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Undergraduate Thesis

Applications, Concepts & State Of The Art Informatics On Mobility, Cars & Smart Cities In The Internet Of Things

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Αφιερωμένο σε όλους όσους με υποστήριξαν μέχρι εδώ, σε ότι και όσους αγαπώ, στους car enthusiasts και στην χώρα του ανατέλλοντος ηλίου.
Η μόνη μάχη που έχασες είναι εκείνη που δεν έδωσες.

Περίληψη

Αυτή η πτυχιακή εργασία εξερευνά τις εφαρμογές, τις έννοιες, τις ιδέες και την τεχνολογία της πληροφορικής που βρίσκεται στο πεδίο της κινητικότητας, των αυτοκινήτων και των έξυπνων πόλεων. Η ταχεία πρόοδος της τεχνολογίας, ειδικότερα του Διαδικτύου των Πραγμάτων (IoT), έχει δημιουργήσει ευκαιρίες μετασχηματισμού για αυτούς τους τομείς. Τα σημερινά αυτοκίνητα έχουν εξελιχθεί σε υπολογιστές πάνω σε τροχούς, με τον αριθμό των αισθητήρων και τον ενσωματωμένων ηλεκτρονικών συνεχώς να αυξάνετε, ενώ τα μοντέρνα αυτοκίνητα κάνουν χρήση ακόμα και πάνω από 50 εγκέφαλους αυτοκινήτου/κεντρικών ηλεκτρονικών μονάδων ελέγχου (ECUs). Η αυτοκινητοβιομηχανία έχει στρέψει την προσοχή της προς την πληροφορική, αγκαλιάζοντας τεχνολογίες όπως η τεχνητή νοημοσύνη (AI) και η συνδεσιμότητα. Οι κατασκευαστές αυτοκινήτων μετασχηματίζονται σε εταιρείες κινητικότητας, παρέχοντας λύσεις κινητικότητας (MaaS, CASE) αξιοποιώντας την τεχνολογία και τα δεδομένα για τη βελτίωση της εμπειρίας των χρηστών. Στο μέλλον, τα οχήματα πιθανών θα μπορούν να προγραμματιστούν μέσω διεπαφών προγραμματισμού εφαρμογών (APIs) και εργαλείων ανάπτυξης λογισμικού (SDKs), ενώ θα δημιουργηθούν πλατφόρμες αυτοκινητικών μεγάλων δεδομένων. Το όραμα είναι να δημιουργηθεί ένας κόσμος όπου τα οχήματα θα μπορούν να επικοινωνούν μεταξύ τους και με το περιβάλλον τους, σχηματίζοντας ένα ελεγχόμενο καθολικό περιβάλλον, γνωστό ως Διαδίκτυο των Πραγμάτων (IoT). Αυτό θα γίνει δυνατό μέσω επικοινωνιών όπως V2X, V2V, V2I κ.λπ., οι οποίες θα φέρουν την επανάσταση στον τομέα της κινητικότητας, θα βελτιώσουν την αστική ζωή και θα προωθήσουν την αειφόρο ανάπτυξη. Επιπλέον, πλήρως αυτοματοποιημένα χαρακτηριστικά ασφαλείας θα ενσωματωθούν στα αυτοκίνητα στο εγγύς μέλλον. Αυτή η εργασία εξετάζει την διεπιστημονική φύση του πεδίου, αναδεικνύοντας την θέση της πληροφορικής στην αυτοκινητοβιομηχανία. Εξετάζοντας το σημερινό τοπίο, αυτή η πτυχιακή ρίχνει φως στις εξελίξεις, τις ευκαιρίες και τις πιθανές επιπτώσεις των τεχνολογιών του Διαδικτύου των Πραγμάτων στην κινητικότητα, τα αυτοκίνητα και τις έξυπνες πόλεις. Πεδίο συζήτησης αποτελούν οι υπερσύγχρονες τεχνολογίες, εφαρμογές, πρότυπα και έννοιες που σχετίζονται με την πληροφορική στον τομέα του αυτοκινήτου και πραγματοποιείται και εξερεύνηση των αναδυόμενων τάσεων. Η εργασία είναι δομημένη έτσι ώστε να παρέχει ολοκληρωμένη και σε βάθος κατανόηση των αυτοκινήτων και της κινητικότητας από την οπτική της πληροφορικής, περιλαμβάνοντας θεωρητικό υπόβαθρο, την κατάσταση της τελευταίας τεχνολογίας, ανασκόπηση της βιβλιογραφίας, λύσεις κινητικότητας και μία ειδική μελέτη περίπτωσης για την Woven City (”Υφασμένη Πόλη”) της Toyota - μιας πρωτοποριακής και φιλόδοξης έξυπνης πόλης που κτίζεται από το μηδέν, με έμφαση στη ”κινητικότητα” και προτεραιότητα στην ανθρώπινη ευημερία. Αναλύοντας την τωρινή σκηνή του αντικειμένου, συνθέτοντας και προβάλλοντας υπάρχουσες έρευνες, αναγνωρίζοντας κενά και εξερευνώντας αναδυόμενες τάσεις, αυτή η μελέτη προσπαθεί να φωτίσει τις εξελίξεις, τις ευκαιρίες και τις πιθανές επιπτώσεις των τεχνολογιών του Διαδικτύου των Πραγμάτων αλλα και

γενικότερα της πληροφορικής στην κινητικότητα, τα αυτοκίνητα και τις έξυπνες πόλεις. Στόχος της εργασίας είναι να προσφέρει πολύτιμες γνώσεις σε ερευνητές που ενδιαφέρονται για τη διασταύρωση της πληροφορικής και της τεχνολογίας των αυτοκινήτων, με στόχο την προώθηση της συνεργασίας μεταξύ των επιστημόνων πληροφορικής, των τεχνικών και μηχανικών αυτοκινήτων, της αυτοκινητοβιομηχανίας αλλά και να προβάλει το μέλλον της κινητικότητας.

Λέξεις Κλειδιά: Αυτοκίνητα, Κινητικότητα, Έννοιες, Πρότυπα και Ιδέες, Woven City, ECU, TCU, OBD, CAN-BUS, IoT, AI, V2X, V2V, VANET, Έξυπνη Πόλη, Υποδομές, Έξυπνη Κοινότητα, Υπερσύγχρονες Τεχνολογίες, Τρέχουσες Τάσεις

Abstract

This undergraduate thesis explores the applications, concepts, and state-of-the-art informatics in the realm of mobility, cars, and smart cities. The rapid advancement of technology, particularly the Internet of Things (IoT), has presented transformative opportunities for these domains. Today's cars have evolved into computers on wheels, with a growing number of sensors and embedded electronics while making use of even over 50 electronic control units (ECUs). The automotive industry has shifted its focus towards informatics, embracing technologies such as artificial intelligence (AI) and connectivity. Car manufacturers re-brand as mobility companies, providing mobility solutions (MaaS, CASE) leveraging technology and data to enhance the user experience. In the future vehicles might be able to be programmed through APIs and SDKs while automotive big data platforms will be created. The vision is to create a world where vehicles can communicate with each other and their surroundings, forming a controlled universal environment known as the internet of things. This will be possible through communications like V2X, V2V, V2I, etc. that have the potential to revolutionize the concept of mobility, enhance urban living, and foster sustainable development. Additionally, fully automated safety features will make their way to cars in the near future. This work delves into the interdisciplinary nature of the field, highlighting the integration of informatics in automotive. By examining the current landscape, this dissertation sheds light on advancements, opportunities, and potential impacts of IoT technologies in mobility, cars, and smart cities. It discusses the state-of-the-art hardware, applications, standards, and concepts related to informatics in the field of automotive and explores emerging trends. The thesis is structured to provide a comprehensive and in-depth understanding of cars and mobility from an IT perspective, encompassing theoretical background, state of the art, literature review, mobility solutions, and a dedicated case study on Toyota's Woven City project—a visionary and ambitious smart city built from the ground up with a focus on "mobility" and prioritizing human well-being. By scrutinizing the current state, synthesizing existing research, identifying gaps, and exploring emerging trends this study endeavors to shed light on advancements, opportunities, and potential impacts of IoT and generally information technologies in mobility, cars, and smart cities. It aims to provide valuable insights for researchers interested in the intersection of informatics and automotive technology, with the goal of fostering collaboration among IT scientists, car mechanics and technicians, or more broadly the automotive industry as well as project the future of mobility.

