internal combustion engine as the dominant design enabled competitors to mimic each other, thereby initiating cumulative progress that significantly enhanced vehicle performance. Although these improvements made the automobile more attractive to consumers, as indicated by the gradual rise in sales, cars remained largely the preserve of wealthy individuals.
The establishment of the internal combustion engine initially forced firms specialized

in alternative propulsion systems either to withdraw from the market or to retreat into niche sectors. This first wave of firm reduction was followed by a further shake-out as surviving firms faced the challenge of raising capital to meet the growing demand created by their enlarged market share following the exit of competitors.
After an initial period of growth, the rate of innovation in product design began to decelerate. Firms increasingly focused their efforts on refining production processes rather than product innovation, anticipating a significant future increase in demand. This shift justified the investment in product-specific process technologies and equipment. It was during this time that Ford implemented the assembly line method, which organized production through sequential actions performed on a moving product via conveyor belt. This innovation significantly reduced production costs and culminated in the introduction of the Ford Model T in 1908. The Model T was the first vehicle affordable to the middle class, paving the way for the mass distribution of automobiles.
As the industry moved towards the transitional phase, the Electrical/Electronic Architecture began to play a more significant role in vehicle design. By the 1920s and 1930s, electrical systems were integrated into cars, enabling features such as electric starters, headlights, and radios. The development of 6-volt electrical systems marked a significant step towards the modernization of vehicles, allowing for greater convenience and reliability in operation.
This phase saw also the early development of safety and driver assistance technologies, though these were relatively rudimentary. For example, the first hydraulic brake systems were introduced in the 1920s, vastly improving vehicle safety. Other innovations included windshield wipers and turn signals, which improved driver visibility and communication.

2.1.3 The Specific Phase

Following the establishment of a dominant design, the consequent reduction in the number of firms, and the adoption of an optimal production process, the technology enters its final specific phase. This phase is characterized by a substantial increase in demand as the automobile industry transitions into the era of mass car distribution.

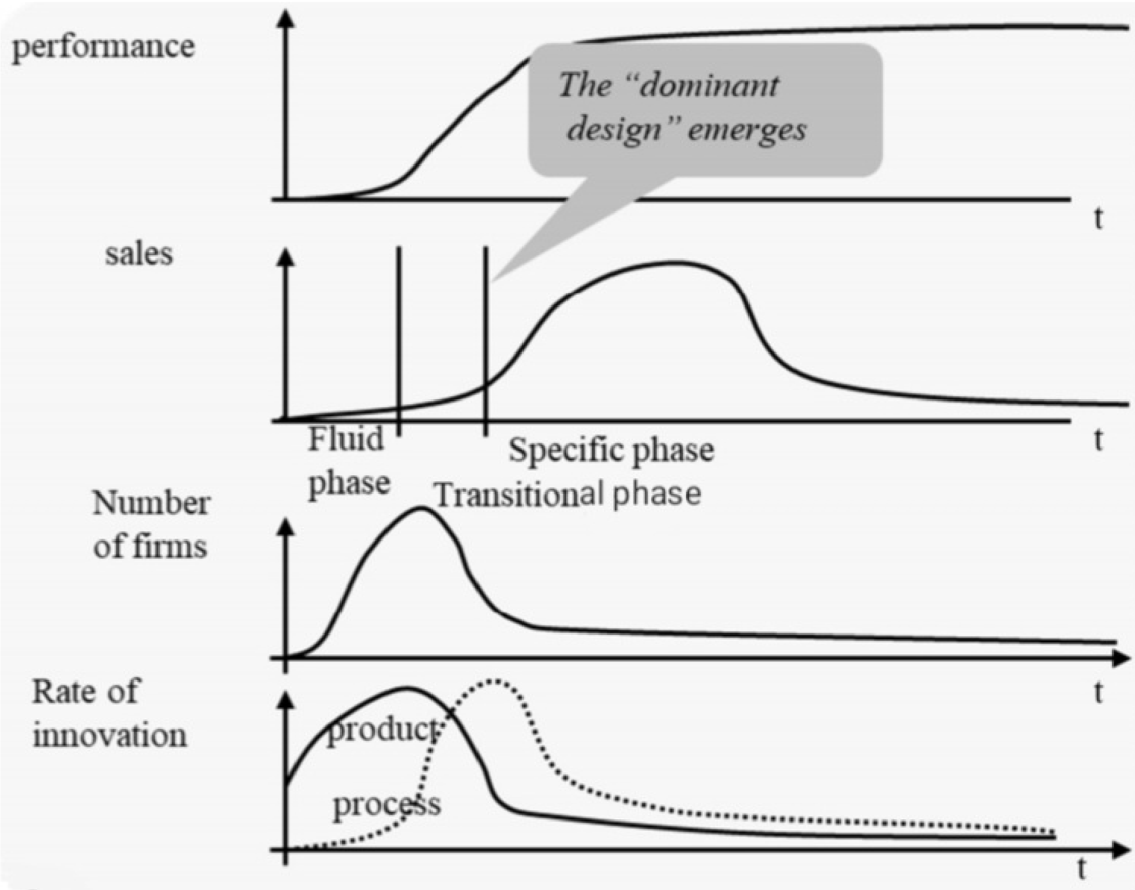


Figure 3: Specific phase

During this phase, vehicle performance, which experienced a steep rise during the transitional phase, continues to improve, albeit at a much slower rate. Performance stabilizes at a high level, as the gap between current capabilities and peak performance narrows. Further enhancements become increasingly difficult and yield diminishing returns, making additional improvements less economically viable.
With the onset of mass distribution to the middle and lower classes, the sales curve experiences a sharp and rapid increase. This period of growth persists until demand approaches saturation, at which point sales begin to decline, eventually stabilizing at a lower level as car ownership becomes widespread across the population.
The number of firms remains stable at a reduced level, similar to the outcome at the conclusion of the transitional phase. The firms that survived the earlier industry shakeout have already made substantial investments in both specific technologies and production processes, allowing them to achieve economies of scale. These economies, coupled with cumulative learning effects over time, enable firms to significantly lower production costs. As a result, the industry now operates under conditions of oligopoly.
Following the introduction of the assembly line method, the rate of innovation begins

to decline as firms universally recognize its potential and incorporate it into their operations. Process innovation becomes focused primarily on refining the existing method, resulting in a gradual deceleration of advancements until the rate of innovation stabilizes at a low level. Similarly, vehicle innovation follows the declining trend that began during the transitional phase, ultimately stabilizing at a reduced rate.

By 1960, vehicles were equipped with 12-volt electrical systems, which became the industry standard and enabled the addition of more powerful electronic components such as radios, air conditioning systems, and improved lighting. The role of Electrical/Electronic Architecture was now firmly established, though still in its infancy compared to today's standards. The focus remained in fact on enhancing convenience and reliability rather than on creating the sophisticated networked systems seen in modern vehicles.

Also advanced safety features began to emerge, signaling the beginnings of more sophisticated driver assistance systems. Features such as seat belts, padded dashboards, and early anti-lock braking systems (ABS) were introduced to improve driver safety. These developments were incremental, representing a growing awareness of vehicle safety, still far away however from today's assistance devices.

2.1.4 The Long Tail

The three phases of the Abernathy-Utterback model effectively account for the historical development of the automobile industry up until approximately 1960. However, it would be inaccurate to extend the specific phase beyond this period, as doing so would imply that the industry has reached persistently low levels in all the key metrics (performance, sales, number of firms and innovation rate) thereby rendering the industry unsustainable.

In particular, it is incorrect to assert that no innovation occurred between 1960 and the present. This can be readily disproven by examining the innovation rate over time, which reveals the emergence of an additional phase following the specific phase, commonly referred to as the "Long Tail".

This final phase of the industry's evolution is marked by a renewed upward trajectory in technological advancement, contradicting the notion of "dematurity" which states that the industry simply follows a repetitive product-process life cycle, with the beginning of a new cycle after the decline of the old one, which takes place at the end of the previously analyzed specific phase.

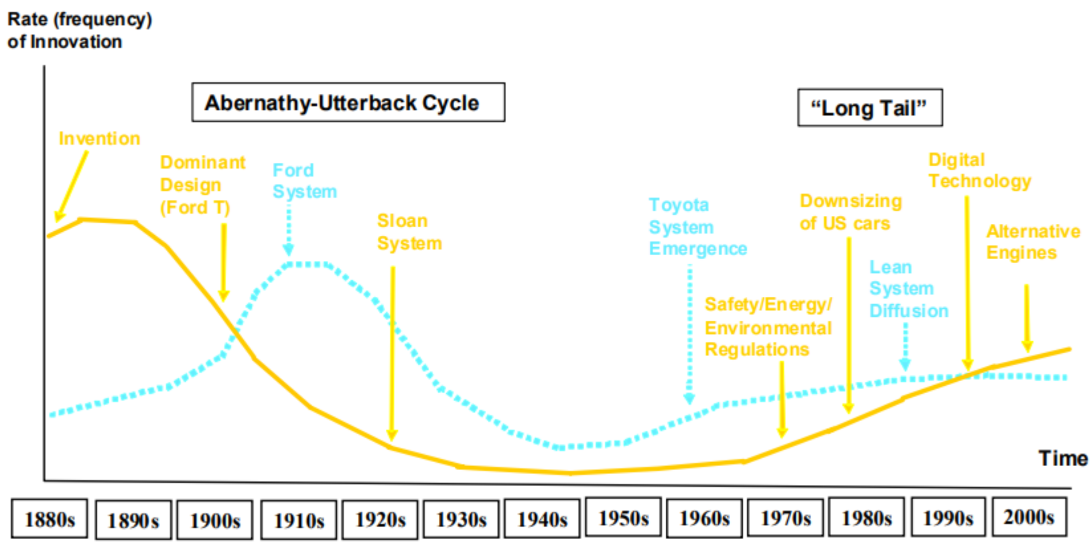


Figure 4: Long tail

As illustrated in the image above, the past 60 years (from 1960 to the present) have been characterized by rapid incremental innovation. During this period, product (yellow curve) and process (azure curve) innovations have not altered the fundamental architecture or structure of the vehicle. Instead, technological advancements have been evolutionary rather than revolutionary, enhancing existing functionalities and competitiveness without rendering previous products obsolete.

Technological development in the global automotive industry has been particularly active since the 1970s, driven by substantial investments in research and development, particularly in Europe, United States and Japan. While cars from 1960 and today may appear similar in terms of their fundamental architecture, exterior design and basic functionalities, vehicles have witnessed significant advancements in functional performances, comfort, safety, fuel efficiency and environmental awareness.

These advancements have been influenced by both sociological factors and remarkable technological progress, particularly in the electronics sector. A key milestone in the evolution of the automobile was the introduction of the Electronic Control Unit (ECU), an embedded system in automotive electronics that controls one or more electrical systems or subsystems within a vehicle. Since its implementation, the ECU has enabled substantial changes to vehicle architecture and structural components.

In terms of process innovation and manufacturing capability, significant evolution has occurred beyond the Ford system. While Ford's assembly line model was efficient and rapid, it proved to be inflexible and poorly suited to the complex and uncertain post-war environment. From 1960 onward, new manufacturing paradigms

emerged, with the Toyota Production System and the later lean manufacturing process becoming dominant. These systems prioritize flexibility and waste reduction, representing a significant departure from Ford's rigid model.
Innovation has also been driven by external factors. The exponential increase in car ownership and daily driving has resulted in an higher frequency of accidents, leading to significant annual fatalities on the road. As a result, passenger safety has become a priority, prompting governments to introduce stricter safety regulations and raising the baseline expectations for safety equipment among consumers. Additionally, growing environmental concerns and the recognition of finite fossil fuel reserves have brought alternative powertrains, such as the electric engine, back into prominence. This resurgence has been further supported by government pollution regulations, contributing to the current momentum of electric vehicle adoption.

2.2 Electrical/Electronic Architecture

With the recent surge in the integration of electric propulsion systems and the exponential advancement of electronic devices, particularly since the development of the Electronic Control Unit (ECU), innovation in modern vehicles is increasingly centered on electrical and electronic systems. Whereas the early automobile was primarily mechanical in nature, the initial introduction of simple electrical circuits to power lights and ignition systems has, particularly in recent decades, evolved into a highly complex and continuously advancing architecture that now governs nearly every aspect of vehicle functionality.
The Electrical/Electronic (E/E) Architecture is defined as the convergence of electronic hardware, network communications, software applications, and wiring into a unified system that controls an expanding range of vehicle functions. These functions encompass vehicle control, body and security, infotainment, active safety, and various comfort, convenience and connectivity features.

2.2.1 E/E Architecture key components and concepts

In order to better understand the analysis of the E/E Architecture that will follow, it is first necessary to delve into some key components and concepts that will be later used, in order to have a more comprehensive and critical view of the following exposed concepts.

Electronic Control Unit

ECUs are microcontroller-based embedded systems that monitor and control specific functions of the overall architecture, such as engine management, climate control, or safety systems. In modern architectures, a typical vehicle may have dozens of ECUs, each dedicated to particular tasks. These units communicate via the bus systems and play a critical role.

Communication Networks (Bus Systems)

Communication networks enable data exchange between different ECUs within the architecture. Common bus systems include Controller Area Network (CAN), Local Interconnect Network (LIN), and Ethernet. These networks allow for real-time communication, synchronization, and interoperability between sensors, actuators, and control systems. The choice of bus system depends on the required data transmission speed, reliability, and fault tolerance of the application.

Middleware

Middleware acts as an intermediary software layer that facilitates communication and data exchange between the application software and the underlying hardware or ECUs. It abstracts the complexities of the hardware architecture, enabling developers to design applications without needing to interact directly with hardware components. In automotive architectures, Automotive Open System Architecture (AUTOSAR) is a widely adopted middleware standard that provides scalability and modularity in software development.

Over the air updates

Over the Air (OTA) updates enable remote software upgrades and diagnostics for ECUs and other electronic components in a system, without the need for physical access. This is particularly valuable in automotive applications, where OTA capabilities allow manufacturers to introduce new features, patch security vulnerabilities, and fix software bugs without requiring vehicles to be taken to a service center. OTA updates are a key enabler of software-defined vehicles and connected systems, offering greater flexibility and lower maintenance costs.

Vehicle-to-Vehicle (V2V) communications

V2V communication allows vehicles to exchange real-time information such as speed, location, and direction with nearby vehicles. This peer-to-peer communication helps vehicles coordinate maneuvers like lane changes, overtaking, or merging into traffic, thereby reducing the risk of accidents. V2V is particularly important for collision avoidance, cooperative adaptive cruise control, and traffic flow optimization. It operates on dedicated short-range communication (DSRC) or cellular networks to ensure low latency and high reliability.

Vehicle-to-Infrastructure (V2I) communications

V2I communication connects vehicles with road infrastructure, such as traffic lights, road signs, and toll gates. By sharing data with infrastructure systems, vehicles can receive information about traffic signals, road conditions, speed limits, and potential hazards. For example, a traffic light can inform a vehicle about when it will change, allowing the vehicle to adjust its speed accordingly. V2I helps optimize traffic flow, reduce congestion, and enhance fuel efficiency by enabling smart traffic management systems.

Vehicle-to-Network (V2N) communications

V2N communication involves connecting vehicles to cellular networks and cloud-based services. Through V2N, vehicles can access real-time traffic data, weather updates, navigation services, and other cloud-based applications. V2N also facilitates the transmission of large volumes of data to and from vehicles, such as software updates, diagnostics, and infotainment content. This connectivity supports the growing trend toward autonomous and connected vehicles by enabling them to access and process vast amounts of external data.

Vehicle-to-Pedestrian (V2P) communications

V2P communication enhances safety by enabling vehicles to detect and communicate with pedestrians, cyclists, and other vulnerable road users who may not be easily visible to the driver or vehicle sensors. Pedestrians with smartphones or wearable devices equipped with V2X technology can send location and movement data to nearby vehicles, helping prevent accidents in busy urban environments. V2P communication is essential for future smart cities, where mixed road use by vehicles and pedestrians must be carefully managed.

Vehicle-to-Grid (V2G) communications

V2G communication connects electric vehicles (EVs) with the power grid, allowing bidirectional energy flow. Through V2G technology, EVs can not only charge from the grid but also discharge stored energy back to the grid during peak demand times. This supports grid stability, energy efficiency, and the integration of renewable energy sources. V2G is particularly important for energy management in smart cities, where the interaction between EVs and the grid can provide critical support to the electrical infrastructure.

Vehicle-to-Everything (V2X) communications

V2X communication is an advanced wireless technology that enables vehicles to communicate with each other, as well as with surrounding infrastructure, pedestrians, and networks. V2X forms the foundation for smart transportation systems and is crucial for the development of autonomous vehicles, enhancing road safety, traffic efficiency, and energy management. V2X encompasses several key subcategories, each of which plays a specific role in enabling this ecosystem.

2.2.2 Different types of E/E Architecture

Following the analysis of these key concepts and components, attention will now be directed toward examining how these components interact to form different types of architectures. Each architecture exhibits unique characteristics, advantages, and limitations, rendering them more or less suitable depending on the specific requirements and challenges of vehicle design and automotive industry.
Currently, three primary types of E/E Architectures can be distinguished:

- Distributed Architecture
- Domain-Centralized Architecture
- Zonal Architecture

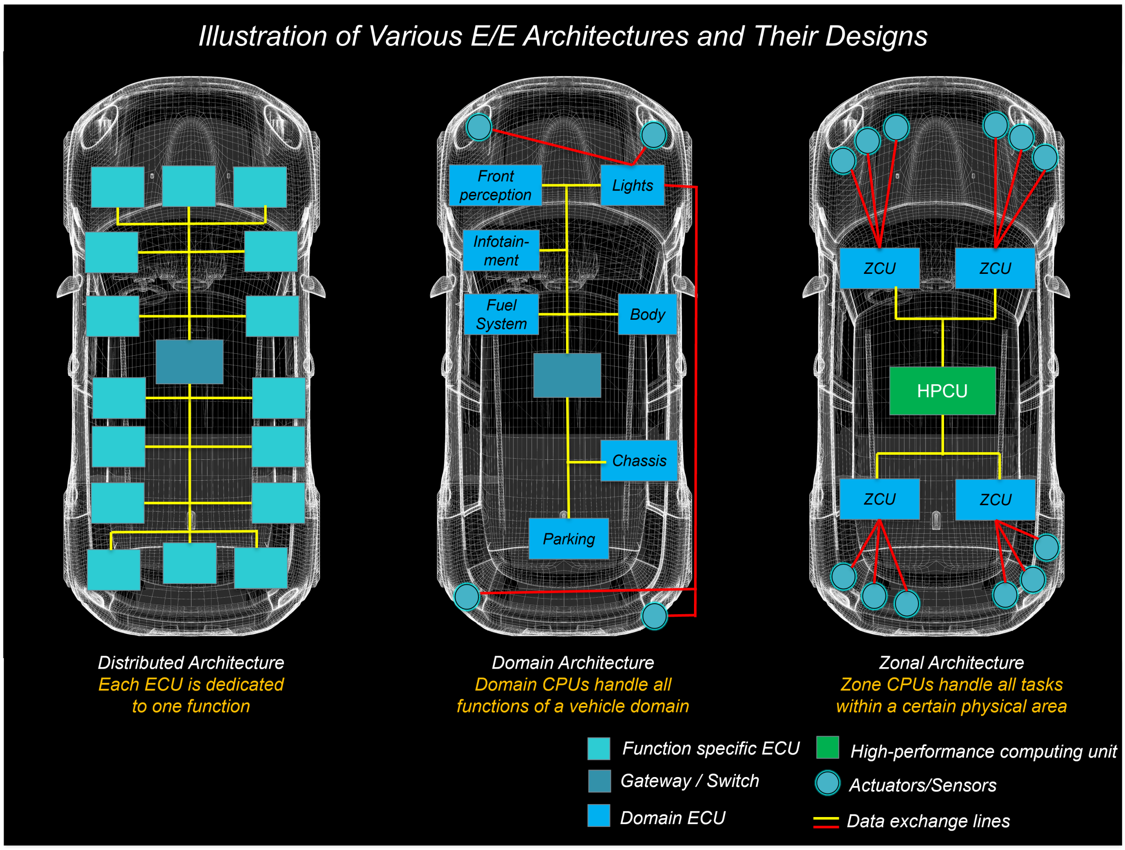


Figure 5: Types of E/E Architectures

Distributed Architecture

Distributed architecture represents one of the earliest configurations of E/E Architecture, in which individual Electronic Control Units (ECUs) are dedicated to managing specific functions within the vehicle. Each ECU operates autonomously, handling distinct basic tasks, and is connected to other ECUs and a central gateway via simple bus systems such as the Controller Area Network (CAN) or the Local Interconnect Network (LIN). The connection to the central gateway facilitates greater collaboration among ECUs and enables cross-functional interactions, thereby supporting more complex operations.
This architecture proved itself to be effective in earlier vehicles, which featured relatively fewer electronic systems and had lower performance requirements. However, as the number of ECUs increased and the communication speed between them became more critical, the distributed architecture began to experience limitations. Its complex wiring network and slower communication speed between ECUs eventually became obstacles to further progress.

Domain-Centralized Architecture

In response to these pressing issues, the next evolutionary step involved the development of domain-centralized architecture. In this architecture, control units are no longer entirely independent; instead, function-specific ECUs are grouped together under domain-specific ECUs and are interconnected via CAN and Ethernet, with all domain-specific ECUs then connected to a central gateway.
This architecture offers enhanced efficiency, allowing for faster communication between systems and enabling more advanced functions. It also provides cost reductions through the consolidation of functions. However, as technology continues to evolve, domain-centralized architecture is becoming increasingly strained by the growing complexity and space consumption of its wiring network.

Zonal Architecture

The growing number and complexity of connections highlighted the need for a paradigm shift, which is happening with the introduction of zonal architecture. Unlike the previous designs, which focused on functional areas, zonal architecture organizes the vehicle based on geographic regions. This approach divides the vehicle into distinct zones, each containing localized ECUs, sensors, and actuators, all managed by a zone-specific controller called zonal ECU. These zonal ECUs are then connected to a central High-Performance Computing Unit (HPCU) via Ethernet.
The primary advantages of zonal architecture lie in its flexibility and modularity. It is highly scalable across different vehicle models or platforms due to the independent control of each zone, and it allows for reduced wiring volume and more efficient wire organization. However, challenges remain in the form of real-time data processing and the complex synchronization required among zonal ECUs for effective implementation of this design.

2.2.3 The future of E/E Architecture

After an initial period of relative stability in the progression of E/E Architecture, recent years have witnessed a surge of exponential innovation. This growth has been driven by both advancements in electrical and electronic technologies and other forces shaped by the evolving needs of vehicles and society as a whole.
One of the primary catalysts for this innovation is vehicle electrification, which has introduced new complexities in managing electric powertrains and increasingly sophisticated electrical components. Alongside this, the need for greater interconnection between a rising number of ECUs, the demand for enhanced performance in

areas such as braking and stability, and the necessity for weight and cost reduction have further propelled the development of E/E Architectures.
Stricter regulations concerning vehicle safety and emissions have also forced automakers to adapt their architectures to meet new standards. Environmental regulations, driven by growing concern about pollution, have led to the adoption of more efficient powertrain management systems and emissions control devices. Simultaneously, safety regulations have prompted widespread implementation of new safety devices and more advanced measures to address the increasing number of accidents and fatalities on the road. Additionally, the growing trend of vehicle connectivity has raised privacy and cybersecurity concerns, requiring strong encryption and secure communication protocols to guard against hacking and data breaches within the architecture and forcing governments to implement personal data management regulations.
Another significant driver of innovation is the rising consumer demand for infotainment and comfort features. High-definition displays, voice recognition, internet access and seamless integration with smartphones and digital assistants have become standard features in modern vehicles, while comfort elements such as adaptive climate control, customizable seating configurations, and advanced lighting systems are increasingly expected by consumers. These features, following the logic behind Kano's model, were previously considered "delighters" but are now always more perceived as "qualifiers" in contemporary vehicles, compelling automakers to develop new E/E Architecture solutions capable of supporting sophisticated user interfaces, high-speed data transmission, and multiple simultaneous digital functions, all while maintaining high levels of responsiveness and reliability.
While current E/E Architectures are able to address many of these evolving demands, the trends themselves are continually advancing, guiding the push for new architectural concepts. The looming challenge of autonomous driving is particularly significant in this sense, as it will likely require more radical innovations, moving beyond the incremental changes seen in previous E/E Architecture evolutions.
At present, two primary visions dominate discussions about the future of E/E Architectures:

- Centralized Architecture
- Service Oriented Architecture

Centralized Architecture

The centralized architecture model represents an incremental innovation, building upon the types of architectures discussed previously. It follows the trend of consolidating control within fewer components and simplifying the communication network between them. In this design, a single, powerful computer is responsible for managing all of the vehicle's functions.

This approach dramatically reduces the complexity of the vehicle's internal systems, simplifying the hardware and allowing for faster data processing, which in turn enables more sophisticated solutions. However, despite its appeal in the near future, the centralized design may present long-term challenges. The central computer must be extremely powerful to handle the vehicle's entire data load and, because it is the sole data processing unit, any failure, malfunction, or security breach could compromise the entire vehicle's functionality.

Furthermore, this architecture still relies on internal data processing within the vehicle, which is beginning to show limitations due to the growing need for continuous software updates, real-time data processing, and greater connectivity with the external environment.

Service-Oriented Architecture

A more radical innovation is found in service-oriented architecture, which marks a significant departure from the previously discussed models. This shift is made possible by decoupling hardware from software, transitioning from traditional hardware-based vehicle control toward software-defined functions and services.

In the service-oriented architecture, instead of relying on fixed ECUs, the vehicle's functions are governed by software services distributed across various computational nodes. These services can be accessed on-demand based on the vehicle's needs and can even connect to cloud-based platforms for additional processing power. This design allows the vehicle to everything connection (V2X), collecting real-time operational data from the environment and sending it to the cloud. With this data, features and services can be continuously updated and enhanced through over-the-air updates, enabling new functionalities to be added without requiring any physical modifications to the vehicle.

Service-oriented architecture offers several advantages, particularly in the context of autonomous driving, where real-time data processing, flexibility and connectivity are essential. However, the complexity of software management and coordination increases significantly with this model, and new challenges arise in terms of cyber-

security and privacy due to the elevated degree of connectivity and communication between services.
Service-oriented architecture can be seen as the logical evolution of five key mobility trends: software and services, personalization, automated driving, connectivity, and electrification. These forces are driving the push for more sophisticated E/E Architectures, which in turn enable the implementation of increasingly complex systems to assist drivers and enhance their driving experiences. One of the most significant beneficiaries of this evolution are the Advanced Driver Assistance Systems (ADAS), which rely on the E/E Architecture to integrate their technologies, composed by the likes of sensors, cameras and actuators, into the vehicle, enabling continuous growth and evolution as new components are continuously added to the ADAS already wide catalog.

2.3 Advanced Driver Assistance Systems

Advanced Driver Assistance Systems (ADAS) represent one of the most significant advancements in modern automotive technology. These systems have been designed to enhance vehicle safety and improve the driving experience by using sensors, cameras, radar and sophisticated algorithms to monitor and assist drivers in making safer decisions on the road.
ADAS equipment enables automation in the vehicle, allowing a level 1 to 2 of autonomous driving in the Society Automotive Engineers (SAE) classification. These two levels enable low or partial automation, but the goal is to advance as soon as possible to level 3, as we already are taking the first steps towards conditional automation. Level 4 and 5 represent instead an even further degree of automation, with level 5 (full automation) being represented ideally by the autonomous vehicle.

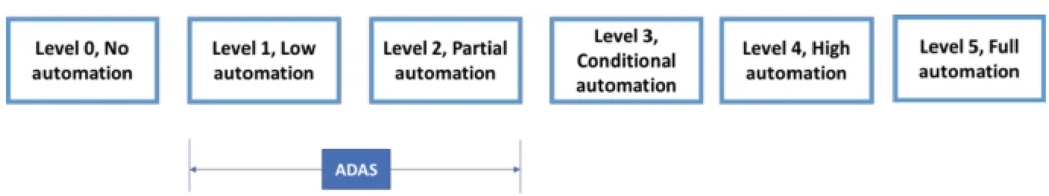


Figure 6: Levels of autonomous driving as per the SAE classification

2.3.1 ADAS technologies

In order to guarantee a partial automation, ADAS can count on various technologies in its array each of them fulfilling a different role, but all working in synergy, with the E/E Architecture assuring a connection between them, assisting in this way the driver and improving its driving experience.

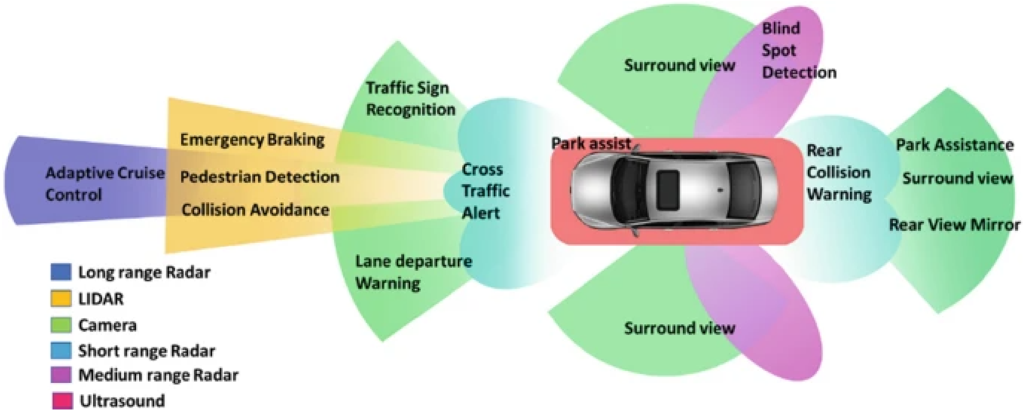


Figure 7: Overview of ADAS technologies used in a vehicle

The image depicts a comprehensive overview of the ADAS main components integrated into a modern vehicle and the technologies they use and are based on in order to fulfill their role.

Radars

Radars emit radio waves that travel through space, reflect off objects, and return to the radar sensor. By measuring the time it takes for the waves to return and their frequency shift (Doppler effect), radar systems can calculate the distance, speed, and direction of moving objects.

Short range radars are in charge of the detection of nearby objects. On this technology are based components like radar collision warning, which offers support in low speed maneuvers detecting objects in the rear of the vehicle, as well as the cross traffic alert, which helps in the detection of approaching vehicles, mainly from the front, when entering a new route or exiting a parking spot.

Medium range radars follow the same logic behind the functioning of short ones, but with an enlarged detection range. Thanks to this, blind spot detection can be enabled, allowing a clearer vision of adjacent lanes and rear of the vehicle, enabling for example in this way a safer lane change.

Long range radars extend even further their reach allowing them to monitor the distance from the vehicle ahead. On this concept is based the adaptive cruise control, which adjusts the vehicle's speed accordingly in order to always maintain the same distance from the vehicle ahead, allowing semi-autonomous driving.

LIDAR

LIDAR (Light Detection and Ranging) uses laser pulses to create detailed, three-dimensional maps of the environment. The sensor emits light pulses (usually in the near-infrared spectrum), which bounce off objects and return to the sensor. By calculating the time it takes for the light to return (Time of Flight), LIDAR can accurately measure distances and create a point cloud 3D representation of the surroundings.
Thanks to this, critical safety measures can be enabled like emergency breaking, pedestrian avoidance and collision avoidance, all of which can operate the vehicle autonomously in case of emergencies to avoid crashes or car accidents.