Keywords: Cars, Mobility, Concepts, Woven City, ECU, TCU, OBD, CAN-BUS, IoT, AI, V2X, V2V, VANET, Smart City, Infrastructure, Smart Community, State of the Art, Current Trends

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Abbreviations

IT	Information Technology
AI	Artificial Intelligence
HCI	Human Computer Interaction
IoT	Internet of Things
ECU	Electronic Control Unit
ECM	Electronic Control Module
PCM	Powertrain control module
CAN	Controller Area Network
OBD	On Board Diagnostics
RPM	Revolutions Per Minute
NaN	Not A Number
SAE	Society of Automotive Engineers
ICE	Internal Combustion Engine
EGR	Exhaust Gas Re-circulation
ABS	Anti-lock Braking Systems
TPS	Throttle Position Sensor
NRZ	Non Returning Zero
DLC	Data Length Code
CRC	Cyclic Redundancy Check
EOF	End of Frame
IFS	Inter Frame Spacing
PW	Pulse Width
HC	Hydrocarbon
NOx	Nitrogen Oxides
NO	Nitric Oxide
NO2	Nitrogen Dioxide
CO	Carbon Monoxide
CO2	Carbon Dioxide
O2	Oxygen
EGO	Exhaust Gas Oxygen Sensor
RFP	Request for Proposal
LGPL	Lesser General Public License
GPL	General Public License
V2X	Vehicle to Everything
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle
DSRC	Dedicated Short-Range Communications
ITS	Intelligent Transpiration Systems
EV	Electric Vehicle
BEV	Battery Electric Vehicle
TCU	Telematics Control Unit
TCM	Telematics Control Module
CPU	Central Processing Unit
GNSS	Global Navigation Satellite System
GPIO	General Purpose Input/output interface
LiDAR	Light Detection and Ranging
API	Application Programming Interface
SDK	Software Development Kit
IVI	In-Vehicle Infotainment
HMI	Human Machine Interface
DDD	Driver Drowsiness Detection
TRI	Toyota Research Institute
HRI	Honda Research Institute
CES	Consumer Electronics Show
ICT	Information and communication technologies
MaaS	Mobility as a Service
CASE	Connected Autonomous Shared Electric

Chapter 1

Introduction

1.1 Motivation

As i was entering the last year of my studies i was coming up with tons of ideas for what kind of project i could do as my thesis in order to graduate. I knew it had to be something i love and that can be combined sufficiently with information technology. So once again i was led to pick either music, cars or video games. I went from the point of having no idea of what to do with them to the point where my notebook was full of project ideas that were a bit too far fetched for the time limit of this thesis. Watching the 2023 Acropolis Rally and the talks taken place there about safety and novel technologies in cars as well as several interactions with car enthusiasts and other people about to make their way to the automotive industry but also Toyota's recent ventures inspired me even more to get involved more. The final push to pick this subject was the information around the mechanics of the automotive technology given freely online from some extremely smart people like Emmanouil Tatouris, Dimitris Korres, Michalis Kalogerakis, the Donut Media team and many more. My love for cars was there but being able to look at these people and their creations and how they work on them with so much care and intelligence while turning automotive creations into a type of art made me want to try as well. I wanted a way to connect with it more, and even though i started wrenching cars i also wanted to show that IT has its place even in this field. I have read works of IT and cars in the past but most of the time they were carried out by mechanics rather than information technology scientists or at least teams of the above and they were focused on certain subjects without capturing the whole magic, so this was all the more of a reason to check what i could do. Thanks to multiple factors influencing me on this choice i decided to take the initiative and create a dissertation dedicated to cars/mobility and make it something i as car enthusiast, as well as other people that are already in the automotive field will see and be proud i committed to it.

1.2 Context, Purpose and Objectives of the Thesis

Today's cars are going through a great technological shift. Many would think cars have little to nothing to do with information technology. They would be surprised after learning that most of their cars' operations are being monitored and carried out by a "computer" that is vital for their smooth functionality. Cars nowadays are basically computers on wheels. The amount of sensors and embedded electronics in cars is continually increasing as a result of technological advancements. A simple modern automobile may make use of over 50 electronic control units (or ECUs for short) in order to keep track of different variables and communicate with the rest of the sensors and electronics. The automotive field has a lot to gain from employing, and at this time, empowering already existing IT solution especially ones making use of novel AI technology.

During the last decade the attention of the companies is clearly steered towards the software running the vehicles compared to the focus on research and development of more traditional safety measures for the drivers and passengers as well as the engine's efficiency, the car's body and other mechanical parts. The software as a service model is starting to rise in the automotive industry with Tesla, BMW, Mercedes and many other well established companies embracing it as more and more advanced systems make their way into cars. Car makers (specializing in designing, manufacturing, and selling of automobiles) re-brand as mobility companies signifying a change in the industry and start to focus in providing transportation services through shared mobility options (MaaS, CASE), leveraging technology and data to connect users and enhance their experience. The vision seems to be a world where all technological products, including vehicles will be able to communicate with each other on their own thus avoiding human errors and providing a controlled universal environment embracing the idea known as the internet of things.

Vehicles nowadays get more and more robust features and automations especially with the rise of artificial intelligence. Some of these features will leverage interconnection with other vehicles and infrastructures. Autonomous driving, parktronic, vehicle health monitoring, driver profiling, collision and driver state detection, fuel consumption modes, trip computers, drowsiness detection systems, advanced driver assistance systems and many more wouldn't be possible without the help of informatics and AI which brought a huge change in the automotive world. Electronics and embedded systems are a vital part of the vehicle as a whole and the technology behind them is directly connected to several sub-fields of information technology including algorithms, security, AI, HCI, IoT, networking but even quantum computing and many more.

The rapid advancement of technology, particularly the Internet of Things (IoT), has brought forth transformative opportunities for various industries and sectors. In the context of mobility, cars, and smart cities, the integration of IoT technologies through communications like V2X, V2V, V2I et.c. has the potential to revolutionize transportation

systems, enhance urban living, and foster sustainable development. Future vehicles will be able to communicate with each other but also with everything else like, traffic lights, smartphones, roadside units the cloud et.c. through cutting edge technologies that are currently on the works and soon to be released. This dissertation explores the applications, concepts, and state-of-the-art informatics in the realm of mobility, cars, and smart cities.

This work focuses on mobility which refers to the ability to travel from point A to point B and differs from the focus on cars that are just a type of media satisfying mobility. Mobility as we know it will diverge immensely from what it is today and this work will show what is subject to change as well as how all of the things that will consist our future ”smart societies” plan to work. By scrutinizing the current landscape, this study endeavors to shed light on the advancements, opportunities, and potential impacts of IoT technologies in these domains. Furthermore, the dissertation seeks to explore the state-of-the-art informatics techniques employed in mobility, cars, and smart cities, including data analytics, machine learning, sensor networks, and other computational approaches.

The main overall goal of this undergraduate thesis is to research the technology behind cars with a focus on the ones connected to the world of informatics, additionally, showcase the interdisciplinary nature of the field and the future of humans and mobility. This work will highlight state of the art concepts and technologies, important recent technological advances in the automotive field, as well as the current state of the automotive (or should i say, mobility) industry. Engines, sensors, standards, everything will be thoroughly explained through an IT perspective, even mechanics since it’s one of the most important field in cars! The work gets in depth but the concepts are explained in a comprehensive manner with enough background provided and structure as if it was part of a book. Through an interdisciplinary lens, this research endeavors to contribute to the growing body of knowledge on the subject matter. By synthesizing existing research, identifying gaps, and exploring emerging trends, this dissertation aims to provide valuable insights for car enthusiast researchers in IT but not only limited to them!

Finally my wish and main incentive of this work is to open new horizons, help me cooperate with car technicians and mechanics, and of course, to have fun and make my way into the car enthusiast world the information technology scientist way!

1.3 Limitations

By taking a look at my a long TXT file stored in my dissertation folder where i wrote my initial ideas about this thesis, there are many ambitious ideas and tests i couldn’t showcase or conduct due to tool limitations, lack of advanced-high level knowledge on the field of car mechanics, lack of connections with mechanics with deep enough knowledge and willing to help, as well as time constraints regarding the writing of this dissertation.

There aren’t many freely available data-sets concerning hybrid vehicles and cycle-hybrid vehicles changing between Otto and Atkinson that are labeled based on that or

offering labels related to the tasks i intended to do. I don't own a vehicle or a driving simulator (I researched and learnt about CLARA but it would add too much complexity and make me stem away from the original incentive pulling me out of the time limits of this dissertation) and even though i reached out to several engineers and people on the automotive field in my area they couldn't help with the task of extracting data by such vehicles. The only vehicle i had access to was my family's car, a Hyundai Atos made at 1998 that was lacking modern additions and was involved in a no injuries crash at the months of the writing, so by the times i visited my hometown where it was, it wasn't usable. Due to these, and many other factors i would rather not disclose, i couldn't create my own data-set. The rest of the data-sets i found online were already almost fully covered and tested in already released papers. In addition to that my computer is pretty old and lacks computational power to perform intensive AI tasks, even though i tried performing some with WEKA, RapidMiner and Keras on some of the data-sets found online, my computer would either crash the program or just never end the task and overheat. Of course in the future i plan on creating my own data-set. Concerning the theoretical part of the work, due to the complex nature of automotive engineering and the continuous need for advancements in various technical aspects there is a good number of papers (especially ones coming from staff of big automotive companies) that are technical papers which my university doesn't have free access to thus requiring money in order to access them that i couldn't afford. Even though i searched for the emails of the authors sometimes to ask kindly if they could provide me at least with a preliminary version of their paper most of the time i couldn't find ways to reach out easily.

Lack of funds and equipment limited the practical and theoretical scope of this work but i did my best and i think the result is great nevertheless! Hope you enjoy reading!

1.4 Organization

The thesis starts with an introduction chapter inserting the reader to the theme of the dissertation and demonstrates the general incentive of the work.