Cameras

Cameras capture images of the vehicle's surroundings by detecting visible light, similar to how the human eye works. ADAS cameras use digital sensors to convert light into electrical signals that can be processed by the vehicle's onboard computer for object detection, classification and tracking.
Cameras are positioned around all the vehicle, enabling a total cover of the surroundings. In the front are present lane departure warning cameras, which monitor lane markings and detect unintended lane drifts issuing warnings to the driver to take corrective actions, and traffic sign recognition cameras, which are in charge of capture images of traffic signs and provide real-time information to the driver or vehicle system. On the sides are present the surrounding view cameras which enables a 360° view of the surroundings for safer parking and maneuvering, work facilitated also by cameras on the rear of the vehicle like the park assistance and rear-view mirror ones.

Ultrasounds

Ultrasonic sensors emit high-frequency sound waves that bounce off nearby objects and return to the sensor. By calculating the time it takes for the sound waves to return the system can measure the distance to nearby objects.
The main user of this technology is the park assist, which thanks to the very close range and precise object detection provided by ultrasounds is able to guide the driver in slow speed actions that need to be accurate, like parking.

All these ADAS systems and technologies are basically classified into information-based assistance systems and manipulation-based assistance systems.

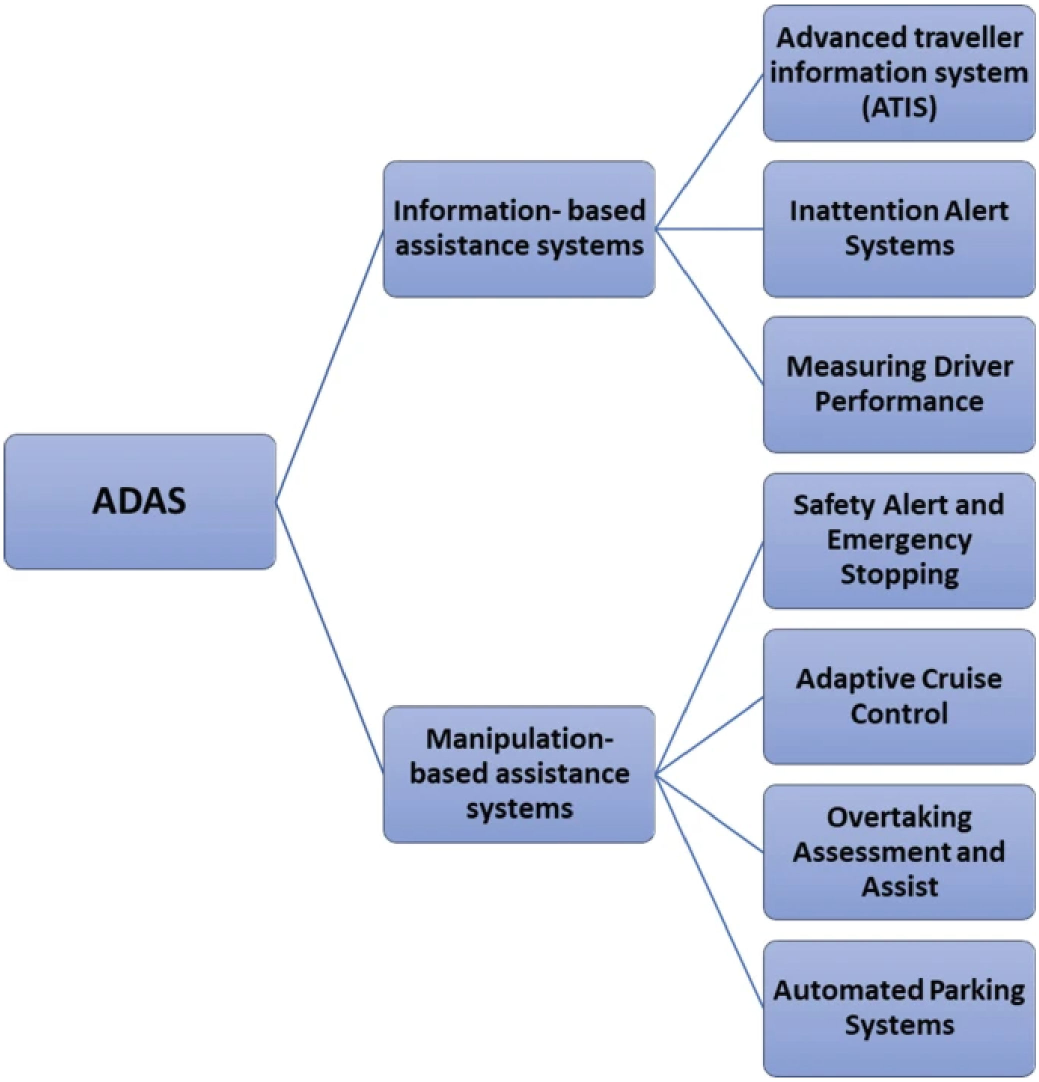


Figure 8: Classification of ADAS technologies

Information-Based Assistance Systems

Information-based assistance systems provide the human driver only with necessary information and warnings, while they don't implement any driving decisions and don't physically operate the vehicle.
During driving, the driver has to face many decisions like which route to take, traffic levels and manage delays, in this field operates the Advanced Traveler Information System (ATIS), which performs functions like dynamic rerouting, anticipation of traffic congestion and provides information about the surroundings. The data for dynamic and historical information about the traffic is made available with the help

of cameras and sensors, such information is used to anticipate congestion and find a better route. These information help the driver making choices, lightening his decision work and allowing him to focus on driving.
Even so, the attention level of the driver could always lower, is in fact important to implement Inattention Alert Systems in order to ensure the concentration of the driver that could come less for causes like sleepiness, tiredness, and distractions due to external factors, possibly caused even by other ADAS technologies. In this category falls the Driver Monitoring System, which will be later analyzed more in depth.
Also the measurement of the driver's performance is important. It could be used by the transportation authority to monitor imprudent drivers and to potentially cancel their driver license. The systems for measuring driver performance are built inside the vehicle to continuously rate the driver. The best ways to indicate the driver's performance are by assessing the distance of the vehicle in front, taking into account fluctuations in speed, and analyzing the ability to make smooth lane changes and to maintain the lanes. Other parameters that can be used to measure the drivers' conditions are the way of handling the steering wheel, the reversal speeds of steering, and the pressure distribution on their seat. All these parameters are helpful also in detecting fatigue and drowsiness of the driver.

Manipulation-Based Assistance Systems

Manipulation-based assistance systems not only detect the state or risk involved in driving but also manipulate the vehicle on behalf of the driver, reaching an higher level of automation. These systems can intervene to perform basic and regular tasks which do not require human wisdom, like maintaining a constant speed of the vehicle, performing particular tasks that human could find difficult for their elevated required precision, as parking in a narrow space, and when emergency actions are needed and there is no time to warn the driver, like stopping immediately the vehicle to avoid a potential crash.

2.3.2 Evolution and future of ADAS

ADAS mark a major breakthrough in automotive technology. These systems utilize an intricate web of sensors such as radars, LIDAR, cameras and ultrasonic detectors, combined with complex algorithms to boost vehicle safety, efficiency and the overall driving experience. By supporting drivers with routine tasks, while also helping to reduce human errors, the leading cause of accidents, ADAS technologies contribute

creating safer driving conditions. Additionally, they play a key role in the automotive industry's slow but steady shift towards fully autonomous vehicles, pushing forward automation in modern cars.
Several factors are contributing to the ongoing development of ADAS, such as technological advancements, regulatory pressures, increasing consumer demand for safety and convenience, and the industry's continuous strive towards achieving higher levels of vehicle automation.
The rapid progression of sensor technology, along with innovations in machine learning and artificial intelligence, has been crucial in enabling vehicles to handle complex environmental data in real-time. This allows them to make calculated decisions that significantly improve safety and driving comfort.
Furthermore, government regulations had a significant impact on the spread of ADAS technology. In various regions, including Europe and United States, strict safety standards have been introduced. These regulations encourage the inclusion of essential safety features, like automatic emergency braking and lane-keeping systems, as standard in new models. Simultaneously, consumers have become increasingly aware of how ADAS can reduce driving-related stress and enhance road safety. This growing consumer consciousness has influenced market trends, turning ADAS into a major selling point for manufacturers and spurring further innovation.
Moreover, the automotive industry's focus on achieving autonomous driving has been a crucial driver behind ADAS advancements. Although fully autonomous vehicles (classified as Level 5) are still in the experimental stages, the current ADAS systems represent key milestones towards this goal by offering higher levels of automation, particularly Levels 2 and 3. The pursuit of full autonomy has pushed manufacturers and tech companies to continually refine and enhance ADAS, moving step by step towards creating vehicles that can operate with little to no human involvement in increasingly complex environments.
In the coming years, ADAS is expected to evolve toward even greater sophistication and automation. As vehicles advance from partial automation (Level 2) to conditional (Level 3) and even higher automation (Level 4), these systems will become ever more deeply integrated, thanks also to more complex E/E Architectures which will enable this, with other vehicle technologies including real-time data processing, mapping, and vehicle-to-everything (V2X) communication. This interconnection will enable vehicles to not only communicate with each other but also interact with their surroundings, from infrastructure to pedestrians, fostering safer and more efficient transportation networks. Additionally, as artificial intelligence becomes more adept at handling large amounts of sensor data, future ADAS technologies will de-

liver more personalized driving experiences, adapting to individual preferences while maintaining the highest safety standards.
However, like in most cases, advancing innovation finds on its path various challenges and obstacles that needs to overcome in order to affirm itself. The main ones, beyond the problem of the technology complexity level needed to implement an higher level of automation not yet reached by the current knowledge, are the rising concerns regarding privacy and cyber security regulations, which are due to the inevitable higher degree of connectivity and customization required by customers and automation. These drivers of innovation, to be implemented at best, necessitate personal data analysis and storage, very delicate topics to be treated carefully. The problems of privacy and cyber security are arising not only in the automotive industry, but are a central node that all humanity is facing right now, for this reason there will be a later section dedicated, where the thematic of interest to this case regarding these topics will be discussed more in depth.
As cars grow increasingly connected and automated, the role of ADAS will continue to expand, empowering drivers with greater control while minimizing human error. However, while these systems reduce the need for direct driver intervention, they introduce a new set of challenges, particularly around ensuring that drivers stay alert and ready to take over when necessary. This new set of challenges highlights the importance of advanced Driver Monitoring Systems (DMS), which must work in tandem with ADAS, especially in situations where drivers may become overly reliant on automation, to ensure road safety.

Chapter 3

Driver Monitoring System

Driver Monitoring Systems (DMS) play a crucial role in addressing the challenges introduced by growing vehicle automation. As drivers become more reliant on ADAS, maintaining driver engagement and situational awareness becomes increasingly important. DMS are designed to ensure that drivers remain attentive and ready to take control when needed, acting as a safeguard especially but not only in highly automated environments.

These systems utilize a combination of cameras, sensors, and AI to continuously monitor the driver's state, tracking their eye movements, head position, and even physiological indicators of fatigue or distraction.

By integrating with ADAS, DMS can create a more dynamic and adaptive driving environment. For example, if DMS detect signs of drowsiness or inattention, it can alert the driver, initiate warnings, or adjust the ADAS systems to reduce speed or hand back control of the vehicle. In more advanced scenarios, the collaboration between DMS and ADAS allows for seamless transitions between automated driving modes and manual control, ensuring that the driver is always in the right state to take over.

This integration not only improves safety but also enhances the effectiveness of ADAS features. The combined use of DMS and ADAS ensures that while automation supports the driving process, the driver remains engaged and alert, creating a balance between human control and machine assistance. This synergy is particularly important as vehicles move towards higher levels of autonomy, where the interaction between human drivers and automated systems must be carefully managed to ensure both trust and safety on the road, guaranteeing that the driver is optimally engaged and ready to take over when necessary.

Since ADAS systems essentially control in fact a good amount of aspects of vehicle motion during driving, it is possible for drivers to become distracted or disengaged regardless of intent. The Yerkes-Dodson law describes an inverted U-shape relationship between stimulation and cognitive performance.

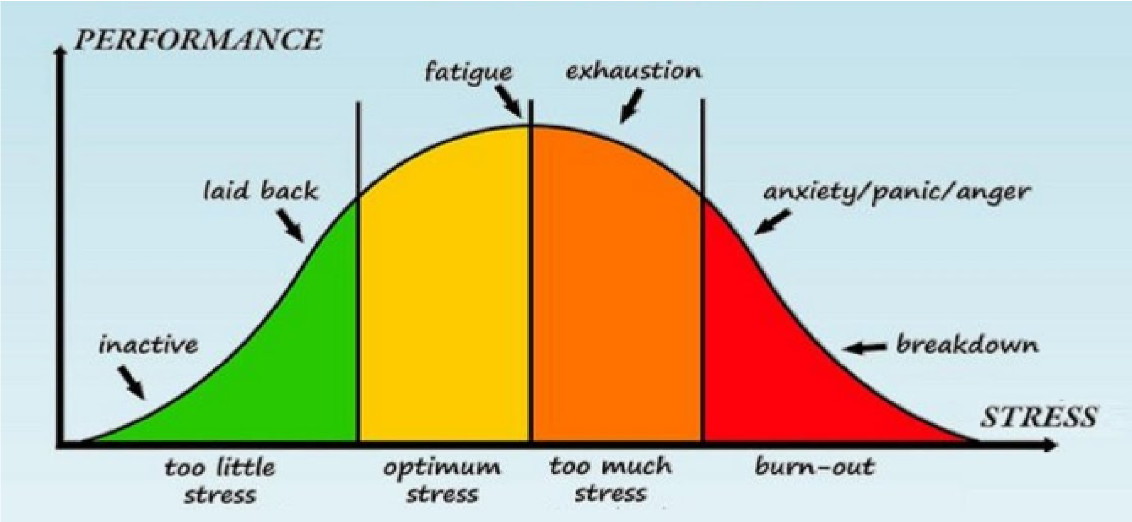


Figure 9: Yarkes-Dodson curve

Specifically, performance will decline when stimulation is either too low or too high in relation to the particular type of task. For a relatively complex task such as driving, performance gradually improves with stimulation, such as interacting with the surrounding environment up to a point, after which, performance declines.

3.1 Causes and effects of driver disengagement

In addition to driver distraction, also driver fatigue is a major factor in on-road accidents, causing combined nearly 25% of all the crashes or near-crashes events concerning motor-vehicles. Both fatigue and distraction can be generalized under the term of 'inattention', which refers to a state in which a driver's focus is diverted away from the primary task of operating a vehicle, leading to a reduction in their ability to perceive, react to, and safely respond to changes in the driving environment, compromising safety driving and increasing risk of accidents.

3.1.1 Driver distraction

With the concept of 'driver distraction' is indicated any external factor which diverts the driver attention from the road and his main tasks of driving and monitoring the vehicle. Many types of distraction exist and can alter the driver's focus, the National Highway Traffic Safety Administration (NHTSA) distinguish between:

- Visual Distraction
- Cognitive Distraction
- Auditory Distraction
- Bio-mechanical Distraction

Visual Distraction

Visual distraction occurs when a driver's attention is diverted away from the road, focusing his eyes on something other than the driving environment. This could happen when a driver looks at a mobile phone screen to read or send a message, interacts with in-car systems like navigation or infotainment, or becomes preoccupied with outside distractions such as billboards or roadside advertisements. Even turning to engage with passengers or looking around searching for items inside the vehicle can momentarily draw the driver's gaze away from the road, reducing their ability to react to potential hazards. Such distractions compromise safety by limiting the driver's situational awareness and increasing the likelihood of accidents.

Cognitive Distraction

Cognitive distraction happens instead when a driver's mind is focused on something other than the task of driving, even though their eyes may still be on the road. This type of distraction can arise when a driver is mentally preoccupied with personal thoughts, conversations, or stress. For instance, engaging in a deep conversation with a passenger or over the phone can shift the driver's attention away from driving. Similarly, daydreaming, planning, or thinking about non-driving-related matters can impair the driver's ability to process information from the driving environment. Although a driver's hands and eyes may be engaged with the vehicle, cognitive distraction also significantly diminishes his capacity to react to changing road conditions or potential dangers.

Auditory Distraction

Auditory distraction occurs when a driver's attention is diverted by sounds that are unrelated to driving, causing them to lose focus on the road. This can happen when the driver is listening to loud music, a podcast, or a conversation that takes their mind off driving. Sudden or unexpected noises, such as a ringing phone, a crying child, or sirens from emergency vehicles, can also pull the driver's focus away from their surroundings. Also in this case, even though his hands and eyes remain on task, auditory distractions can impair the driver's ability to concentrate and react to important auditory cues coming from the driving environment, such as honking horns or warning signals.

Bio-mechanical Distraction

Bio-mechanical distraction occurs when a driver's hands or body are engaged in physical activities unrelated to driving, leading to a temporary loss of control or focus on operating the vehicle. This might happen when the driver reaches for something inside the car, such as adjusting controls, eating, drinking, or picking up a dropped item. Other examples include manipulating devices like phones or adjusting clothing. Although the driver's eyes may remain on the road, bio-mechanical distraction compromises his ability to maintain proper vehicle control, as hands or posture are not fully engaged in driving tasks, increasing the risk of accidents.

3.1.2 Driver fatigue

The term 'driver fatigue' comprehends instead a combination of symptoms such as impaired performance and a subjective feeling of drowsiness. As seen for distraction, also fatigue can cause driver disengagement and consequentially create potential dangers on the road for the people inside and outside the vehicle. Fatigue can affect various systems and organs of the body, causing different types of fatigue, each of them affecting the driver in different ways.
We can distinguish mainly between:

- Local physical fatigue
- General physical fatigue
- Central nervous fatigue
- Mental fatigue

Physical fatigue

Physical fatigue, in the context of driving, refers to a decline in the driver's physical ability to maintain control over the vehicle due to muscle exhaustion or prolonged physical strain. It can be categorized into local and general fatigue, both of which impact driving performance differently.

Local fatigue occurs when specific muscle groups become exhausted due to repetitive movements or sustained postures. For instance, drivers may experience localized fatigue in their arms, neck, or back during long periods of steering, or from maintaining the same seated position for extended duration. This type of fatigue can lead to discomfort and a reduction in motor coordination, potentially impairing the driver's ability to operate the vehicle effectively. It can affect also ocular muscles due to extended periods of visual concentration caused for example by prolonged driving. When the ocular muscles become fatigued, individuals may experience symptoms such as blurred vision, difficulty focusing, eye soreness, and an increased effort to maintain clear vision. These symptoms can impair visual tracking and depth perception, making it more challenging for the eyes to quickly adjust to changes in the environment. Being the eyes a fundamental instrument for driving, the downgrade of ocular performances affects directly the driver performances, causing a reduction in the driver's ability to scan the road effectively, leading to delayed recognition of hazards, signs, or other vehicles, diminishing also safety for all people on the road.

In contrast, general fatigue affects the entire body, often as a result of overall physical exertion, prolonged driving sessions, or lack of sleep. This widespread tiredness can reduce reaction times, lower alertness, and impair decision-making abilities. When a driver is generally fatigued, their ability to remain focused and responsive to road conditions diminishes significantly, increasing the likelihood of errors or accidents.

Both forms of physical fatigue present serious risks to road safety by reducing the driver's capacity to maintain control and awareness over the vehicle and the surrounding environment.

Central nervous fatigue

Central nervous fatigue refers to a reduction in the capacity of the central nervous system to effectively activate and coordinate body functions through neurological terminations, resulting in decreased physical performance and cognitive efficiency. This type of fatigue originates from the brain and spinal cord, where prolonged or intense mental and physical exertion leads to a diminished ability to generate motor signals, impeding voluntary muscle activation and overall endurance. Central

nervous fatigue also affects cognitive processes, such as attention, decision-making, and reaction times.
In driving, central nervous fatigue can manifest through a gradual decline in alertness, slower reaction times, and impaired decision-making, as the brain struggles to maintain focus and respond to stimuli. For example, after hours of continuous driving, a driver may find it increasingly difficult to stay mentally engaged with the task, resulting in delayed responses to traffic signals, slower hazard recognition, or a diminished capacity to maintain consistent control of the vehicle. This form of fatigue poses significant risks to safety, as it compromises both the driver's physical abilities and cognitive functions necessary for an effective driving performance.

Mental fatigue

Mental fatigue is a state of cognitive exhaustion that arises from prolonged periods of intense mental activity or sustained attention, leading to a decline in cognitive performance and the ability to process information efficiently. It is characterized by reduced focus, impaired decision-making, slower reaction times, and difficulty maintaining attention on tasks. Mental fatigue often develops when the brain is subjected to continuous demands for concentration or problem-solving, without sufficient rest or recovery, which can lead to a state of not having the mental energy to do anything.
In the context of driving, mental fatigue can manifest as diminished alertness and slower reactions to changes in traffic or road conditions. For example, after long hours behind the wheel, a driver may find it challenging to stay focused on the road, resulting in delayed responses to signals or unexpected hazards. Additionally, mental fatigue may lead to lapses in judgment or an inability to assess complex driving situations accurately, increasing the likelihood of errors or accidents.

The two latter types of fatigue can be considered as the most dangerous to driving because both can lead to sleepiness, one of the main and most dangerous causes of accidents. It is important to specify that sleepiness is subjective, and different factors can influence and enhance this condition at different levels for different people. Some of these factors can be disturbed sleep, low point in the circadian rhythm, and hard work prior to driving, with the sleepy condition being more accentuated during late evening and night periods, times in which the body and brain are tired for the daily activities, diminishing in this way concentration, which instead should be augmented due to the poor light conditions.
Different level of distraction caused by sleepiness exist, and are categorized through

the Karolinska Sleepiness Scale (KSS)

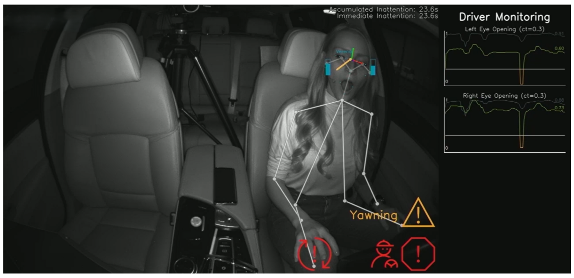
Level	Verbal description	Vigilance stage
1	extremely alert	alert
2	very alert	
3	alert	
4	rather alert	hypovigilant
5	neither alert nor sleepy	
6	some signs of sleepiness	
7	sleepy, but no difficulty to remain alert	drowsy
8	sleepy, some effort to keep alert	
9	extremely sleepy, fighting sleep	sleep onset

Figure 10: Karolinska Sleepiness Scale

In the attempt to avoid or due to be in the higher levels of this scale (8-9), which are the most dangerous for the safety of driving, and staying awake, drivers usually show actions and symptoms such as:

- repeated yawning
- daydreaming
- difficulty in keeping eyes open
- lazy steering
- heart races
- swaying of the head from nodding off
- slower reaction and responses
- vehicle wandering from the road or into another lane

These actions and symptoms, if recognized, can be a warning for DMS to send an alert to the vehicle system, preventing the driver for potentially falling asleep.



Figures 11 & 12: Examples of sleepiness (image 11) and yawning (image 12) detected by DMS

3.2 Safety challenges and innovation drivers to DMS introduction

These problems all contribute to mine the driver's safety. This topic is being addressed more and more since the recent past, with both governments and customers pushing and requiring improvement in this ambit.
The development and implementation of DMS has been driven by the need to address significant safety challenges arising from driver fatigue, distraction, and inattention. As ADAS and autonomous vehicle technologies have evolved, it has also become increasingly clear that while automation can enhance safety, it also introduces new risks related to driver disengagement. These challenges have made DMS a crucial component in the pursuit of safer driving environments.
The introduction and evolution of DMS has been driven by several innovative forces in both technology and regulation. Innovations in sensor technology have been pivotal in advancing DMS capabilities; modern DMS incorporate a variety of sensors, including infrared cameras for low-light conditions, heart rate monitors, and even sensors that detect bio-metric changes linked to stress or fatigue. These advancements allow for continuous, non-invasive monitoring of the driver's physical and mental state, providing an holistic view of their alertness and fitness to drive. In addition advances in artificial intelligence (AI) and machine learning have enabled the development of more sophisticated monitoring systems that can analyze complex patterns of driver behavior in real-time and try to prevent disengagement.
The regulatory landscape has also been a significant driver of DMS innovation. With increasing emphasis on road safety from customers, governments and automotive safety organizations, there has been growing pressure on manufacturers to integrate DMS into vehicles, particularly in light of the European Union's General Safety Regulation mandating DMS for new cars starting from the near future. These

regulations have accelerated the adoption of DMS technologies, pushing automakers to develop more reliable and accurate systems capable of meeting stringent safety standards to prevent driver's inattention due to fatigue and distraction.

3.3 Direct and Indirect DMS

Various metrics and methods can be used in order to monitor the state of the driver. Depending on which method is used DMS can come in basically two forms:

- Direct driver monitoring system
- Indirect driver monitoring system

The term 'direct Driver Monitoring System' (direct DMS) refers to a technology that employs a driver-facing camera, either visual or infrared, to track and analyze the driver's head position and gaze direction. In contrast, an 'indirect Driver Monitoring System' (indirect DMS) relies on measurements of steering wheel torque and touch-sensitive sensors embedded within the steering wheel to assess the driver's condition.
While both methods are effective for monitoring driver engagement, indirect DMS is generally regarded as a more outdated approach, with current advancements focusing primarily on the direct DMS. The integration of a driver-facing camera allows for real-time tracking of facial features and eye movement, providing a significantly more accurate assessment of driver fatigue and distraction compared to systems that solely rely on steering wheel inputs.
This distinction is further demonstrated in the following images, which depict a comparative analysis of direct and indirect DMS performance during testing conducted by the American Automobile Association (AAA). The study evaluated driver disengagement in two specific scenarios:

- Scenario A (red): Hands off the steering wheel, head up and facing toward the road ahead, gaze directed downward
- Scenario B (blue): Hands off the steering wheel, head and gaze directed downward to the right towards the center console (simulating a distraction caused by an ADAS system)

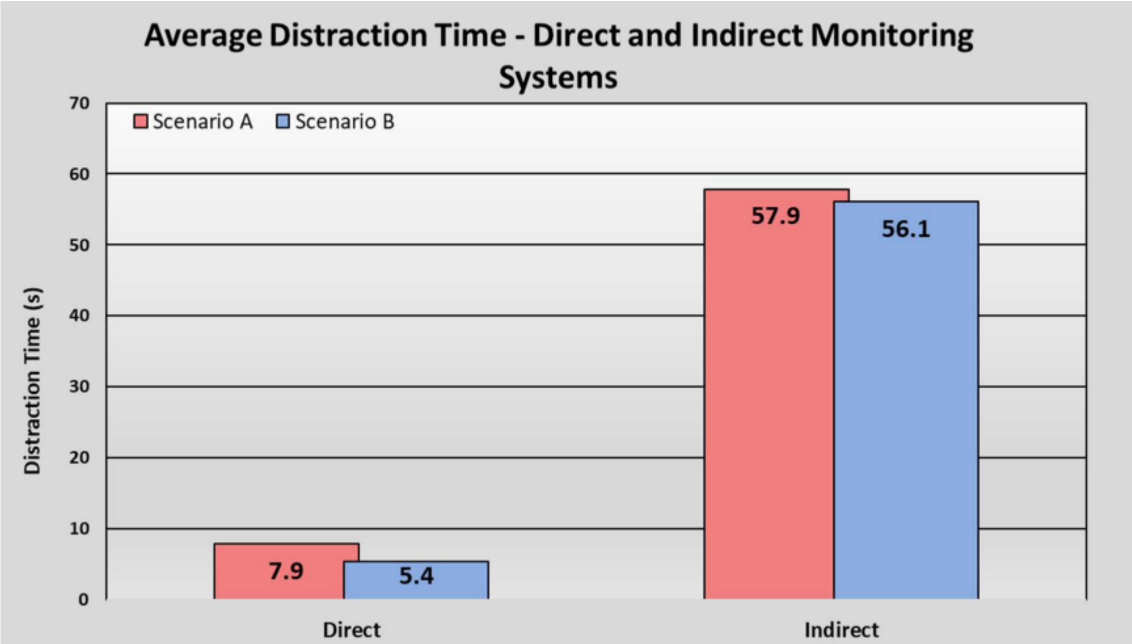


Figure 13: Average Distraction Time for direct and indirect DMS in both scenarios

The first image illustrates that, on average, direct DMS alerted the driver 50 seconds earlier than indirect systems in Scenario A, halting driver disengagement after 7.9 seconds, compared to the 57.9 seconds of the indirect systems. In Scenario B, the difference in alert timing was even more pronounced, with direct systems issuing alerts 50.7 seconds sooner than their indirect counterparts on average.

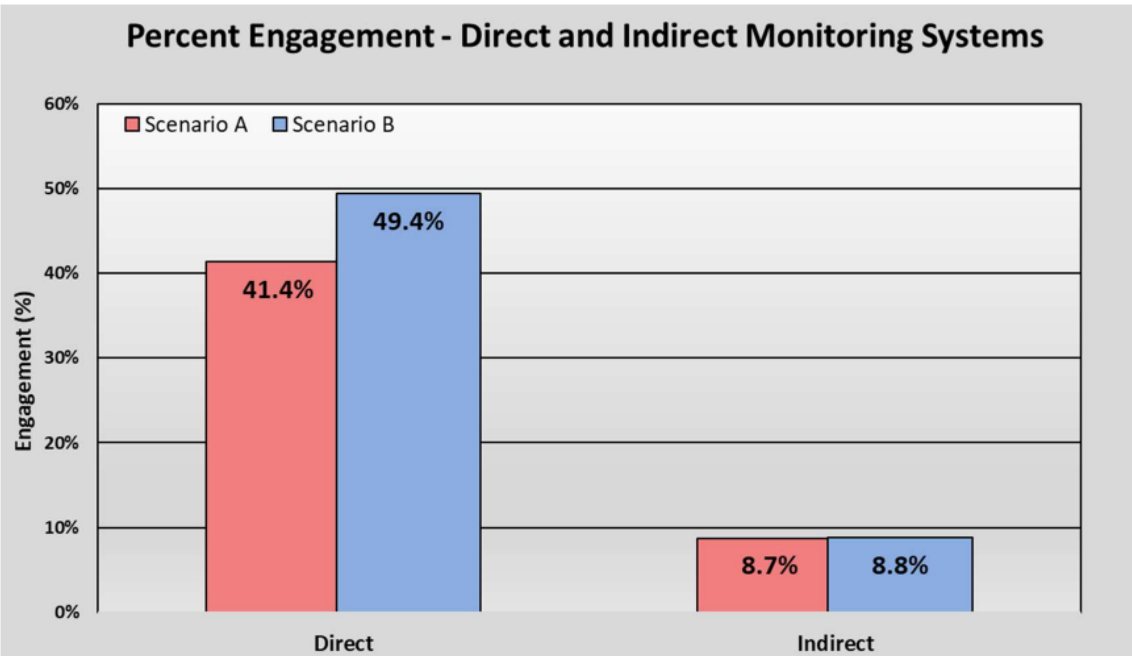


Figure 14: Percentage of Engagement for direct and indirect DMS in both scenarios

The second image demonstrates that the direct driver monitoring systems (direct DMS) maintained driver engagement for a significantly higher percentage of time compared to indirect systems. In Scenario A, direct DMS exhibited a 33 percentage point increase in engagement over indirect systems, while in Scenario B, the increase was 41 percentage points on average.
In summary, the tested direct DMS systems outperformed the indirect ones by a substantial margin. In both scenarios, indirect DMS allowed for over 50 additional seconds of simulated driver disengagement between alerts, compared to direct DMS. Consequently, drivers remained engaged approximately five times longer when using direct systems versus indirect ones.
Direct DMS becomes especially compelling when considering the potential integration of Artificial Intelligence (AI). The use of AI would enable the system to learn and recognize key patterns in driver behavior over time, further enhancing its effectiveness. Additionally, the presence of a driver-facing camera opens to interesting future possibilities that extend beyond safety features. It is for these reasons that the following analysis will be focused on the direct DMS and, for the remainder of this discussion, any further reference to DMS will imply the direct ones.