The second chapter (Theoretical Background & State of the Art) will give the reader all the necessary theoretical background to conduct research on cars (in a simplified but in depth way to be easily understood by IT scientists), as well as explain the state of the art and the future and current concepts, standards and hardware that will be used in vehicles. The interdisciplinary nature of the field will shine as knowledge from different disciplines are needed to truly understand cars' working principles. The architecture of automotive electronic systems and mechanics will also be described and will showcase ways to extract, interpret and analyze car data.

On chapter 3 a literature review is conducted which contains a comprehensive explanation and commentary of some articles around the subject showing different applications of IT on automotive data which are deemed exciting and important while

assisting for in getting better understanding of AI work on cars. Additionally, there will be a section showcasing the focus subjects of the leading automotive companies and their R&D institutes and what they want to achieve by focusing their research in these subjects. With this useful insights about the future on the roads will be provided while the currents trends will be highlighted.

Later on, the thesis focuses on mobility solutions, connected vehicles, the car's position in the society, and smart city infrastructure and will explore the future of mobility through a dedicated case study to the Toyota's Woven City project, a dreamy and ambitious smart city meant to shape the future of smart cities, societies and mobility while being build from the ground up focused on "mobility" and prioritising human's well-being.

The final chapter will be devoted to a brief recapitulation, discussion of the most important developments and findings as well as reference to future work planned and some limitations of the thesis.

Chapter 2

Theoretical Background & State of the Art

Today's cars have multiple electronic as well as many mechanical parts and are products linked to many scientific fields including physics, chemistry, mechanics and informatics. In order to gain better understanding of the literature on the subject as well as the research conducted it is mandatory to know the fundamentals behind the technology in vehicles, including mechanics. Information technology shows its brilliance when it harmonically coexists and enhances creation of multiple fields of study. Reviewing the technology used in the automotive field and interconnecting it with knowledge from several fields will offer flexibility and get us used to the field's terms, providing easier understanding of the wide variety of possible concepts and applications. The theoretical background will be presented in a simplified way to be easily understood by IT scientists and will focus on the electronics and mechanics that will further concern us later on. In this chapter we will also discuss and provide compiled info about several future state of the art implementations, technologies and concepts on mobility.

2.1 Internal Combustion Engine

The engine is the "heart" of the vehicle and what makes the kinetic power to push the vehicle forward. Even though there are serious attempts to move to electric, and to be more precise, battery powered vehicles, and even though there where huge technological advancements on this field, vehicles powered by gasoline engines are the ones that still have the biggest portion of the market as well as the ones found overwhelming the public roads. The electrification of vehicles has gained significant traction but it is not yet the norm, the main focus of this work will be on internal combustion engines as they are an integral part of automotive, helps newcomers gain better knowledge but also because it is focused on by car manufacturers since they are facing significant pressure to enhance the environmental efficiency of their internal combustion engines in order to meet the increasingly strict emissions standards. We will need to clarify in a simple way how

internal combustion engines work in order to get better understanding of the research reviewed as well as the following terms and technicalities.

If we access the engine bay of a car we will immediately spot the engine block which covers the biggest portion. An internal combustion engine (ICE for short) is a heat engine able to convert thermal energy to kinetic energy that turns the vehicle's wheels. In most cars this engine operates by burning either gasoline or petrol. To understand how the engine makes this ”conversion” happen we need to take a look at what an ICE is made of.

In the left of picture 1 we get an internal view of an ICE and are able to see the basic parts. In an engine block we can find multiple of these cylinders as seen on picture 1. Today's conventional car engines (especially in EU) usually have 3 or 4 cylinders in an inline layout (meaning the pistons are placed in a straight line). The crankshaft at the bottom of the figure is what converts the reciprocating motion into rotational motion and used to transfer kinetic energy to the vehicle. The pistons through a connect rod are able to move the crankshaft by their forward and backward motion inside the combustion chamber. They achieve this movement with the help of combustions, that we will explain in the following subsection. The intake and exhaust valves are moved by the camshaft of the engine (not visible in the picture, but its a shaft with a series of pointed cams) which as it moves, the cams make the valves open in the appropriate time. The intake valve is responsible for allowing air-fuel inside the engine that will later be burned to release energy while the exhaust valve responsible for allowing the disposal of the burnt gases after the finish of the combustion. The fuel of course doesn't burn on its own, the spark plug seen at the top of the chamber light up to ignite it. With this we have covered the basic parts but in order to explain their working principle better we will have to take a look at the engine cycles.

2.1.1 Engine Cycles

Cycles are the principles on which an internal combustion engine runs at. They are called that way since its a repeating process that happens as an engine runs. There are many cycles with applications on ICE, with different principles and number of strokes, but there two of them that are used the most in the modern production vehicles.

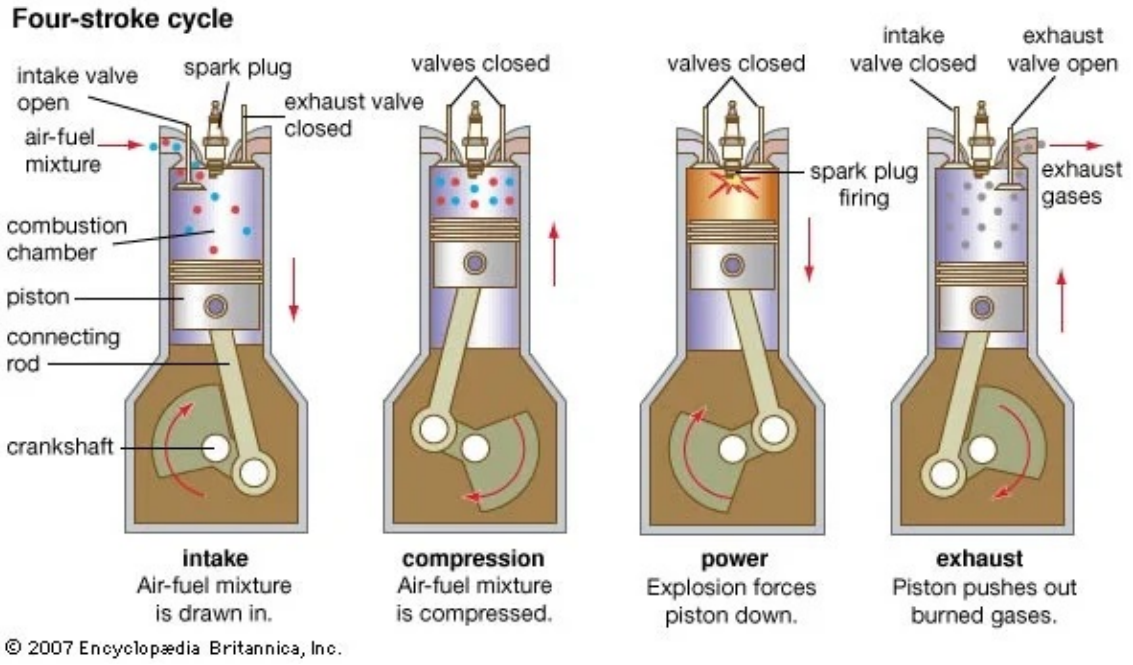


Figure 1. Basic engine parts of the internal combustion engine and the Otto cycle. As the piston moves during each stroke, it turns the crankshaft that then moves the vehicle's wheels.

Source: https://www.britannica.com/technology/four-stroke-cycle

2.1.2 Otto-Cycle

The most used so far is the one developed by Nicolaus Otto in 1876 in the Otto engine, the forerunner of today's internal combustion engines. The Otto piston cycle completes in the 4 strokes (intake, compression, combustion, and exhaust):

1. The first stroke is called intake stroke since as the piston moves downwards the intake valve opens and allows air inside the combustion chamber. After the intake valve is closed fuel is sprayed into the chamber in order to create a flammable mixture (in engine with direct injection systems). If not a direct injection system premixed air and fuel are inserted from the valve instead. The electronic control unit, or ECU for short, regulates air and fuel mixture as seen on the later sections.

2. Right after follows the compression stroke where the piston moves upwards compressing the air and fuel mixture. With both valves now completely closed and the chamber completely sealed the piston moves upwards compressing the mixture. This makes the temperature rise and allows more energy to be released.

3. Right before the end of the compression stroke the spark plug at the top side of the chamber fires igniting the compressed mixture leading to a phenomenon called combustion. As the mixture ignites the piston is forced downwards by the intense

pressure created by the expanding gases. The exhaust valve is opens slightly in order to make the pressure drop to almost atmospheric levels. This part of the cycle is where the energy is released.

4. The final phase is the exhaust stroke. At that time the exhaust valve opens to the full in order for the remaining waste gases to be expelled and make their way through the exhaust pipe, passing through the catalytic converted and then to the environment. The cycle can then be repeated as the piston is back to its original position.

2.1.3 Atkinson-Cycle

In 1882 James Atkinson created the Atkinson-cycle. The Atkinson cycle intended to be much more efficient than Otto, but in order to achieve this it sacrificed power density. Atkinson's cycle allows for much better fuel economy, less pollution, good torque and in all better efficiency. The working principle is mostly the same as the Otto cycle (which seems to be what allowed for its hybrid implementation in vehicles) but with a clever twist in the combustion process! Keep in mind that this the modern implementation since the original Atkinson cycle concept had different piston travel distance per stroke.