3.4 How DMS work and technologies overview

The functioning of DMS involves the seamless interaction of multiple technologies, including cameras, sensors, artificial intelligence (AI), and machine learning algorithms, all working together to monitor and assess the driver's condition in real-time.

3.4.1 Face and eye tracking cameras

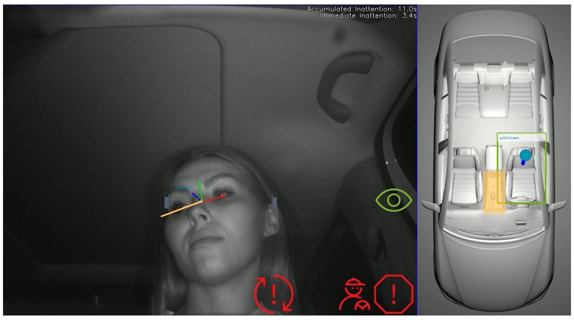
At DMS' core is the camera-based driver monitoring, which typically relies on one or more infrared cameras positioned in the vehicle's cabin. These cameras are designed to focus on the driver's face and upper body, capturing a range of visual cues that provide insight into their state of alertness. Key technologies within this category include facial expressions recognition and eye-tracking systems.

Facial expressions recognition

This feature allows DMS to detect signs of fatigue or distraction by analyzing key facial features such as eyelid movements, eye blinking rates, and the position of the head. For instance, frequent or prolonged eye closures may indicate drowsiness, while a driver's head turning away from the road suggests distraction. Additionally, facial recognition can assess facial muscle relaxation, a potential indicator of fatigue, and identify signs of cognitive engagement, such as furrowed brows or tense facial expressions.

Eye-tracking

This technology is another critical component, using infrared sensors, useful to enable effective monitoring also in poor light conditions, to detect the position and movement of the driver's eyes. Eye-tracking systems can determine whether the driver is focused on the road, looking at in-car devices, or staring off into the distance. This real-time analysis of gaze direction helps the system assess whether the driver is paying attention to driving tasks or is distracted by external or internal stimuli.




Figures 15 & 16: Examples of distraction, also caused by other ADAS technologies (image 16 on the right), detected by DMS

Another measure enabled by this type of technology is the PERcent of eye CLOSure (PERCLOS), this feature is calculated as the total time that the driver's eyelids are 80% or more closed, which indicates a possible state of drowsiness for the driver.

3.4.2 Behavioral and Bio-metric sensors

In addition to cameras, DMS also incorporates a range of sensors that measure the driver's physiological and behavioral states. These sensors track various bio-metric parameters that serve as indicators of fatigue, stress, or distraction.

Behavioral sensors

Their role is to track the driver's physical actions and movements to assess his attentiveness and control over the vehicle. These sensors monitor steering patterns, such as erratic or inconsistent steering behavior, and other physical cues like hand positioning or body posture. By detecting unusual behaviors, such as swerving, delayed corrections, or prolonged inactivity, these sensors help identify signs of distraction, drowsiness, or impaired driving. When abnormal behavior is detected, the system can issue alerts or take corrective actions to enhance driving safety.

Bio-metric sensors

This type of sensors can be integrated into the driver's seat or steering wheel to monitor heart rate, breathing patterns, and skin conductivity. These physiological markers help assess stress levels, alertness, and overall wellness. A spike in heart rate or rapid breathing may suggest heightened stress or distraction, while slower heart rates combined with shallow breathing might indicate fatigue or sleepiness.

3.4.3 AI and machine learning algorithms

The data captured by cameras and sensors is processed by sophisticated AI and machine learning algorithms that analyze patterns, recognize abnormal behaviors, and predict potential safety risks. AI enables DMS to process a vast amount of real-time data and make intelligent decisions regarding the driver's condition. The system constantly learns from collected data, refining its ability to identify patterns associated with driver fatigue, distraction, and stress.
Machine learning models are trained using large datasets of driver behaviors, both normal and impaired. Over time, these models improve their accuracy in detecting subtle deviations from normal driving behavior that may indicate risk. For instance, if the system notices that a driver typically blinks at a certain rate, and then observes a decrease in blinking frequency or an increase in eye closures, it can infer that the driver may be fatigued and trigger alerts accordingly. Similarly, machine learning can help predict distraction by identifying shifts in eye movement patterns, facial expressions, or hand positioning that differ from the driver's usual habits.
AI and machine learning can contribute also to predictive monitoring, which helps forecast future risks based on current driver behavior and contextual information such as driving conditions or time of day. For instance, if the system detects that a driver is showing early signs of fatigue during a long nighttime journey, it might suggest a rest break before critical performance deteriorates further. Predictive monitoring can be seen as a critical factor to enhance safety, giving AI and machine learning a central role in the future of DMS.

3.5 Future Perspectives and challenges

To sum up, DMS present numerous advantages, particularly in the realm of enhancing vehicular safety and improving driver behavior. Among the most significant advantages is the potential for DMS to reduce accidents caused by driver inattention, drowsiness or distraction. By continuously monitoring the driver's physical and cognitive state, DMS can identify signs of fatigue, loss of focus, or risky behavior, triggering timely alerts to the driver or even initiating corrective actions through ADAS. This capability leads to a substantial reduction in road accidents and fatalities, contributing to safer roads and overall enhanced traffic management.
However, despite these substantial benefits, there are several disadvantages and current limitations, chief among them is the concern over data privacy. Additionally, technical limitations, such as false positives or the possible difficulties of the system to effectively monitor drivers in varying conditions can reduce the system's effectiveness and create mistrust among users.

3.5.1 Innovation drivers and future prospects

To address these disadvantages, DMS need a continuous evolution and innovation. Innovation which is primarily driven by the convergence of advanced technologies such as artificial intelligence (AI), machine learning, computer vision, and sensor fusion. AI-powered algorithms are playing a crucial role in improving the accuracy of DMS by refining data interpretation, reducing false alarms, and enabling more nuanced assessments of driver states. Also the integration of bio-metric data with machine learning models opens the door to real-time, individualized driver profiling, offering a more personalized and effective response to varying states of alertness and distraction.
In addition, the shift toward fully autonomous vehicles is a key innovation driver. Although autonomy may reduce the need for constant driver monitoring in some cases, transitional periods where vehicles operate in semi-autonomous modes will still necessitate effective DMS to ensure the driver remains prepared to take over control when required. Moreover, the increasing focus on smart cities and connected vehicle ecosystems underscores the importance of robust DMS systems as part of an integrated approach to traffic safety and management.
So looking forward, the future of DMS lies in the further integration of AI, advanced bio-metric systems, and perhaps even emotion recognition technologies. In tandem with the development of fully autonomous vehicles, DMS will evolve to include more predictive capabilities, where driver state assessments are made proactively, antic-

ipating potential issues before they occur. With this evolution, DMS could move from a reactive to a more preventive approach to road safety.
Until now DMS has been seen only under the light of a safety device, but the implementation of a driver-facing camera with the integration of face and eyes recognition technologies, possibly opens the door to a change of perspective in DMS duties. Other than guaranteeing all the safety features previously discussed, DMS could be used to implement various comfort features in collaboration with ADAS. The driver could be recognized through its face, enabling in this way the automated implementation of personalized settings based on the person in the driver's seat. This change of perspective of DMS will also be guided by the augmenting trend towards comfort and personalization that customers are requiring.

3.5.2 Challenges and privacy concerns

For what concerns the challenges which DMS is dealing with right now and will have to face in the future, the main ones can be identified in the technology needed to reach the near perfection level required, the problems regarding privacy and data security, and the customers' opinions, concerns and possible misconceptions.
The ever evolving automotive environment and the always rising security standards, required by both governments and customers, are forcing and will force automotive industries to search for upgrades in the current technologies and new solutions bordering perfection for DMS, in order to enable an absolute precision in driver's disengagement detection, ensuring better safety levels and guaranteeing the readiness of the driver to take over when necessary in cases of semi-automated or fully-automated driving situations. The key technologies involved in DMS evolution, which are undergoing an evolution process themselves, could be identified as the ones regarding the areas of Artificial Intelligence (AI) and machine learning, computer vision, sensor fusion, Vehicle-to-Everything (V2X) communication, and sensible data processing and storing.
It is exactly the latter which is considered one of the main obstacles to overcome for DMS. As already mentioned in fact the management of privacy and personal data is one of the main concerns, not only arising in the automotive industry, but in all different sectors, as the world is becoming more and more connected. Additionally, the trend of personalization is also in ascent, leading inevitably to an increased amount of collected and processed personal data in order to better adapt the product or service to the single individual's specific needs.
The enormous amount of processed and stored data brings to the light the topic of privacy and cybersecurity, one of the main focus is in fact on which type of data can

be collected, which can be processed, and which must be deleted immediately after usage; with particular attention also on how to protect sensible information from breaches and hacking attacks in order to prevent the spill-out of private data.
The subject is so delicate and brings forth so much ambiguity of interpretation, with its subjectivity on which type of data can be considered sensible and how information can be processed and managed, that governments were obligated to step in as regulators in order to impose an objective standard to be followed, with heavy penalties in case of breaches, given the delicacy of the topic especially in present times.
In this direction, for what regards DMS, has acted the European Parliament and Council, with the General Safety Regulation (GSR), which states that:

> ***"Any processing of personal data, such as information about the driver processed in event data recorders or information about the driver's drowsiness and attention or the driver's distraction, should be carried out in accordance with Union data protection law, in particular Regulation (EU) 2016/679 of the European Parliament and of the Council. Event data recorders should operate on a closed-loop system, in which the data stored is overwritten, and which does not allow the vehicle or holder to be identified. In addition, the driver drowsiness and attention warning or advanced driver distraction warning should not continuously record nor retain any data other than what is necessary in relation to the purposes for which they were collected or otherwise processed within the closed-loop system... Furthermore, those data shall not be accessible or made available to third parties at any time and shall be immediately deleted after processing." GSR, L 325/3, 14***

This regulation mandates that DMS must function within a closed loop, ensuring that no data is made available to third parties and that all collected data is deleted immediately after being processed. These requirements have a significant impact on software developers, hardware manufacturers, and original equipment manufacturers (OEMs), who are all key stakeholders in DMS development process.
It is also important to specify that, under the General Data Protection Regulation (GDPR), the data gathered by DMS, including behavioral and physiological information, are classified as "health data", as they can be used to infer an individual's health status, and so need to be treated as such. Additionally, the implementation of DMS is expected to become mandatory by governmental regulations in the near future.
While these regulations are currently enforceable, they are expected to evolve as the issues they address, and public attitudes toward them, continue to develop.
Therefore, it is crucial to understand how people currently perceive DMS, the challenges and concerns associated with it, and their expectations for its future. This knowledge will provide a more comprehensive understanding of the present situation and help guide the necessary steps to ensure broader acceptance and successful

global implementation of this technology, which otherwise risks to only be a passing shooting star in the automotive industry.

Chapter 4

Interviews

The widespread use of DMS, also in light of the governmental regulations making it mandatory for the near future, seems unavoidable. Its mass implementation will bring, also thanks to its interaction with ADAS systems, numerous individual and social benefits, empowering both road's safety and automated driving security and adoption.
However, these benefits, in order to be exploited to the maximum, need not only the mandatory implementation imposed by governments, but also for drivers to accept the implementation of DMS and trust its functionalities, otherwise the risk for DMS of being only a brief appearance in the automotive industry may concertize itself. The public perception of automation and in general of new technology acceptance is in fact a dynamic and multi-faced topic based mainly on system reliability, system transparency, and perceived privacy risks.
Many theoretical models such as the Unified Theory of Acceptance and Use of Technology (UTAUT) and the Technology Acceptance Model (TAM) move in the direction of examining and predicting behavior towards new technologies. These models however bear the risk of reducing complex interactions between humans and technology to a handful of predictive factors, especially in areas where a very small knowledge base exist, such as DMS.
The need for a qualitative analysis therefor presents itself, in order to better understand people attitude towards DMS, analyzing in depth and accurately the interaction between people and the emerging topic more than a quantitative analysis, which instead includes the risk of reducing complex data only to an handful of numerical data, leaving to the side important opinions and interpretations.
Quantitative analysis in fact relies on the statistical analysis of numerical data obtained from surveys, experiments, or administrative records. Meanwhile qualitative analysis relies on thick description and deep understanding of the subject being re-

searched, obtained from in-depth interviews, observations, and/or close readings of text.

	Qualitative Analysis	Quantitative Analysis
Type of data	Words, text, descriptions, direct observations	Numbers, figures, statistics
How data is collected	Observations, interviews, and textual analysis	Measuring and counting things
How data is analyzed	Text analysis; grouping data into meaningful themes or categories	Statistical analysis
Level of analysis	Small groups, case studies, local phenomena; more subjective	Large-scale, generalizable, fixed
Type of findings	"Thick description", understanding the why or how about phenomena	How much, how many, or how often; correlations or causation among variables

Figure 17: Differences between qualitative and quantitative analysis

4.1 Interviews presentation

Given the previous reasons, in order to understand how people currently perceive DMS, the challenges and concerns associated with it, and their expectations for its future, qualitative analysis will be used. In particular the qualitative analysis will be conducted following semi-structured interviews, to singular individuals.
Semi-structured interviews are in fact a mix of structured and unstructured interviews, proposing some predetermined questions, while others are not planned or phrased in advance. Additionally, the choice of a semi-structured format enables a flexible schedule, not imposing a predetermined order to the questions and allowing participants to express topic inherent opinions not included in the plain demands prepared in advance that are being asked. Opinions which can guide further research questions not planned, and enrich the dataset of answers available at the end with precious extra thoughts which enable a more in depth and personal comprehension of the topic being discussed.

The catalog obtained at the end of the interviews rounds was composed of 20 interviews, each of them conducted individually using a face to face or a video call approach with the interviewed person, with an approximate duration of 30 minutes each. The park of people interviewed was as diverse as possible, with different ages, nationalities and backgrounds.
Some interviewees were close to the interviewer, but the majority came from external contacts, the age was ranging from 19 to 82 years old (with a mean of 39 years old), and all people were in possession of a driver license, in order to ensure their relevance to the subject matter. The main nationality of the interviewees was Italian, the same of the interviewer, with the interviews in these cases conducted in Italian for simplicity and then transcribed in English, but other nationalities were also taken into consideration, in particular Iranian and American.
The aim of the interviews was to understand the current people perception of DMS, with their concerns, its positive and negative aspects, perceived barriers and facilitation to its implementation, challenges, and expectation for the future.
Given these insights, a more comprehensive understanding of the present situation will be achieved, guiding the necessary steps to ensure a broader and successful global implementation of DMS, enabling a safer and more comfortable driving experience.

4.2 Structure and methodology

The interviews all started with the moderator giving a brief overview of the structure of the session, clarifying how the main goal was to understand different opinions and critics, and not to force approval over the acceptance of DMS.
Subsequently a set of informal personal questions was asked to the interviewees in order to break the ice and make them more comfortable.
After that, two video clips, for a combined duration of around 6 minutes were shown. The videos had the objective of giving the participants a general presentation of DMS and an overview of its main features and functionalities. It is important to clarify that the videos had only an educational purpose: the goal was to provide a base of knowledge where one was not present, to better face the incoming interview, and not to force a determined point of view of DMS, limit the incoming discussion to the contents shown in the video, or influence subjects to favor the technology. Also, where some preexisting base knowledge was already present, it was encouraged to bring it to the interview in order to provide more multifaceted points of view, the videos were in fact shown only to enrich this already existing knowledge and not with the purpose of influencing or overwriting it.