Compared to Otto, an engine running on Atkinson-cycle during a compression stroke doesn't close the intake valve immediately. Since there is an opening the piston doesn't have to exert as much force to overcome friction because of the cylinder's reduced pressure. Through the open valve, some gas will escape back into the intake manifold as the piston moves back to the top dead center, but it will be drawn back in the next time the valve opens. Just like that the cycle manages to increase fuel economy just by delaying the closing of the intake valve.

The cycle's advantages are clear though there are some notable drawbacks beyond the great sacrifice in power output an engine can make at a time and that's where it can be assisted from informatics and other fields. The Atkinson cycle can only run when the load is stable and the engine speed is low and steady without big fluctuations (e.g. in straight road) [87]. Even though there are some drawbacks it is very important to try and implement as well as enhance such technologies in modern engines as it focuses on efficiency and through that assists in pollution reduction.

Up until today these cycles met great enhancements in both efficiency and power output. Originally Toyota was the first to introduce the use of Atkinson in production vehicles especially in the hybrid electric as the well known and revolutionary Toyota Prius. Many other Japanese automobile makers including Honda, Lexus, and Mazda as well as American ones like Ford and many others have embraced the idea of Atkinson cycle and allow for its hybrid implementation with an Otto cycle or an Electric motor [96]. Today's vehicles make use of the benefits of this cycle in a very smart way that utilizes the electric control unit (ECU, explained in the next sections). Hybrids are able to interchange between cycles. The Atkinson cycle can run only on the aforementioned applicable conditions that

can be recognized by the ECU. On the other hand when the ECU senses the driver stepping on the gas beyond the acceptable limit it signals to change back to the Otto cycle. That way an equilibrium between power and efficiency as well as less pollution is achieved!

2.2 ECU - ECM

All cars nowadays make use of multiple electronic controlled units (or ECU for short) in order to process data collected from multiple sensor available in the vehicle and regulate certain events as well as take actions to ensure that the engine performs optimally. Cars used to be much more mechanical but today they get closer to computers on wheels while a simple modern automobile may make use of up to 70 electronic control units [5]. It is also many times called electric control module (ECM) as it usually is a rectangle shaped module but also powertrain control module (PCM).

The ECUs are able to interpret signals from multiple sensors and systems and are like computers fit for a vehicle. Back before ECUs were implemented in vehicles things where controlled mechanically. Now multiple parameters can be adjusted through the ECU and handle tasks like temperature regulation, variable valve timing, rev limit, as well as fuel delivery, optimal air and fuel mixture calculation and many many more. Thanks to that, programming was introduced to vehicles and enhancements for more efficient operation thank to the real-time understanding of events started to take place. Without a computer taking care of these tasks we wouldn't be able to have any modern additions like the ABS, traction control, knock detection, collision detection, airbag deployment, cruise control, driving assist etc. as well as the ability to monitor and log data. ECUs are responsible for all these kind of tasks that require interpretation of data provided from various other car parts. In later sections we will more thoroughly explain some of the most important sensors and data that can be extracted through the OBD port which gives us access to the ECU and will further understand the operations of the ECU.

2.3 CAN-BUS

We will get a little more technical and talk about networking in cars. For the data to get shared across the multiple ECUs and other electronics and embedded systems found in modern vehicles, a protocol that enables communication between them is needed. Controller Area Network Bus, or CAN-BUS for short, is a simple protocol used in the automotive industry for asynchronous communication between micro-controllers and in-vehicle devices in general. With CAN-BUS and the introduction of information technology in the automotive field the ability to implement a wide range of safety, economy, and convenience features using software alone came forth. For such features as the ones found in modern cars to be implemented mechanically/conventionally would be a complexity nightmare but also extremely expensive, or even impossible at times.

With that we are able to have an efficient and simple way of communication across all in-vehicle electronics.

CAN-BUS was initially developed by Bosch since 1983 and was officially released and presented in 1986 at the well known Society of Automotive Engineers (SAE) conference. The first CAN controller chips were brought to life by Intel in 1987 and later followed Philips Semiconductors [33]. In 1991 Bosch published CAN specification 2.0 which is the version used up until today. This standard is divided into two sections. Part A which refers to the conventional format featuring an 11-bit identification (usually called CAN 2.0A), while Part B contains a 29-bit identifier and is the extended format (CAN 2.0B). At the same year the first car that featured the CAN protocol was also released.

The automotive industry adopted CAN as an international standard with the number ISO 11898 from the International Organization for Standardization in 1993, and has been installed in every vehicle made to gather data from the car's sensors since. This ISO standard refers to the data link and high-speed physical layer of the networking OSI model (The Open Systems Interconnection model specifies seven levels via which computer systems communicate across a network) as we can see in figure 2.

As the industry demanded more bandwidth for in-vehicle networks, Bosch in 2012 released the CAN FD 1.0 featuring flexible data rate which is backwards compatible with CAN 2.0 devices. It also featured an extended payload up to 64 byte long a huge upgrade to the 8 byte one [38]. In 2015 CAN FD was also standardized as ISO 11898-1. Other revised CAN specifications have been standardized. ISO 11898-1 describes the 'CAN data link layer', ISO 11898-2 standardizes the 'Non fault-tolerant' CAN physical layer', and ISO 11898-3 specifies the 'Fault-tolerant CAN physical layer'. The ISO 11992 series (truck and trailer interface) and the ISO 11783 (agriculture and forestry machines) series specify application profiles based on the SAE J1939 network approach which is a standard focused for heavy duty vehicles [33]. Additionally to the above, CAN-BUS is a protocol used in the on-board vehicle diagnostics standard which is mandatory for all modern cars and we will also discuss in the following sections.

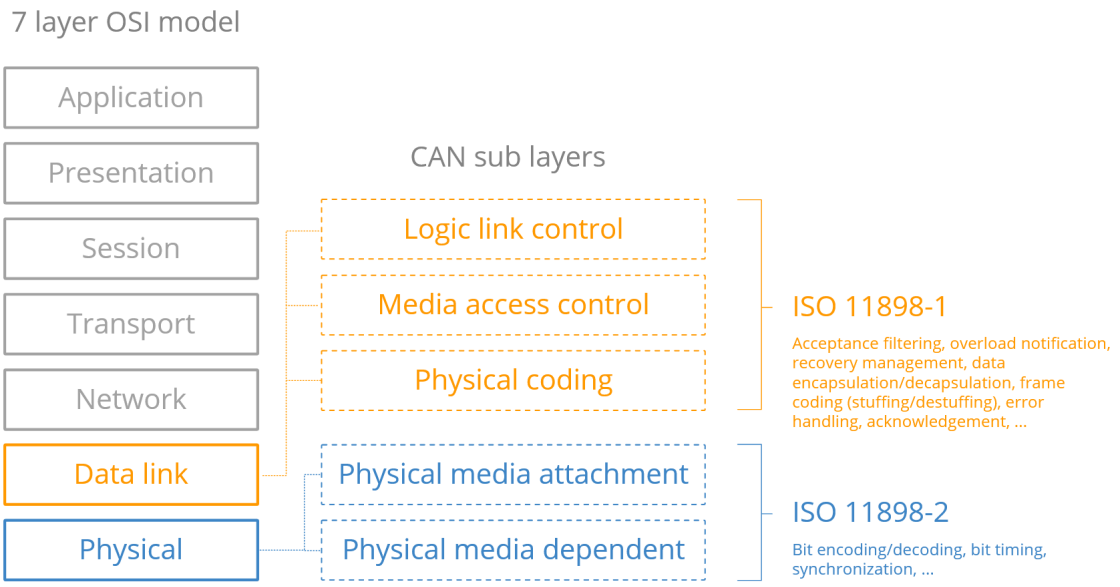


Figure 2. CAN-Bus standards and their place in the 7-layer OSI networking model

Source: https://www.csselectronics.com/pages/can-bus-simple-intro-tutorial

In the future there will be another update on the CAN-BUS protocol called CAN XL, as it is spotted on Bosch's website [14]. The CAN XL protocol will support payloads of up to 2048 bytes, give access to higher layer protocols such as TCP, and feature Ethernet frame tunneling. Moreover it will offer user-configurable speeds up to 20Mbit/s. These advancements enhance flexibility, speed, efficiency, and reliability. The protocol and physical layer specifications are established by CiA (CAN in Automation) in the CiA610 document series [15] and the specifications for the OSI Layer 1 and 2 are released as a DSP. According to [14] CAN XL's specifications will be added to ISO11898 when updated in the future.

As about the principles of the protocol, CAN-BUS is a multi-master message-based protocol where data are being send in frames and are transmitted serially. All ECUs also referred to as nodes interconnect physically with a conventional two wire bus that has a 120-ohm resistor on the termination ends. The access to information and systems is made easy since as previously mentioned, communication in the bus is asynchronous and there is no clock signal meaning any device is able to send any message at any point in time. When a message is transmitted, all the nodes will be able to hear it, each node can then check the content and decide whether to receive or ignore it. Collision avoidance is possible thanks to a frame ID priority system making communication across the great number of systems extremely efficient. [5]

CAN is comprised of two wires: CAN high (CANH) and CAN low (CANL). Vehicle-critical communication, such as RPM management, throttle control and braking, occurs on high-speed bus lines, whereas noncritical communication occurs on low-speed bus lines, such as A/C control, dashboard lights, central lock etc.. In figure 2 we observe the CAN

protocols and their place in the OSI model as well as the usual operations they take care of. The high speed CAN bus ISO 11898-2 can be found in the physical layer and is the most used and popular standard. It supports bit rates from 40 kbit/s to 1 Mbit/s. On the other hand ISO 11898-3 referred as low speed CAN supports bit rates ranging from 40 kbit/s up to 125 kbit/s and permits CAN bus communication to continue even if one of the two wires fail, because of that the term ”fault tolerant CAN” is also used for it [52]. The low speed bus can either follow a star network topology (where all nodes are connected to a central node), multiple star buses connected by a linear one, or a simple linear one.

Another feature employed in CAN is differential signaling, which means that when a signal arrives, CAN raises the voltage on one line while decreasing the voltage on the other equally. Thanks to that the system is fault tolerant, resistant to electric disturbances and electromagnetic interference, making it appropriate for automotive application where safety is the number one priority [83]. This is also the way bits of data are transferred through messages. As we can also see in figure 3 when CANH raises the voltage CANL drops it and vise versa. When the voltage is raised/dropped on the according lines the dominant differential voltage get to 2V resulting in a CAN ”low” signal, seen in the figure at CANRX which is the result of the CANH and CANL. Respectively, when the voltage on the lines gets to about the same the differentials gets to 0V thus signifying a ”high” signal on CANRX.

Because CAN is a low-level protocol, it does not offer any security measures by default. This is a major concern in the automotive industry today as more and more attacks targeting vehicles occur. Standard CAN implementations lack encryption, and are vulnerable to man-in-the-middle frame interception attacks. Security is implemented in a custom way from the automakers and there is no standard in the in-vehicle software security approach. Attacker’s ability to place messages on the bus, and the failure to establish proper security measures has resulted in variety of attacks. The rise in attacks as well as major trends like IoT, vehicle intercommunication, autonomous driving and cloud computing is sure to reshape the CAN technology.

2.3.1 CAN-BUS Frames

We talked about CAN-BUS, its working principles, the different frame lengths, types as well as differential signaling. Now we will focus on the frame layout which is basically the message or the packet that is send through the lines. In figure 3 we are able to see a complete CAN-BUS frame as it would be sniffed. We can also see the signals of CAN-High and CAN-Low as previously mentioned and explained the the final CANRX signal created as a results of their voltage.

The two main frame formats used in the CAN bus are standard (CAN 2.0A) and extended (CAN 2.0B). The conventional format A features 11-bit identification, and B a 29-bit identifier. As they are cross compatible in devices that are able to read the extended format their distinction is made with an IDE (Seen first in the control section of

the frame) bit transmitted as dominant for the A format and recessive for the B.

Additionally there are four different frame types in CAN:

- **Data frame**: Containing node data for transmission
- **Remote frame**: For requesting the transmission of a specific identifier
- **Error frame**: Transmitted by any node when detecting an error
- **Overload frame**: Used to inject a delay between data or remote frames

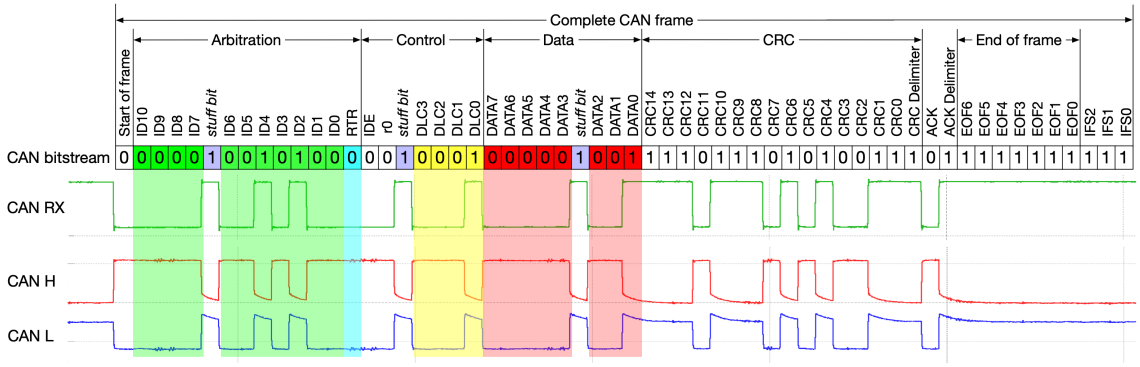


Figure 3. A complete CAN bus frame, including stuff bits, a correct CRC, and inter-frame spacing. The final result (CAN RX) can be obtained after adding both CAN-High and CAN-Low signals together.

Source: https://commons.wikimedia.org/wiki/File:CAN-bus-frame-with-stuff-bit-and-correct-CRC.png

All frames start with a start-of-frame (SOF) bit that signals the start of the transmission. Then an Arbitration field follows for the ID frame identifier. Since in CAN every device listens to all the packets sent by any node and any node can transmit in any point, it makes use of carrier sense multiple access with collision detection (CSMA/CD for short) [66] in order to ensure that highest priority messages are transmitted first. CSMA/CD is a well known CSMA protocol for regulating communications and it was even used in early Ethernet. The priority of the message is determined by the identifier's numerical value in the arbitration field. The lowest number has the highest priority. The Remote Transmission Request bit (RTR, light blue color in the arbitration field) signifies if this is a data or remote frame, it takes the value 0 for data and 1 for remote.

To maintain synchronization, stuffed bits are used (light purple in the figure) found in several fields in the frame. This bit of opposite polarity is inserted after five consecutive bits of the same polarity. This practice is called bit stuffing, and is necessary due to the non-return-to-zero (NRZ) coding used with CAN. The stuffed data frames are destuffed by the receiver. [5]

The control field apart from the IDE bit it contains 4 DLC bits (Data Length Code) that specify the number of bytes to be transferred. This would be either 0 to 8 bytes for Simple CAN while as aforementioned CAN-FD's payload is able to go up to 64 byte. The r0 bit in the control field is just a reserved bit for the packet that can either be dominant or recessive.

The data field simply contains the data to be transmitted. Right after there is the CRC field which is used for the cyclic redundancy check that ensures data integrity. Each recipient who accepts the message recalculates the CRC value and compares it with the value delivered. If the CRC fields don't return the same value after the recalculation an error flag is set. The ACK slot indicates if the receiver node has acknowledged and received the data correctly. Finally there is an End-of-frame (EOF) section that must be full of recessive bits. The last 3 bits are referring to the Inter-frame spacing (IFS) and should be all recessive (1). This part also carries the bus idle time (amount of time that the channel needs to be free of transmission). No node is allowed to initiate a transmission during the intermission, if a dominating bit is detected in IFS, an overload frame will be created.

2.4 OBD-II

In real world applications two ECUs should be able to connect with each other and transfer data through the CAN protocol. Even though CAN offers a way to connect this is insufficient to accomplish communication between the ECUs. In order for this to happen ECUs must also be able to detect, utilise and interpret the data received from each other. To make all ECUs "speak the same language" the OBD-II standard (On Board Diagnostics 2) was introduced. You can think of On Board Diagnostics as the language devices use to communicate (like Greek or Japanese) and CAN-BUS as the method, (like phone or message apps are for humans) [52]. OBD-II is also usually the easy go-to method of extracting data from vehicles.

In software OBD-II is a higher level protocol used along with CAN. During communication of in-vehicle devices that use the standard the OBD-II message is generated, then this message becomes the content of the CAN message that is sent on the bus. When the ECU receives the CAN message it makes the same process in reverse to obtain the OBD data [74]. On picture 4 the five OBD-II compliant signal protocols are presented. Most vehicles implement only one of them. Based on the region that the vehicle is designed to be sold different protocols are more used than others. ISO15765-4 is the one mostly used nowadays while for older EU vehicles ISO9141-2 is very common. The protocol utilized is frequently deduced based on which pins are present on the J1962 connector as seen on the right side of the picture.

As its name suggest OBD is able to diagnose problems in a vehicle and it is used as a diagnostic tool by technicians. Thanks to it dashboards lights referring to errors also light up to warn the driver when OBD detects something. To achieve this and also

help mechanics in the maintenance process the OBD-II standard has an extensible list diagnostic trouble codes (or DTCs for short) with many of them standardized by SAE. DTCs are 4-digit codes, preceded by a letter. For example P0420 hints a Catalyst system that under-performs. The front letter in DTCs refers to the part that might malfunction P is for powertrain (engine and transmission), B for body, C for chassis, and U for network. The first number can take values from 0-3, if its 0 it means that the DTC is a standardized one by SAE and the code is generic, 1 indicates a manufacturer-specific code while 2 or 3 are less usual and depend on the letter, but typically its manufacturer-specific. The second number reveals a subsystem fault and take values from 1-8 based on the referred subsystem (e.g. emissions, ignition etc.) while the last two numbers are used to identify the root of the exact issue [63]. DTCs can be logged and make vehicle maintenance way easier.