As already said, the structure was flexible, however a set of questions was prepared in advance in order to make sure to touch all the focal points of interest to the study and give a solid skeleton to the interviews:

4.2.1 Personal questions

This group of questions was made at the beginning of the interview with the aim of knowing better the interviewed people, making them more comfortable and understanding their background:

- What is your name?
- How old are you?
- What is your level of instruction?
- What is your job?
- Where do you live?
- For what reason do you usually drive?
- Which kind of vehicle do you drive?
- How frequently do you drive?
- How much time do you spend driving?

After these questions, the two video clips already discussed earlier were shown.

4.2.2 General awareness and understanding of the topic

This set of questions was designed in order to discover the interviewees awareness of the topic both prior and after the videos, exploring also what first impressions and thoughts of DMS were deriving from the videos just shown:

- Did you already hear of DMS prior to this interview? If yes, where? What is your experience with it?
- What is your general impression on DMS after having watched these videos?

4.2.3 Perceived benefits and useful features

In this part the perceived benefits and useful functionalities are explored. The aim is to discover which strong points DMS already possess and to understand what makes them so:

- Do you find DMS a useful tool? If yes, in which scenarios could it be more beneficial?
- Do you think DMS could improve safety and reduce accidents?
- Do you trust the technology behind DMS?
- Would you feel safer in a car with implemented DMS?
- How do you feel about alerts or warnings given when you are distracted?
- How do you feel about the use of artificial intelligence in monitoring driver behavior?
- How would you feel about comfort features enabled by facial recognition?

4.2.4 Concerns and perceived challenges

In this section are evidenced the concerns, doubts, and perceived challenges that the interviewees found about DMS. This is fundamental in order to understand which are the critical aspects of the technology in which an improvement or a radical change of perspective is needed to achieve global acceptance in the future:

- Do you have concerns about DMS? If yes, which ones?
- How comfortable would you be knowing a system in your car is monitoring your driving behavior?
- How would you react if a driver monitoring system wrongly detected that you were not paying attention and issued a warning?
- Do you think DMS could be more of a distraction than a benefit? If yes, in which situations?
- How comfortable would you be knowing a system in your car is monitoring your driving behavior?
- Would you be concerned about your privacy during the use of DMS?

4.2.5 Privacy concerns

Privacy and sensible personal data usage is a delicate topic and one of the main ambits of discussion around the technology of DMS. The acceptance of privacy terms by the final customer would be fundamental in order to enable all the potentialities of cameras, sensors, and Artificial Intelligence (AI) of which DMS is provided. This set of questions explores the perceived privacy problems by the interviewees, with the aim of understanding which are their main concerns about the topic, which type of data are seen as more sensible, and if the trade-off between benefits and privacy problems could be in some way surpassed:

- How concerned are you about your privacy when it comes to driver monitoring systems that use cameras or sensors?
- Would you be comfortable with the car company or third parties accessing data collected by a driver monitoring system?
- What kinds of data do you think should never be collected by these systems?
- Do you feel the privacy problems could be surpassed by a favorable trade-off between benefits and data collected?
- Would you be more inclined to accept privacy policies if the data collected could be used to implement comfort features (like automated personalized settings as soon as you enter the vehicle)?

4.2.6 Final opinions and future development of DMS

In this last portion of questions, a final thought on DMS was asked. In addition, some considerations for the future of the technology were questioned in order to understand which are its future expectations from the customer side and if some interesting ideas were to emerge:

- How do you think driver monitoring systems will impact driving habits over time?
- Would you be willing to pay extra for a car with an advanced driver monitoring system?
- Would you recommend a driver monitoring system to a friend or family member? Why or why not?

- Is there anything you think could be improved in existing driver monitoring systems?
- How do you imagine driver monitoring systems evolving in the next ten years?

4.2.7 Interviews results

At the end of all the 20 interviews conducted with the above mentioned structure and methodology, the following results, here resumed for an easier and more linear reading, were obtained:

NAME	GENDER	AGE	BACKGROUND	RELEVANT OPINIONS
GIACOMO	MALE	34	Is a daily driver, well-informed on technology	Sees DMS as useful for safety but feels uneasy about constant surveillance. He trusts the technology if it's reliable but expresses frustration over potential false positives. His primary concern lies in balancing safety and the invasive nature of monitoring
SOFIA	FEMALE	19	Drives a few times a week, unfamiliar with DMS	Initially unaware of DMS, finds it promising for safety but potentially intrusive. Privacy concerns dominate her view, especially regarding third-party data access. She is cautious about recommending the system without assurance that it wouldn't interfere with driving
AHMED	MALE	45	Drives long hours daily and has some experience with DMS	Appreciates DMS for managing fatigue during long shifts but finds false positives annoying. While comfortable with monitoring in his profession, he prefers that not all aspects of his driving be tracked, especially by external parties
MARIA	FEMALE	57	Drives daily and is new to DMS	Views DMS as beneficial for safety but too invasive for her liking. She is particularly concerned about how companies might use her data. While she acknowledges the potential of AI in DMS, it makes her nervous due to its potential for misuse or error
ALESSANDRO	MALE	25	Drives a few times a week and has no prior knowledge of DMS	Sees the safety potential in DMS but fears it could become annoying with too many alerts. Privacy is a significant concern, as he feels uncomfortable with the idea of being constantly monitored
NAME	GENDER	AGE	BACKGROUND	RELEVANT OPINIONS
KAY	FEMALE	39	Drives daily and is familiar with DMS, especially in legal contexts	Sees DMS as useful for addressing distracted driving but is extremely concerned about privacy. She emphasizes the need for strong privacy protections before she would feel comfortable recommending the system
GIUSEPPE	MALE	82	Drives a few times a week, mostly for errands	Finds DMS helpful, especially for older drivers who may become distracted more easily. False positives could frustrate him, but he feels that the added safety is worth the inconvenience. He is interested in comfort features like automatic adjustments
ALICE	FEMALE	31	Drives daily but had limited prior exposure to DMS	Is cautiously optimistic about DMS but worries about its accuracy. While she acknowledges the safety benefits, constant alerts could reduce her confidence in the system. Privacy remains a concern, especially in trusting companies with personal data
PAUL	MALE	50	Drives long hours as part of his job and has experience with DMS	Appreciates the role of DMS in managing fatigue but is annoyed by false positives. Despite the occasional irritation, he still recommends the system, particularly for long-haul drivers, due to its safety benefits
MAHDI	MALE	23	Drives primarily on weekends and is unfamiliar with DMS	Finds DMS interesting but worries it might detract from the driving experience. While comfort features are appealing, privacy is her primary concern, as she is uncomfortable with the idea of her data being accessible to third parties

NAME	GENDER	AGE	BACKGROUND	RELEVANT OPINIONS
LORENZO	MALE	41	Drives daily and keeps up with tech developments, including DMS	Recognizes the potential for DMS to reduce accidents but is skeptical about the risk of false positives. He has strong concerns about data security and would need assurances that his data would remain private before fully trusting the system
ALESSANDRA	FEMALE	35	Drives daily but is unfamiliar with DMS	Is intrigued by DMS but uncomfortable with the idea of being constantly monitored. While she sees the value in AI-driven monitoring for safety, she worries about how accurate it would be in practice
LUIGI	MALE	59	Drives regularly for business trips and is familiar with luxury car systems	Supports the concept of DMS but is wary of frequent alerts, which could distract him. Privacy is a major issue, particularly regarding the sale of personal data. He would consider paying extra for DMS only if it proved highly accurate and reliable
ALESSIA	FEMALE	29	Drives occasionally for work-related travel	Finds DMS intriguing but is concerned about the possibility of false alarms. She values the convenience of comfort features but prioritizes privacy, insisting that her data must remain confidential
OMAR	MALE	48	Drives daily for work and is familiar with DMS	Believes DMS could help prevent accidents but is concerned about it becoming a distraction with frequent false positives. He is generally positive about the safety benefits, though he stresses the importance of system accuracy
NAME	GENDER	AGE	BACKGROUND	RELEVANT OPINIONS
EMILY	FEMALE	32	Drives a few times a week and has some knowledge of DMS from tech reviews	Is cautiously optimistic about the potential of DMS but remains skeptical about its current capabilities. Privacy is a central concern for her, and she would only recommend the system if it demonstrated reliability and ensured data security
LIAM	MALE	27	Drives daily to work and is new to DMS	Finds the concept of DMS interesting but worries about false alarms distracting him while driving. While he is comfortable with safety monitoring, he insists on maintaining control over his data and would only consider DMS if privacy is protected
TINA	FEMALE	53	Drives daily to work and has read about DMS in automotive publications	Believes DMS is a good way to enhance road safety but has reservations about false positives. Her primary concern is privacy, particularly the possibility of third-party data sharing, which she sees as a barrier to full acceptance of the system
ANTONIO	MALE	35	Drives almost daily and is familiar with basic DMS systems in cars	Supports the idea of DMS but expresses concern over constant alerts, especially for experienced drivers. He appreciates the convenience of comfort features like automatic seat adjustments but would be frustrated by frequent false alarms
MARTA	FEMALE	24	Drives occasionally and has no prior knowledge of DMS	Finds DMS useful but dislikes the idea of being constantly watched. Privacy is her biggest concern, and she would hesitate to adopt the system unless she had full control over her data. The safety benefits are appealing, but only if the system proves effective and non-intrusive

4.3 The analytic tool: Thematic Analysis method

The choice of a qualitative study, manifested through interviews, offers the opportunity to choose between a various numbers of analysis methods and tools, the one selected to carry on the analysis of the collected data will be the thematic analysis method. This type of analysis emphasizes the data itself, enabling the researcher to derive significant insights directly from the collected information.

In particular, it can be identified as a methodologically sound and versatile tool, offering both depth and flexibility. As a qualitative method, its strength lies in its ability to distill rich, detailed data into coherent insights that can address a broad range of research questions. By systematically identifying and analyzing themes within data, it provides a means of exploring complex patterns of meaning, making it invaluable for research that seeks to understand lived experiences, cultural contexts, or psychological phenomena.

To do so the thematic analysis involves six stages that follow each other after the initial collection of data through interviews has been completed:

1. **Familiarization with the data**
   This initial step consists in immersive reading and re-reading the interviews transcripts in order to gain a deep understanding of it. This phase is fundamental to become acquainted with the data, to do so the researcher could also start taking some notes about initial ideas of potential patterns and recurring topic recognized which could need a later further exploration

2. **Generating initial code**
   After familiarizing with the data, the researcher proceeds to systematically work through the data set and generate codes from segments of text which are relevant to the research aims. Codes are concise labels that categorize important features of the data that may form the basis of emerging themes

3. **Searching for themes**
   Once the data has been fully coded, the next step is to collate codes into potential final candidate themes. This involves examining the codes and the data extracts associated with them to identify significant broader patterns that capture something important about the data in relation to the research goals

4. **Reviewing themes**
   After identifying potential themes, it's crucial to review them. This step involves two levels of review: first, checking the themes against the coded extracts to ensure they form a coherent pattern, and second, ensuring each theme is distinct and meaningful in relation to the other identified themes. During this phase, some themes might be split, combined, or discarded as the analysis refines and sharpens the thematic map of the data

5. **Defining and naming themes**
   Having reviewed the themes, the next task is to define and refine them, giving each one a clear and informative name. Defining themes involves articulating what each theme captures about the data and why it is significant in relation to the research question. Naming a theme should succinctly convey the essence of what it represents, allowing readers to understand the core of what was found

6. **Producing the report**
   The final step in thematic analysis is to produce a coherent and compelling report. The report should tell a coherent story about the data, clearly linking the analysis to the research question and the existing literature

4.3.1 Reflexive thematic analysis

Once the analysis method has been selected, the next step is choosing the type of thematic analysis most suitable for the research. The most notable approaches to thematic analysis are three, each with distinct characteristics and applications, tailored to specific research needs

- Inductive thematic analysis
- Deductive thematic analysis
- Reflexive thematic analysis

The first type is characterized by a bottom-up approach and finds itself being guided by data instead of preexisting theories or expectations, themes emerge directly from data, making the inductive thematic analysis especially useful when dealing with under-researched or relatively new topics.
Deductive thematic analysis is on the contrary a top-down approach where the research is guided by preexisting theories and codes. This method allows the exploration of only predefined themes and so is particularly suited for a focused examination, making possible for the investigation to remain closely aligned with the research aim.
Meanwhile both these first two methods are valid, the choice of the analytic tool for the analysis of the data collected falls on the latter one.
Reflexive thematic analysis emphasizes in fact the active role of the researcher in the analytic process, involving continuous reflection on the way researcher's biases, assumptions, and backgrounds influence the interpretation of the data, recognizing also that themes do not simply emerge from the data but are co-constructed through the researcher's reflexive engagement with both the data and the theoretical frameworks guiding the analysis. In this way the approach is not only deeper and more credible, but also gives to the analysis an enhanced rigor and transparency.
This method was chosen both for its ability to facilitate an inductive, bottom-up analysis and for its ability to foreground the richness of qualitative data and offer deep, nuanced understandings of complex social phenomena, making it an ideal approach for research that aims to explore subjective experiences and contextual meanings.
To do so the reflexive thematic analysis method follows the six steps process discussed earlier, but not in a linear way. It introduces in fact the concept of recursion, allowing for flexibility as the researcher continuously revisits earlier phases in light of new insights.

4.3.2 Advantages of reflexive thematic analysis

Reflexive thematic analysis offers several significant advantages in qualitative research, primarily its flexibility and adaptability.
It can be tailored to different theoretical perspectives, ranging from essentialist to constructionist, allowing researchers to align their methodological approach with their specific research questions and epistemological stance. This flexibility makes reflexive thematic analysis suitable for a diverse array of qualitative research settings.
Moreover, it strongly emphasizes researcher reflexivity, which is pivotal in ensuring transparency throughout the analytical process. By acknowledging and incorporating the researcher's subjective experiences, the reflexivity used allows for the co-construction of meaning, which often results in a nuanced and enriched interpretation of the data. This is particularly advantageous when studying complex social phenomena, as it enables a deep exploration of the underlying themes and contextual meanings.
Another notable strength of the reflexive thematic analysis is its accessibility, which is beneficial for both novice and experienced researchers. It does not impose strict data collection requirements or methodological rules, making it adaptable to a range of research contexts and data types, such as interviews, written texts, and multimedia, further enhancing its versatility.

4.3.3 Disadvantages of reflexive thematic analysis

However, there are also several disadvantages associated with reflexive thematic analysis. Its reflexive nature means that the analysis is inherently subjective, which can result in a lack of consensus regarding the themes produced. Since themes are co-constructed rather than objectively "discovered", the analysis may be critiqued for lacking the scalability and objectivity associated with more positivist methodologies.
This subjectivity also raises the potential risk of over-reliance on the researcher's interpretive abilities. The quality and credibility of the findings are largely contingent on how well the researcher can critically and reflexively engage with the data; insufficient reflexivity could lead to analyses that are more reflective of researcher bias than rigorously grounded in the data.
Establishing the validity of findings can also be a challenge, as reflexive thematic analysis' interpretive approach makes it difficult to employ standard validity measures.
Furthermore, the iterative nature of the analysis can make the process time-consuming and labor-intensive, particularly when working with extensive datasets, as it requires

ongoing reflection and constant refinement of themes.

Lastly, although reflexive thematic analysis provides a general framework through its six phases, the absence of detailed procedural guidelines can lead to ambiguity in its application. Researchers might struggle with determining when to conclude each phase, potentially resulting in inconsistencies in the quality and depth of analyses across different studies.

4.4 The analytic process

Given a generic view about the reflexive thematic analysis, it is now time to apply this method to the data set of answers obtained, which has been already summarized above.

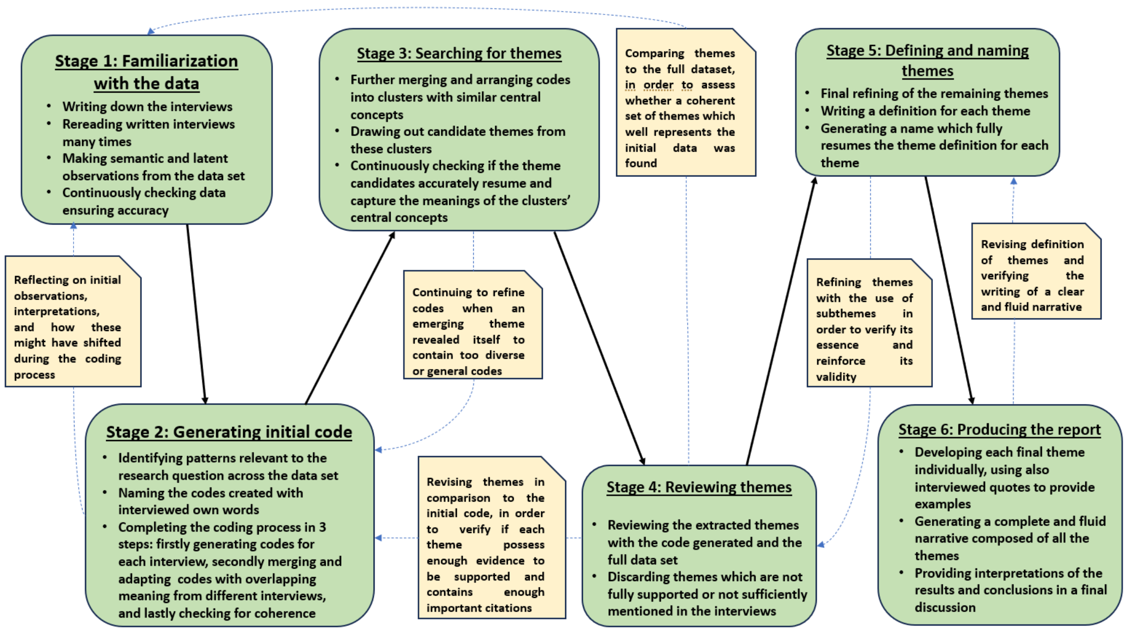


Figure 18: Reflexive Thematic Analysis

During the execution of the analysis, as shown in the image above, the six stages earlier explained have been followed, with additional recursive phases in order to achieve a more meticulous analysis of the data and being in line with the concept of reflexivity.

4.4.1 Familiarization with the data

The analysis begins with a better familiarization with the data. This first stage was faced by reading and rereading the interviews that were previously written down in

order to gain an in-depth understanding of participants' views on DMS.
It is in fact crucial at this stage to focus on how participants speak about their experiences and emotions concerning the topic, with not only the aim of knowing what a person answered to a specific question, but of understanding the general thoughts and perception about DMS, making semantic and latent observations, and gaining in this way a more comprehensive and immersive view of the entire data set of answers.
Already from this first stage some general concepts started to emerge, making a few initial observations possible.
It was clear in fact how a significant portion of interviewees was initially unfamiliar with DMS, as it is possible to understand for example from Marta's (interview 20) words "being monitored by my own car while I am driving is a concept completely unheard to me, I must say I am new to it. I didn't believe it was possible."
Across the board it is possible to note how mixed views of DMS exist, with some people expressing privacy and general other concerns, meanwhile others highlighted the potential safety benefits and its utility. Like the professional taxi and truck drivers Ahmed (interview 3) and Paul (interview 9), who both said "I drive for a living and spend many hours at the wheel, tiredness could be always a factor. Also, like, my passengers would feel more comfortable knowing their driver is monitored and concentrated on its main task".
It is curious also how mainly younger participants and those with high technical literacy displayed greater skepticism about how well the system would perform in terms of false positives or over-sensitivity, with Alessandro (Interview 5) and Emily (Interview 16) voicing such concerns.

4.4.2 Generating initial code

At this stage, meaningful features of the data were coded systematically across all the interviews generating initial codes. In particular codes represent specific pieces of data that stand out and recur across the dataset.
Patterns relevant to the research question were identified and a name was associated to the obtained codes.
Some examples of the codes identified, with some interviewees citation to enforce them, are:

- **Safety:** there were many comments regarding DMS' potential to reduce accidents and to enhance safety, like "It seems useful, especially for the general safety of the road", "I think I would feel safer", "It could save many accidents from happening! While I drive, I see a lot of distracted drivers"

- **False alarms:** participants' annoyance with inaccurate warnings was also a recurring feature. Expressions like "It would ruin my driving experience", "In the end is going to distract me even more", "It is going to make me want to turn it off (DMS)"

- **Privacy:** also recurring concerns about data collection raised: "I don't trust when they say my data won't be shared", "My privacy is going to be violated", "Sensible data in the wrong hands can be a serious problem", "I won't allow it"

- **Comfort features:** positive comments regarding comfort features like automatic seat adjustment were individualized: "Who wouldn't want it (extra personalization)", "For sure it would be a nice extra", "It can even make me forgot I am observed"

During all the coding process a recursive work has been conducted, reflecting on the initial observations and how these might have shifted during the coding process itself, influencing it.

4.4.3 Searching for themes

During this phase, a further merging and refining of the previously found codes into clusters occurred. These clusters were all characterized by different central concepts, around which all the codes with similar meaning were grouped to the corresponding cluster.
The aim of this process was to go beyond the plain codes and to start drawing out of the data set some candidate themes which were able to better highlight the most cited and recursive topics, and to underline meanings and perspectives.
In the searching for themes, it was clear how the codes regarding safety were in number the more present, so, in order to put the right weight on it, a first theme entitled 'Safety' was extracted from the respective cluster.
The second most present topic was the shared concern about privacy and sensible data sharing, and for this reason the general theme 'Privacy Concerns' was created, including all the codes grouped around the homonym cluster.
Also the 'Driver Autonomy & Responsibility' provisional theme was created, highlighting the recursive codes regarding this topic found and the general participants' concern about DMS taking out the pleasure of driving.
From the cluster containing the code 'False alarms' were extracted the 'Frustration

with false positives' and the 'Trust in technology' themes, and an ulterior theme named 'Comfort Features appreciation' was created form another cluster.
It is important to highlight how, during all this phase, a recursive process of continue refining of codes and individualizing of themes was undergone when an emerging theme revealed itself to contain too diverse, general or redundant within other themes codes, in order to enhance coherence.

4.4.4 Reviewing themes

This fourth phase is characterized by a review of the obtained preliminary themes and the merging and elimination of some of them. This process was executed by continuously comparing themes to the full data set in order to verify if a coherent set of themes which well represents the initial data was found, and by revising themes with the initial code in order to make sure that each theme possessed enough evidence to be supported.
During this procedure for example the theme 'Trust in technology' was eliminated and its contents were merged within the 'Safety' and 'Frustration with false positive' provisional themes.
In particular the 'Safety' theme was strengthened by reviewing specific comments about trust in the system, such as Alessandra's (Interview 12) remark that "While DMS might help, I am unsure about its accuracy", and other comments that helped sharpen this theme.
"Frustration with False Positives" was refined by focusing more on specific frustrations about over-sensitivity, such as Paul's (Interview 9) complaint that DMS flagged him even when he was attentive.
The theme of 'Privacy' was broadened to include both general data sharing concerns and the specific concern of third-party access to personal information, which Kay (Interview 6) and others repeatedly mentioned.
The theme 'Driver Autonomy & Responsibility' was refined to capture the tension between appreciating automation and enjoying the driving experience. This theme also absorbed some concerns about over-surveillance.
To conclude the theme 'Comfort Features appreciation' was streamlined to focus on excitement around advanced, personalized comfort features, including automatic seat adjustments and AI-driven comfort settings guided by face recognition technology.

4.4.5 Defining and naming themes

Here, the themes are defined and named in a way that captures their essence while retaining connections to the data. Each theme must clearly reflect the underlying ideas gathered from the participants and be engaging for the reader.
At the end the analysis highlighted five final themes:

- **Safety as Priority:** This theme emphasizes the widely shared belief that DMS can improve road safety by preventing accidents and detecting distracted drivers, highlighting the share sentiment that DMS' primary value lies in its potential to enhance safety, especially for long-haul or distracted driving.

- **User Frustration with False Positives and Over-Sensitivity:** This theme captures the tension between appreciating the system's safety features and finding it overbearing. Participants repeatedly noted that while safety is a priority, DMS' over-sensitivity and frequent false positives could become annoying or even distracting, presenting frustration over being wrongly flagged for inattention.

- **Privacy and Data Sharing Concerns:** A major concern, particularly among younger or tech-savvy participants, was the fear of being constantly monitored and the potential for companies or third parties to misuse the collected data. Expressing their concern about not trusting DMS if it jeopardized their privacy.

- **Balancing Autonomy with Driver Responsibility:** This theme focuses on participants' concerns that DMS technology could undermine the joy and autonomy of driving. Expressing concerns about how the system might make driving feel less personal or enjoyable, raising questions about how much control drivers should retain in the age of automation.

- **Optimism Surrounding the Implementation of Comfort Features:** Despite concerns about privacy and autonomy, many participants saw value in the comfort features enabled by DMS. Participants specifically mentioned being excited about how facial recognition could make their driving experience more comfortable and efficient, enabling personalized settings and other comfort features.

During the final defining and naming process, each theme was refined with the use of sub-themes, in order to verify its essence, reinforce its validity, and enabling a further breakdown of the various sub-topics grouped under its title.

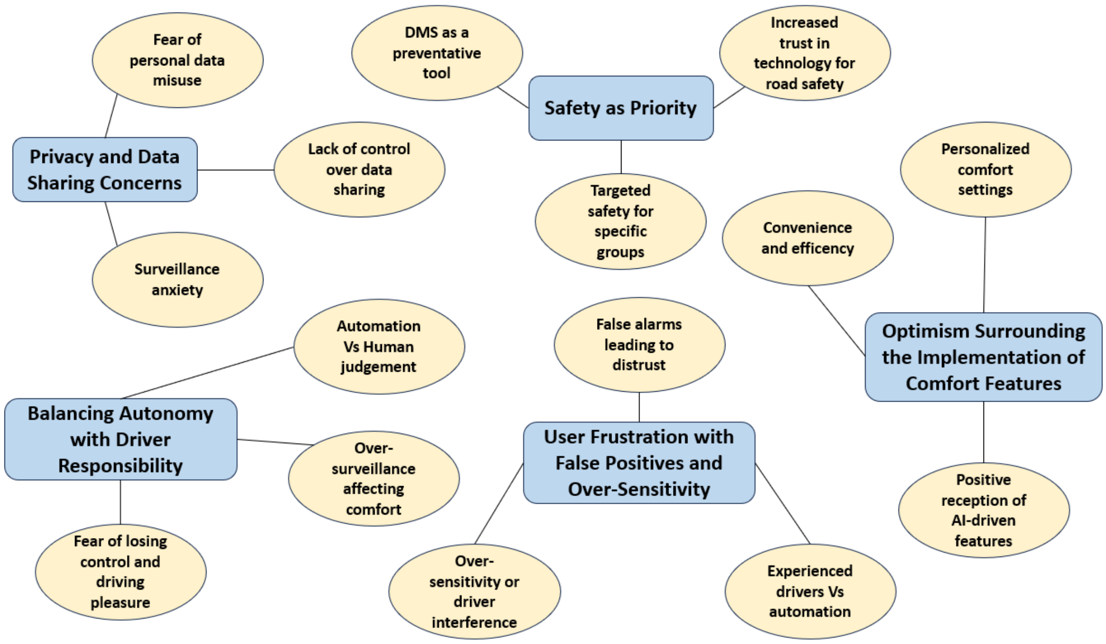


Figure 19: Main themes and sub-themes obtained

4.4.6 Producing the report

In this final stage will be at first faced an in-depth analysis of the final themes and corresponding sub-themes, always revising and using as following the definitions previously defined, using as reference the image above, and later a cohesive narrative analyzing the overall findings related to DMS will be done.

Safety as Priority

This theme encapsulates the fundamental rationale behind the implementation of DMS. Across the data, participants consistently recognized safety as a key concern in driving, with many viewing DMS as a vital tool in addressing road safety challenges. This theme reflects the belief that DMS could significantly reduce road accidents by monitoring driver behavior, particularly in detecting fatigue, disengagement, inattention, or distraction. It also groups under its name the following sub-themes, which enrich and articulate it:

- **DMS as a preventative tool:** one of the central sub-themes emerging under safety is the idea of DMS as a preventative tool. The participants expressed optimism that DMS could prevent accidents by acting as an early warning system, identifying potential hazards related to distracted or impaired driving. This sub-theme reflects a shared belief that technology could augment human awareness, especially in high-risk situations such as long-distance driving or during monotonous commutes, where the likelihood of fatigue increases. DMS' potential to intervene before an incident occurs, positions it as a critical safeguard, particularly in scenarios where human attention may falter.

- **Increased trust in technology for road safety:** another key sub-theme is the growing trust in technology to enhance road safety. Although some skepticism was expressed about the reliability of DMS, several participants believed that with technological advancement, DMS could become a dependable element of vehicle safety systems. This sub-theme indicates a gradual shift in societal attitudes, where drivers increasingly accept technology as a co-pilot or assistant in ensuring safe driving practices. The use of real-time data and artificial intelligence (AI) to monitor and respond to driver behavior is perceived as a promising innovation that, once perfected, could minimize human error, which remains the leading cause of traffic accidents globally.

- **Targeted safety for specific groups:** a third sub-theme under safety emphasizes the usefulness of DMS for specific groups of drivers. Commercial and long-haul drivers, for instance, are particularly vulnerable to fatigue-related accidents. Therefore, DMS' ability to monitor for signs of fatigue or distraction holds significant appeal for both individual drivers and companies seeking to enhance safety and reduce liability. This sub-theme underscores the perception that DMS is not a one-size-fits-all solution but rather a targeted intervention for high-risk driving populations, suggesting its broader societal value in improving road safety among specific demographics.

User Frustration with False Positives and Over-Sensitivity

While the safety benefits of DMS are widely acknowledged, many participants expressed concerns about false positives and the over-sensitivity of these systems. This theme highlights the potential for user frustration when DMS issues unnecessary or incorrect alerts, which can diminish the overall driving experience and erode trust in the system. In particular, the main sub-topics identified are:

- **False Alarms Leading to Distrust:** a dominant sub-theme is the issue of false alarms. False positives situations where DMS incorrectly identifies a driver as distracted or inattentive are a significant source of frustration. Drivers expressed concern that these incorrect alerts could lead to unnecessary distractions, which may ironically compromise safety rather than enhance it. This sub-theme suggests that DMS, while designed to assist drivers, can become a source of irritation when it fails to accurately interpret driver behavior. Such errors, particularly when frequent, could erode trust in the system, making drivers more likely to ignore warnings or disable the system altogether, thereby undermining its intended purpose.

- **Over-Sensitivity and Driving Interference:** closely related to false positives is the sub-theme of over-sensitivity. Participants expressed concerns that DMS might be overly reactive, issuing alerts in situations where the driver is in full control. For example, systems that trigger warnings for brief glances away from the road—such as checking mirrors or looking at the dashboard—can lead to unnecessary interruptions. This sub-theme highlights the delicate balance that DMS must strike between being vigilant and being intrusive. Over-sensitive systems may result in an overly cautious driving experience, which could frustrate skilled drivers and reduce their overall comfort behind the wheel. Moreover, such constant interference could lead to driver disengagement, or the system being perceived as a nuisance.