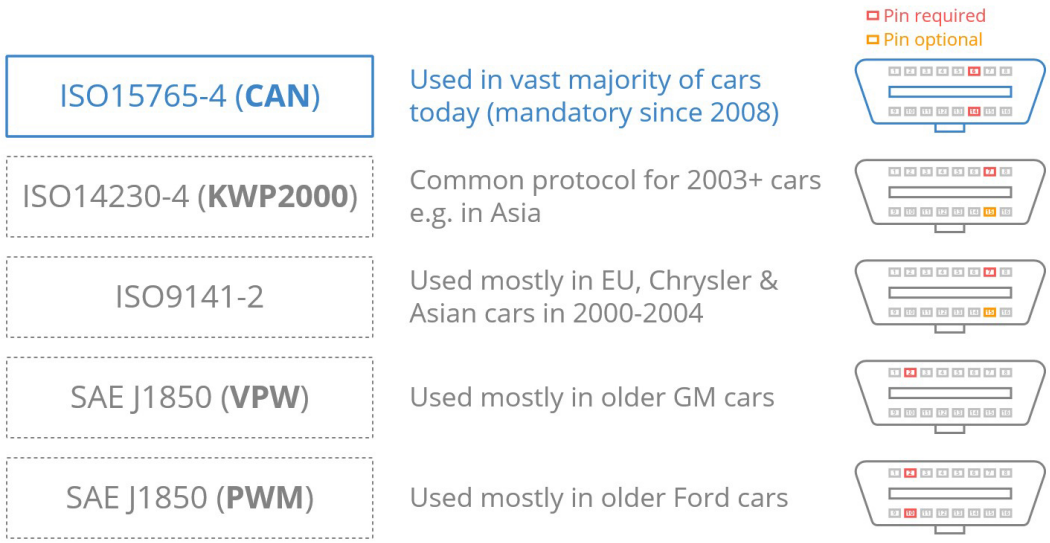


Figure 4. The five OBD-II compliant signal protocols.

Source: https://www.csselectronics.com/pages/obd2-explained-simple-intro

Apart from DTCs, OBD is able to return On-board Diagnostics Parameter IDs (also known as PIDs) that are basically codes used to request data from a vehicle. Getting the requested bytes of data retrieved from PIDs and using formulas we are able to get human-readable data like Temperature, RPM, Emission requirements and many more data retrieved from the aforementioned car sensors.

On-board diagnostics specify both hardware and software and it is not just a communication standard. It also specifies the OBD-II connector (right side of picture 4), a mandatory piece in vehicles that gives us access to important information from the CAN-BUS. The ports original objective was to give to car mechanics access to certain data like error codes in order to perform easier maintenance on the vehicle as well as data related

to emissions and the identity of the car. The ports capabilities sparked great interest in the research world and many researchers and enthusiasts were able to get their hands on real time powertrain data thanks to the port's existence and widely available OBD tools that we will mention later. The port is usually present in the passenger compartment or near the steering wheel column, but they can be found in more unconventional places like under the steering wheel and above the pedals. That's where my family car's OBD port was located at least, as seen in picture 5.

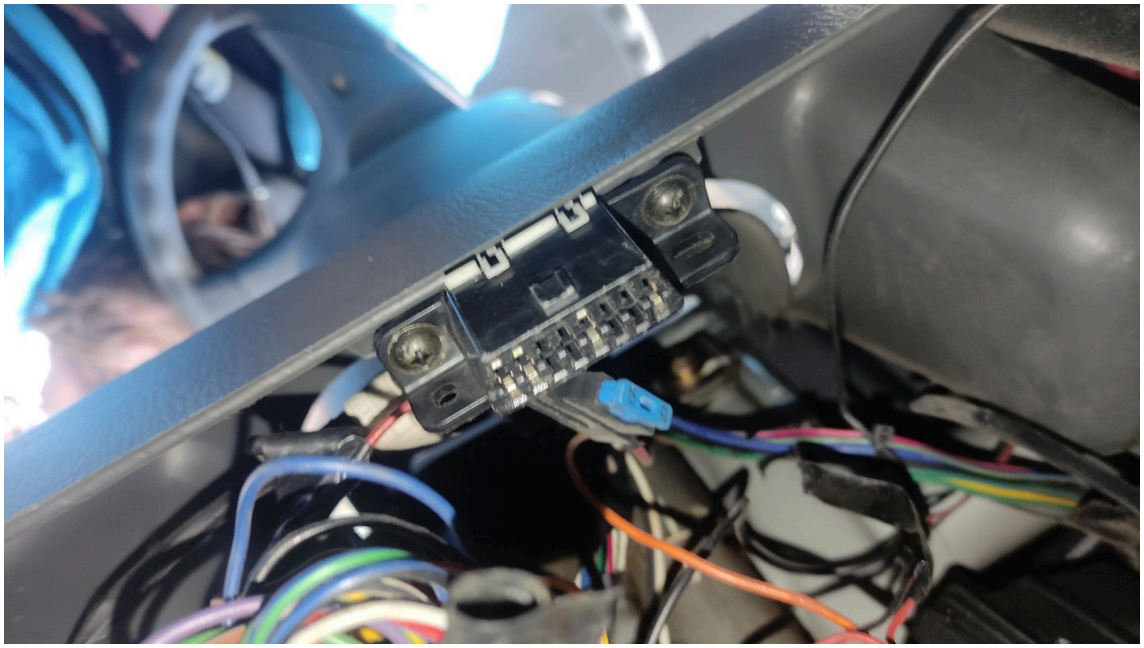


Figure 5. OBD-II port from my family's car a Hyundai Atos model 98'

OBD history has started at 1988 with the "creation of OBD-I" by CARB (California Air Resources Board), of course the term OBD-I wasnt used up until the introduction of OBD-II. At that time CARB required that all vehicles sold should have some basic OBD capabilities, so these specifications were referred to as OBD-I later on. OBD-I connector and protocol wasn't standardized. SAE on the other hand recommended that a standardized diagnostic connector and set of diagnostic test signals be established [6]. OBD-I was developed as a tool for the fight against the growing pollution and the incentive was to encourage auto manufacturers to design reliable emission control systems. It failed to accomplish this as there was no standardization while the creators at [11] report that the systems were not calibrated to a specified level of emission performance so they couldn't fit for any use case and were restricted to monitoring only a few of the emission-related components.

Aiming to conduct vehicle emission testing and monitoring, beginning in 1996, CARB issues the revolutionary OBD-II specification, as suggested by SAE, and requires that all automobiles sold in California implement it. The OBD-II connector was standardized through SAE J1962 along with DTCs and is now required to be within 0.61 meters from

the steering wheel. In 1996 OBD-II becomes mandatory for USA vehicles. Following the advancements, in 2001, EOBD (the European version of OBD) becomes mandatory for all gasoline cars in EU while in 2003 the same applied for diesel powered vehicles. An OBD-1.5 version also existed and it was a partial implementation of OBD-II used in some GM vehicles in the years 1994 to 1996 [6], of course this is not an official term.

As described in the possible extracted data section, OBD has gone a long way and nowadays it is able to offer great amount of reliable data apart from diagnostic codes. The data that are able to be extracted are thoroughly explained in that later section.

2.5 The future: OBD-III

OBD-III is the very controversial advancement over the OBD-II standard that is supposed to offer telematic functionalities useful to IoT and minimize the delay between detection of an emissions' malfunction and repair of the vehicle. OBD-III is not an official standard and very little to no information apart from the general incentive behind this future standard is released to the public. As of 2023, the year of writing, it has not yet been implemented anywhere as originally described. As the purpose of this work is to research the technology behind cars from the information technology perspective a review on whatever was possible to be found about this future standard is deemed useful.

As said previously OBD's initial purpose was emission control. CARB on [11] reports that our single largest source of smog-forming pollutants is the millions of automobiles on the road and the rising kilometers they cover each day. Improper maintenance or malfunctioning components can cause vehicle emission levels to skyrocket and according to studies, around 50% of overall emissions from late-model vehicles are excess emissions caused by malfunctions in emission-related parts [11]. Such claims that finding a way to quickly identify problems and act as fast as possible to repair them could dramatically decrease pollution while also increase safety.

Manual emission control tests is the current way of avoiding the above. They are both expensive to perform as well as time consuming, and the most important is that they take place every year or two. This means that for this whole time period between emission checks (or even after that counting illegally running vehicles and ones passing checks deviously) there are malfunctioning or modified vehicles that both excessively pollute the environment while at the same time might be unsafe for similar reasons in other parts.

2.5.1 Mechanisms and Possible Functionalities

The main purpose of OBD-III is to eliminate the stationary check-ups and rather send real-time data directly to servers thus knowing when a malfunction appears on a vehicle in no time and immediately request its repair. The great upgrade of the OBD standard will for sure include remote access to CAN data without the owner's interaction.

OBD-III will achieve its goal by adding telematics to all cars. Since OBD-II already

has the capabilities to communicate with the ECU and offer such useful and reliable information it is a matter of an easy upgrade to the standard for today's technology to make it go wireless. A simple roadside radio transponder installed on every car, just like the ones found in bridge tolls would do the work but local station networks, cell phones and satellites which have also met great technological advancements can also be used for this communication. Then data like the vehicle's identity, logged DTCs, real-time OBD data and literally any data that flows in the vehicle can be transmitted through WiFi to a centralized server for inspections. The owner's linked data can also be found and even if there are multiple owners we can know exactly who drives it thanks to machine learning that makes this identification an extremely easy task as we will see in the literature review. We can also easily identify reckless driving and excess emissions even without DTCs sent but simple OBD data.