- **Experienced drivers Vs Automation:** another sub-theme in this area is the tension between experienced drivers and automated systems. Skilled drivers, particularly those who have spent years on the road, may feel that DMS undermines their expertise by imposing rigid monitoring criteria. Experienced drivers may view DMS as redundant, believing that their situational awareness and driving habits are sufficient for safe driving. This sub-theme reflects a broader cultural resistance to automation, where human skill and judgment are valued, and the imposition of technological oversight is seen as unnecessary or even disrespectful of their driving ability. Such resistance underscores the importance of designing systems that adapt to varying levels of driver experience.

Privacy and Data Sharing Concerns

Privacy and data sharing concerns emerged as one of the most significant and contentious themes in the discussion of DMS. While participants recognized the potential safety benefits of DMS, many expressed deep unease regarding how sensitive data, particularly bio-metric and personal data, would be collected, stored, and shared. This theme reflects the growing societal awareness and sensitivity towards privacy in the digital age, especially as more technologies rely on the collection of personal information.

- **Fear of personal data misuse:** a key sub-theme within privacy concerns is the fear of personal data misuse. Participants worried that the data collected by DMS, including facial recognition data and other bio-metric information, could be misused by car manufacturers, insurers, or even third parties. This sub-theme reflects the fear that data intended for safety purposes could be repurposed for commercial gain or surveillance, infringing on personal privacy. The potential for this data to be sold to advertisers, shared with insurance companies to adjust premiums, or even hacked, compounds these concerns. This sub-theme suggests a critical barrier to DMS adoption unless stringent data protection measures are put in place.

- **Lack of control over data sharing:** closely tied to the fear of data misuse is the concern about the lack of control over how data is shared. Participants expressed discomfort with the idea that data collected by DMS could be accessed or shared without their explicit consent. This sub-theme speaks to a broader anxiety over the erosion of personal autonomy in the face of pervasive data collection technologies. Drivers want clear and transparent control over who has access to their data and how it is used. Without such control, the perceived benefits of DMS may be outweighed by the perceived risks related to privacy and autonomy.

- **Surveillance Anxiety:** another sub-theme under privacy concerns is the anxiety surrounding constant surveillance. For some drivers, the mere knowledge that they are being monitored, whether or not the data is shared externally, provokes discomfort. This surveillance anxiety reflects a deeper philosophical concern about the intrusion of technology into personal spaces, in this case, the car. The vehicle has traditionally been a private space where drivers can relax and focus solely on the act of driving. DMS, by monitoring and potentially recording driver behavior, threatens to erode this sense of privacy, transforming the car into a space where a sense of being continuously observed pervades.

Balancing Autonomy with Driver Responsibility

Another central tension in the adoption of DMS is the balance between driver autonomy and the system's oversight, captured in this theme. While DMS aims to enhance safety, it also raises concerns about the extent to which it interferes with the driver's sense of control and responsibility. This generates a contrast between automation and human responsibilities, which flows into the following sub-themes:

- **Fear of losing control or driving pleasure:** one significant sub-theme is the fear of losing control or the pleasure associated with driving. For many drivers, especially those who enjoy driving as a skill or hobby, DMS represents an encroachment on their personal control of the vehicle. This sub-theme reflects concerns that automation, by monitoring and occasionally intervening in driving behavior, reduces the driver's role to that of a passive observer. The fear is that as systems like DMS become more integrated, the personal and experiential aspects of driving will be lost, leading to a more regulated and less enjoyable driving experience.

- **Automation Vs Human judgment:** another sub-theme is the tension between automation and human judgment. Drivers may feel that DMS, while useful, cannot fully replicate the nuance and context of human decision-making. Automated systems operate on predefined algorithms and thresholds, which may not always align with real-world driving conditions. This sub-theme reflects skepticism towards DMS' ability to make accurate judgments in complex or ambiguous situations where human experience and intuition are critical. Drivers may resent systems that override or second-guess their decisions, particularly in cases where they feel their judgment is superior to that of the machine.

- **Over-surveillance affecting comfort:** a related sub-theme focuses on how the awareness of constant monitoring affects the comfort of drivers. While safety is paramount, the constant oversight of DMS can create a sense of unease, where drivers feel they are being scrutinized in ways that impact on their comfort and peace of mind. This sub-theme reflects a broader cultural resistance to surveillance technologies, particularly when such systems are embedded in personal environments like vehicles. The discomfort caused by feeling constantly watched can diminish the sense of freedom that many associate with driving.

Optimism Surrounding the Implementation of Comfort Features

Despite the concerns raised about safety, privacy, and autonomy, participants also expressed optimism regarding comfort features enabled by DMS helping to overcome these problems. This theme encapsulates the positive reception of DMS also as a means of enhancing the driving experience through personalization and convenience, and not only as a safety device. In particular, it is possible to highlight the following sub-topics:

- **Personalized comfort settings:** a prominent sub-theme is the potential for personalized comfort settings. Drivers appreciated the possibility that DMS could use facial recognition and other bio-metric data to automatically adjust seat positions, climate control, and other in-car settings based on individual preferences. This sub-theme highlights how drivers envision DMS moving beyond safety to offer tailored experiences that enhance convenience and comfort, making driving a more personalized and enjoyable activity.

- **Convenience and efficiency:** another sub-theme focuses on the convenience and efficiency of AI-driven comfort features. Participants expressed enthusiasm for how DMS could streamline their driving experience, saving time by automatically adjusting settings without manual input. This sub-theme reflects the desire for efficiency in modern driving, where convenience technologies are increasingly valued. DMS, by anticipating and responding to the driver's needs, is seen as a way to simplify and optimize the driving process, particularly for those with busy or demanding schedules.

- **Positive reception of AI-driven features:** the final sub-theme is the generally positive reception of AI-driven features that enhance comfort. While AI was met with skepticism in the context of safety monitoring, participants were more open to its application in delivering comfort-oriented features. This sub-theme suggests that drivers are more willing to embrace AI when it is used to enhance their driving experience, rather than to monitor or restrict their behavior. This acceptance points to a potential pathway for greater DMS integration if it can balance its safety monitoring functions with features that add tangible value to the driver's experience.

4.5 Narrative of findings

In conclusion the reflexive thematic analysis of the interviews regarding the Driver Monitoring Systems (DMS) has revealed a complex interplay between the perceived benefits and challenges of the technology, structured around five central themes: Safety as a Priority, User Frustration with False Positives and Over-Sensitivity, Privacy and Data Sharing Concerns, Balancing Autonomy with Driver Responsibility, and Optimism Surrounding the Implementation of Comfort Features.

Participants universally recognized the potential of DMS to enhance road safety, especially in preventing accidents caused by driver fatigue or distraction. However, frustrations emerged regarding the technology's current limitations, particularly in its tendency to generate false positives and issue unnecessary alerts, which could diminish trust in the system and create new distractions for drivers.

Other concerns especially prominent were the ones regarding privacy, with fears of data misuse and anxiety about constant surveillance. Drivers were wary of how their personal and bio-metric data might be shared or exploited without their consent, highlighting the need for transparency and control over data collection and usage.

Additionally, the tension between driver autonomy and the oversight imposed by DMS was evident. Many participants expressed concerns that DMS could reduce the pleasure of driving and interfere with their control, particularly in situations where human judgment might conflict with automated interventions.

Despite these concerns, optimism was noted regarding the implementation of comfort features enabled by DMS. The ability of the system to autonomously personalize driving experiences, such as adjusting seats and climate control based on the driver's preferences, was seen as a significant benefit, contributing to the overall convenience and efficiency of the driving experience.

In summary, while DMS is largely viewed as a positive technological advancement with considerable safety potential, its success will depend on addressing key concerns around accuracy, privacy, and the preservation of driver autonomy, while leveraging its potential to enhance comfort and convenience in order to help to overcome and balance the discomfort caused by the previously cited problems, and adding tangible value to the driver's experience.

Chapter 5

Conclusions

The evolution of automotive technologies has brought both remarkable advancements and new safety challenges, especially as vehicles become increasingly automated. One of the most critical areas to address in this shift towards automation is the role of the driver and the need for effective Driver Monitoring Systems (DMS) in order to monitor the driver's disengagement, inattention, and drowsiness. This thesis has explored the historical development of automotive technologies, examined the current state of DMS, and analyzed the perceptions of key stakeholders through interviews and the use of reflexive thematic analysis to offer insights into the future of these systems and facilitate their global implementation.

5.1 Conclusions and future for DMS

DMS play a pivotal role in ensuring driver safety in semi-autonomous and fully autonomous vehicles. With the rise of automation, drivers are required to engage with vehicles in different ways, often transitioning between active control and passive supervision. This shift increases the risk of inattention, distraction, and fatigue, which are leading causes of traffic accidents. Current DMS technologies have made substantial progress, utilizing innovations like eye-tracking, biometric sensors, and AI-driven algorithms for real-time cognitive assessment of drivers in order to ensure early detection of disengagement and prompt timely interventions.

However, despite these technological advancements, several challenges remain. The accuracy of existing DMS still requires improvement. Moreover, the reliance on sensitive personal data raises significant concerns about user privacy, data security, and ethical use. Interviews conducted as part of this study highlighted in fact these privacy concerns as one of the most pressing barriers to the widespread adoption of DMS. Users are particularly wary of how their data is collected, stored, and

potentially shared by manufacturers and third-party entities.
Looking to the future, advancements in artificial intelligence and machine learning hold the potential to significantly enhance the accuracy and predictive capabilities of DMS. By integrating these technologies, DMS could become more sophisticated in identifying subtle behavioral cues and predicting disengagement before it leads to a safety risk. Moreover, the evolution of non-invasive monitoring techniques, such as radar-based systems and behavioral analytics, and a clearer communication to the end costumer could help overcome privacy concerns by minimizing the need for intrusive bio-metric data collection and clarifying transparently the use of the collected data.

5.2 Possible suggestions

To further improve DMS and increase their acceptance, several key areas need attention. It is clear how improvements in system accuracy are needed. From the empirical research it is clear in fact how false alarms are perceived as intrusive and as a serious discomfort to the driver's experience. Being distracted for no reason by DMS while being correctly focused on driving can cause a growing distrust in these technologies as it seems like, not only they wrongly absolve their job, but they do it in the complete opposite way, distracting the driver while he is concentrated. To assess this problem, advancement in key monitoring technologies like infrared cameras, eye tracking and behavioral predictive sensors, and the development of more accurate AI algorithms, all implemented in DMS, are fundamental. Through these improvements, a better monitoring even in poor lighting conditions and ambiguous situations could be achieved, limiting the number of false alarms and enhancing in this way the trust in DMS technologies.
Another fundamental step necessary is the development of non-intrusive monitoring techniques. To address the evident privacy concerns, future research should in fact explore these types of methods for monitoring driver behavior. Technologies such as in-cabin radar, which tracks movements without capturing personal data, or advanced algorithms that assess driving patterns, could serve as alternatives to more personal data capturing technologies, putting in this way the driver in a more comfortable situation.
From the results of the interviews emerged also how transparent data usage policies are a fundamental step to ensure customers' trust in the technology. Automakers and DMS providers need to adopt transparent and ethical data management, to this goal implementing clear communication about what data is being collected, how it

is stored, and who has access to it are all crucial steps to a more DMS knowledgeable user. This can be reinforced by adherence to stringent data protection regulations, ensuring user consent by providing a written contract and offering in this way a greater control over personal information.
This can be further facilitated thanks to governments' and industry bodies' intervention with the emission of regulations and establishment of standards for DMS technologies, assuring a consistent implementation across the automotive sector. Regulations should address both the technological requirements and the ethical aspects, fostering trust among consumers while ensuring that DMS meet high safety standards without giving up to crucial sensible data to its functioning.
In order to outweigh these problems, some more tangible value has to be offered to the end customer. In this light, an interesting added value could be the implementation of comfort features to the already present safety ones. This topic has already gotten major positive feedback through the empiric study, in particular by the use of the camera already utilized for driver monitoring, a face ID recognition technology could be implemented. This enables, in combination with other ADAS technologies through an E/E Architecture, the recognition of the person seated in the driver position and sub-sequentially the implementation of numerous features like for example the starting of the vehicle only when the owner's face is recognized and the possibility to autonomously adjust the vehicle's settings, like seat position, music, and air conditioning, as soon as the driver enters the vehicle or in response to a driver change.
This also reinforce the already existing concept of the car perceived as an ever more connected and smart device, bringing the necessity for automakers to develop specific software capabilities or to collaborate with already existing big software companies, also external to the automotive sector, in order to implement these extra features.
In the end, as everything in the vehicle is becoming more connected, seamless integration with vehicle systems seems like a logical step to adopt. As in fact vehicles continue to evolve into more autonomous systems, DMS should be fully integrated into the vehicle's architecture. This integration can facilitate better coordination between DMS and other systems such as ADAS, allowing for more holistic safety solutions and smoother transitions between manual and automated driving modes.

5.3 Final considerations

In conclusion, the future of driver safety, especially in the context of increasing automation, heavily relies on the continued development and adoption of Driver

Monitoring Systems. DMS technologies have the potential to significantly reduce accidents and save lives by ensuring that drivers remain engaged and alert. However, for these systems to reach their full potential, they must evolve to address the challenges of accuracy and privacy. This requires ongoing innovation, collaborative industry efforts, the creation of clear regulatory frameworks, and balancing its safety monitoring functions with features, like comfort ones, that add tangible value to the driver's experience.
Following these steps and by addressing the technical challenges and ethical concerns surrounding these systems, DMS can play a pivotal role in enhancing driver and road safety, shaping the future of automotive technologies.
As vehicles become more autonomous in fact, the role of the driver may continue to change, but the need for vigilant monitoring will remain crucial. By embracing technological advancements, responding to user concerns, and prioritizing safety, the automotive industry can ensure that DMS become a cornerstone of road safety in the future of mobility.

Chapter 6

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Ringraziamenti

Alla fine di questo percorso, voglio fermarmi un istante a guardare indietro, consapevole che nessuna meta importante si raggiunge mai da soli.
Il primo grazie va *a tutta la mia famiglia*: in particolare *ai miei genitori e a mia sorella*, che in questi due anni lontano da casa non mi hanno mai fatto mancare il loro supporto ed il loro affetto. Nonostante la distanza, mi sono sempre sentito vicino a voi.
Un pensiero speciale va *ai miei nonni*, a tutti loro, anche a chi purtroppo è venuto a mancare durante questo percorso. Siete stati per me un esempio prezioso, un faro di saggezza e valori, e porto con me tutto ciò che mi avete insegnato.
Ai miei amici dell'università, quelli 'vecchi' che vecchi non sembreranno mai, e quelli 'nuovi' con cui ho condiviso questo cammino. Grazie per aver reso unico questo viaggio. Le vostre risate, i confronti, e il sostegno reciproco sono stati fondamentali per rendere tutto più bello.
Un ringraziamento di cuore va *ai colleghi di Bosch Italia*: per i sei mesi meravigliosi passati insieme, in cui mi avete accolto con calore e rispetto, facendomi sentire parte di qualcosa di grande e mai l'ultimo arrivato.
A Loki ed Holly, per la compagnia e per aver contribuito ad alleggerire le giornate.
All'8etto, gli amici di una vita: quelli che, anche quando la distanza ci separa ed il tempo passa, sanno come far sembrare tutto immutato, come se non fosse trascorso nemmeno un giorno, davanti ad una birra ed una risata.
Un grazie speciale *alla mia Mimmi*, con cui ho condiviso questo percorso. Per avermi sopportato ogni giorno, sostenuto nei momenti più difficili e festeggiato con me quelli felici. Con te ho trovato una casa lontano da casa, perché in fondo casa non è un luogo, ma le persone che si amano.
E, infine, un grazie *a me stesso*. Perché in fondo questo percorso l'ho chiuso io, per aver conservato l'entusiasmo e la leggerezza, anche quando le cose sembravano pesanti. Perché alla fine la cosa più importante è saper dare il giusto peso alle cose ed affrontarle a cuor leggero, avendo sempre fiducia in sé stessi.

A tutte queste persone dico ***GRAZIE!*** Questa laurea è anche vostra.