Apart from the emissions checking collecting and analysing vehicle data in real time can benefit many other fields and will be extremely useful at our future smart cities in the IoT. For our current societies a first beneficiary would be insurance companies since they could monitor the vehicles well-being from afar. Additionally it could provide cooperative techniques for police pursuits as some described in [12]. Thanks to certain devices a vehicle would receive a coded radio frequency signal that would produce progressive speed reduction or shut down the automobile. Additionally in [12], which includes part of an RFP (request for proposal) of CARB stating mechanisms and functionalities of the OBD-III, there are claims that such systems are planned for implementation in the year 2000 and later. They also acknowledge that the most difficult issue to overcome is public acceptance and they propose including this technology as part of a package including other benefits (like anti-theft and pollution smog readout devices) as a strategy for gaining public acceptance.

CARB has already started testing roadside readers for OBD-III since 1994, and were able to capture data from eight lanes of traffic moving at 100 mph [83]. Then the VIN and the DTCs would be sent to a nearby transponder if the system detected defects. The readers may be utilized from a fixed position or with portable or mobile devices. Many devices today already facilitate transfer of CAN or OBD2 data via WiFi/cellular (e.g. the CANedge2 WiFi CAN logger by CSSElectronics, or the OBD-II/CANLogger by IOSi) [53]. The move to a wireless standard accomplishing those goals seems rather trivial and will be convenient and cost-effective, but it also raises concerns for mass surveillance and faces many other legal issues.

2.5.2 Legal Issues

OBD-III is a very contentious upgrade to the OBD-II standard. According to SEMA (Specialty Equipment Market Association of the automobile aftermarket) on [12], OBD-III imposes sanctions based on ”suspicionless mass surveillance” of private property due to the following incentives in the use of this technology:

- Random, possibly frequent testing
- No advanced knowledge vehicle will be tested
- Results of testing not immediately available (unless roadside pullover follows)
- No opportunity to confront or rebut
- Possible use of system for other purposes (Police pursuit/immobilization, tracking, cite speeders)

OBD III is seen as an invasion of privacy and that's totally a serious concern. A small trip i did with my uncle in his Ford Puma allowed me to understand more about the current matter. The infotainment system on such vehicles already offers an abundance of information thanks to collected data. In the dash we were able to see the maximum allowed speed allowed in the road we were going as well as other warning signs, vehicle as well as road condition and many more. Collision avoidance was constantly turning on during certain overtakes that were deemed dangerous while our location was always known and other data from the ECU could easily be used to identify the driving style and create profiles. Today's vehicles very much know what we do wrong. This is just the tip of the iceberg and just some simple examples from what we already see in modern cars.

As a Ford executive once said at a CES (Consumer Technology Association) convention panel "We know everyone who breaks the law, we know when you're doing it. We have GPS in your car, so we know what you're doing. By the way, we don't supply that data to anyone," [51]. Of course he later retracted his statements by clarifying "I absolutely left the wrong impression about how Ford operates. We do not track our customers in their cars without their approval or their consent," [50]. Even though the initial statement is controversial and sparked backfires, the facts previously presented should make it less surprising. Even though the technical upgrade might be trivial, there are several concerns that should be solved in order for our societies to take the next great leap concerning mobility and smart future.

2.5.3 Open vs. Closed Standards

Additionally to all the above there are also questions rising about the openness of the protocols and standards in the future. We should know that the initial purpose of OBD-II was for stationary emission controls and checks performed by certified technicians. In the past we've seen companies referring to this matter, Christoph Grote, Senior Vice President Electronics at BMW had claimed that "This access path will be closed bit by bit" [59]. He added that "The access path will only be deactivated when the cars are driving; as long as the wheels stand still, nothing will change.". He also clarified that "OBD has been designed to service cars in repair shops. In no way, it has been intended to allow third parties to build a form of data-driven economy on the access through this interface".

Of course that is absolutely understandable and logical given the original aim of the OBD in general, but it is also extremely important to understand that limiting this power of collecting data from genuinely owned vehicles would probably limit the advancements of the field. Countless papers on the literature review chapter make use of this exact method in order to obtain data. Closing down on the standard would hurt the enthusiast and even more the academic community that is able to offer so much. Even this work might not have been possible if not for the open approach. It is sad to see that there are thoughts of ”closing down” the OBD standard. If it wasn’t for the openness of this technology countless of useful and important research wouldn’t have been conducted. Certainly though there are always risks in giving easy availability to such data and there are several known attacks utilizing the OBD protocol. Still we don’t know if making the OBD usable by third parties only when a vehicle is stationary would actually tackle this and we don’t know how that would be implemented and if hackers would try to bypass this limit, no standardization is also a problem. Generally experts on [89] deem attacks through the port unlikely and with low benefits, we will later see a game theoretical approach to hacking and remediation of attacks.

To be fair though BMW in the same presentation at the 19th VDA technical congress proposed that data will instead be collected by the auto-makers and will be made accessible to interested third parties through a neutral server, and also claimed that this architecture is intended to improve security [59]. BMW in 2019 at [1] announced that BMW group will be providing traffic data for the first Neutral Server Project in Europe making them freely available to everyone under the Creative Commons licensing model. This certainly is not the same as getting direct access to CAN-BUS and automotive companies are the owners of the data while there is no flexibility.

There are several other companies (in the field of automotive, IoT and Telematics) and individuals that have seen through this and believe that is the automotive companies’ way to compete with the rising IT giants like Microsoft, Apple, Google and Amazon and with this politics the car manufacturers will be in control of the automotive big data [78], [53]. On a business insights article at Navixy’s website [89] opinions from certain company representatives voice that this approach could be an attempt to collect and sell data. Others supported that this idea might have gotten traction due to the then recent Volkswagen carbon emission scandal [7] and that we still have to wait and see the kind of implementation of the ideas presented. As seen on [1] BMW actually attempts to complete the initial concept.

A great article by Matthieu Noel (Principal at Roland Berger) [78] on the other hand says that the incentive of ending open access to OBD car data is not novel. He also highlighted that companies wouldn’t be able to directly monetize data since they do not own them but they would be able to charge for access to their cloud platform and APIs. This seems possible as automotive makers follow the software as a service approach for certain included features in their vehicles. Of course no one would deny that an open,

standardized and neutral platform that securely and freely offers data serving for the security enhancement and advancements on the field would be more than welcome. Data seems to be the king and key for success in today's business and controlling them would certainly give automakers great power with the rise of IoT and smart cities where mobility will play a major role. Hopefully the rise of OBD-III will bring a better tomorrow for everyone!

2.6 Sensors

Today's vehicles utilize a plethora of sensors that are able to monitor the conditions of certain aspects of the car and send the information over to the ECU which in turn makes adjustments in order to keep the vehicle running optimally. As automotive technology advances more and more sensors are introduced that are used to collect data and offer new features while they also get more and more precise.

There are hundreds of sensors that can be found in a modern vehicle. All of them interconnect with technologies and protocols that were aforementioned. Each sensor has its own functions and working principles while each offers different kind of data. The number of sensors used is really big and the variety of functionalities is even broader than one would think. Even though different, every sensor's objective is to send its monitored data over to the ECUs in order to run algorithms that take actions based on the sensors' feedback and keep the vehicle in perfect running conditions.

Since the possible sensors used in a vehicle are way too many to include and their working principles might insert unnecessary complexity on the matter that is not needed in our case, we will provide a table of the most known sensors and ones fundamental to any modern car. Of course this table shows only a tiny section of all the possible sensors and offers an extremely brief one line explanation just for the shake of getting to understand the car's system. As the work progresses, any of these sensors or even additional that will be referred if they are needed as well as the values their report will be thoroughly explained at the time of reference. Some of the sensors featured in modern cars are featured in picture 6.

Sensor	Functionalities
Air Bag Sensor	Monitor variables correlated to forceful collision
Proximity Sensors	Detect objects in close proximity
Tyre Pressure Monitoring Sensor	Reports low tire pressure when detected
Vehicle Speed Sensor	Monitor the speed of each wheels speed
Speed Sensor	Monitor the speed of each wheels speed
Throttle Position Sensor	Reports the position of the throttle valve
Temperature Sensor	Monitors the temperature of the engine coolant
Intake-Air Temperature Sensor	Monitors the temperature of the air incoming to the combustion chamber
Fuel Temperature Sensor	Monitors the temperature of the fuel
Air-flow Sensor	Measures the density and volume of the air entering the combustion chamber
Lambda Sensor	Indicates rich or lean mixture as it measures oxygen levels in exhaust gasses
NOx Sensor	Measures the Oxides of Nitrogen emissions in the exhaust gases.
Knock Sensor	Detects engine knocks (uneven/unusual combustion)
Camshaft position sensor	It keeps track of the location and timing of the camshaft
Mass Air Flow Sensor	Measures the mass of incoming air
Manifold Absolute Pressure Sensor	Measures the air pressure in the manifold
Combo Steering Torque Sensor	Measures the speed at which the steering wheel position changes and the torsion bar angle. Its used for electric power steering systems.

Table 1. Basic Car Sensors and Their Functionalities in Summary

2.7 Ways to Extract CAN-BUS Data

Thanks to the brilliant OBD-II port as well as other widely available tools, applications and devices, even car enthusiasts, researchers and people that weren't previously associated with the automotive field are able to get their hands to precious powertrain data. The ways to capture powertrain data from a vehicle are many and vary, but we will mention some of the most used ones so far, some of them can be seen in the middle portion of picture 6 while the caption explains the information flow.

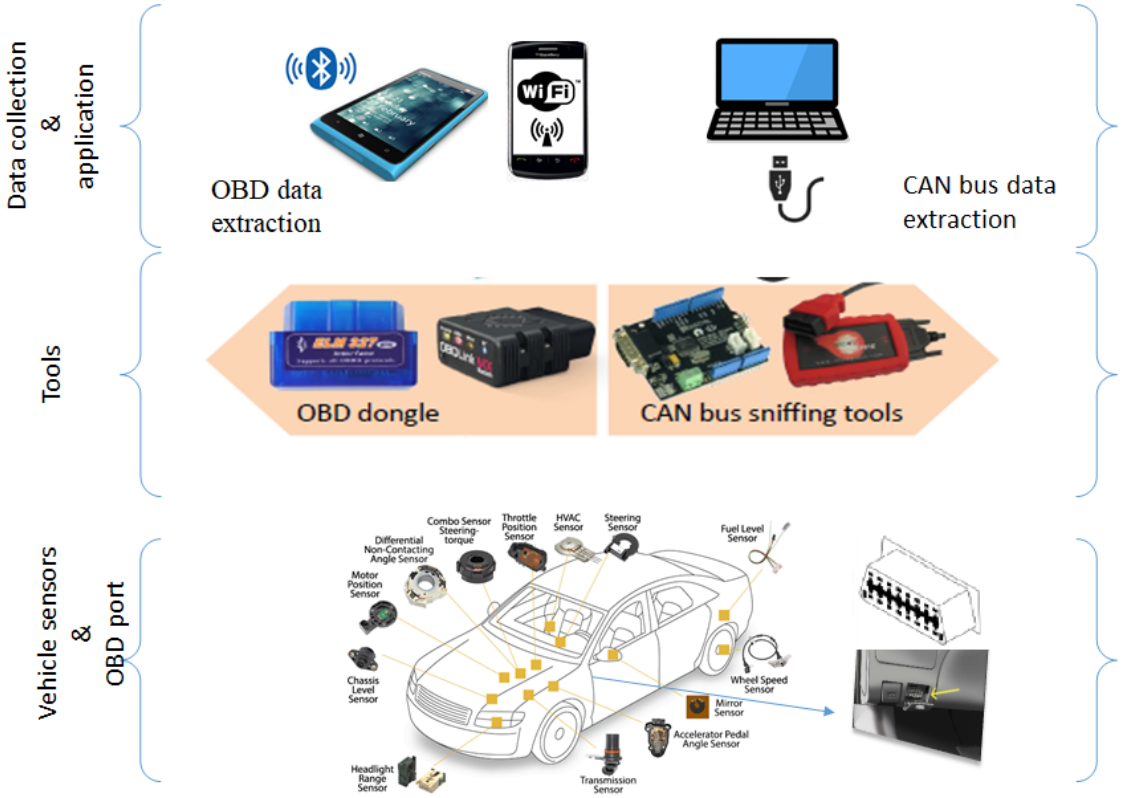


Figure 6. In-Vehicle (telematics) data acquisition through OBD-II interface. Devices and Applications connect through OBD readers and extract data from the ECU that were obtained from the vehicle's sensors.

Source: https://github.com/Abeni18/Deep-LSTM-for-Driver-Identification-

2.7.1 General OBD Scanners

OBD scanners and dongles are widely available and depending on their quality and cost they might use different micro-controllers and offer different features and ways to connect. When mechanics want to extract data from the vehicle in order to locate malfunctions they usually make use of an OBD scanner that connects to the OBD-II port. They usually have and LCD screen and connect by wire to the OBD port. They are able to read DTCs, clean errors and display various info useful for repairs. Connecting to an external device is also usually possible. Usually those types of scanners specified for mechanics are an all-in-one package that have their own software and hardware combined in a single device and don't require the use of laptops or smartphones, thus improving the workflow of technicians and mechanics. Apart from the mechanic specific readers there are smaller hand-held dongles that connect to the OBD port and are able to extract real-time data when accompanied by devices like smartphones and computers.

2.7.2 ELM

The most used controller (especially amongst enthusiast and researchers) is the ELM327, a very cheap and compact programmed micro-controller produced for translating OBD data. It makes use of a PIC18F2480 micro-controller and is implemented by multiple vendors apart from ELM. The most popular blue ELM327 can be seen on the left of picture 6. It is basically a very small OBD dongle that connects to the OBD port in order to provide data. For the user to receive the data another device like a smartphone or a computer is needed to read and interpret the data. The ELM327 controllers depending on the implementation can communicate either by Bluetooth, Wi-Fi or even through a wired connection by USB or RS-232. An appropriate application should also be installed on the desired device that is able to understand the real-time data sent from the controller.

The ELM327 is basically a PIC18F2480 chip that has been modified with proprietary code by ELM Electronics. When ELM Electronics marketed version 1.0 of the ELM327, the copy protection function of the chip was disabled thus allowing for pirates to read the firmware as a binary blob and then buying the exact same chip to create unofficial replicas. Copies of the ELM327 were extensively distributed, however there have been reports of issues with unofficial copies [8]. So it is advised to be careful when picking such dongles.

2.7.3 Arduino & Raspberry

Arduino is an open-source electronics platform based on easy-to-use hardware and software and is one of the leading manufacturers of single-board micro-controllers for digital devices. The open-source approach of the company is what made Arduino the most loved. Its software is distributed under the GNU Lesser General Public License (LGPL) or the GNU General Public License (GPL). The hardware components are released under a CC BY-SA license. This allows anybody to produce Arduino boards and distribute its software thus finding an abundance of cheap reliable boards on the market to use in projects even when not directly made from Arduino.

Essentially, the hardware consists of a board with a microprocessor on it. Through a computer we are able to upload code written to the Arduino circuit board. Arduino is able to be paired with countless chips and micro-controllers. In order to get access to CAN-BUS with Arduino a CAN controller is needed. The most used in this case is the MCP2515 which is a standalone CAN controller that complies with the CAN specification and can send and receive both standard and extended frames as well as remote ones. An extended description of the controller is given by Microchip at [13] along with figures about the protocol and the controller's layout. An ESP8266 Wi-Fi module might also come in handy for wireless capabilities. This microchip is a very low-cost one and offers built-in TCP/IP networking software. Raspberry, which is a circuit board with similar features, can also make use of the same chips to get access to CAN-BUS but will be more expensive.

2.7.4 Software

In order for the data extracted from the OBD tools to be translated, a program that is able to communicate using the aforementioned protocols should be installed on either a computer or a mobile device. Since most devices feature Wi-Fi as well as Bluetooth apart from wired connections like USB and Ethernet, connection with the tools is made easy. There are countless programs that can serve the above purpose each with different functionalities, features as well as intended use. Usually they at least offer the following features:

- Tracking of multiple sensors
- Tracing, logging, exportation and replay of real-time captured data
- Sending of pre-defined messages
- Post data analysis
- DTC detection as well as clearing
- Good looking graphic displays for data representation
- Certain ones might even allow the user to program custom scripts for execution

There are several aspects to consider while choosing the application that will be utilized for a certain objectives and there are countless variants. For quick reference purposes a few will be named below fit for different types of devices.

For mobile phones (Android/iOS): Torque, Hondata, Car Scanner ELM OBD2 App, FasLink X, DashCommand, OBD Auto Doctor

For computers (Windows/Mac): Awesome CAN Bus, CANLab, Wireshark, TOAD, PCMSCAN, ECM Spy, OBDWiz, ScanMaster, PyOBD, AutoEnginuity, Delphi DS150, OBD Auto Doctor, Movi, EOBD Facile, Octane, Vehicle Spy

Some examples of programs that are able to communicate with OBD tools can be seen in figures 7, 8 and 9.



Figure 7. Screenshots from the Torque app

Source: Torque Pro in Google Play



Figure 8. Screenshots from the Hondata app

Source: Hondata in Google Play



Figure 9. Screenshot from the CANLab network analysis software

Source: https://www.accuratetechnologies.com/Products/CANLabSoftware

2.8 Possible Extracted Features-Data

There are several data that can be extracted through the OBD port of a vehicle. In this section we will present and give a small explanation of some of the possible features that can be extracted from the port when conducting tests and ones that usually appear

on data-sets found on the internet. Usual correlations between them and their impact on certain phenomena will also be highlighted. Keep in mind that most of these values are formatted later after the capturing of the data raw or through an app designed for this purpose. They are not initially formatted to values corresponding to certain unit systems and measures and they vary through every vehicles company implementation. Thanks to advanced software developed on the matter, like the aforementioned ones, the packets can be quickly/instantly translated and saved to human friendly ones.

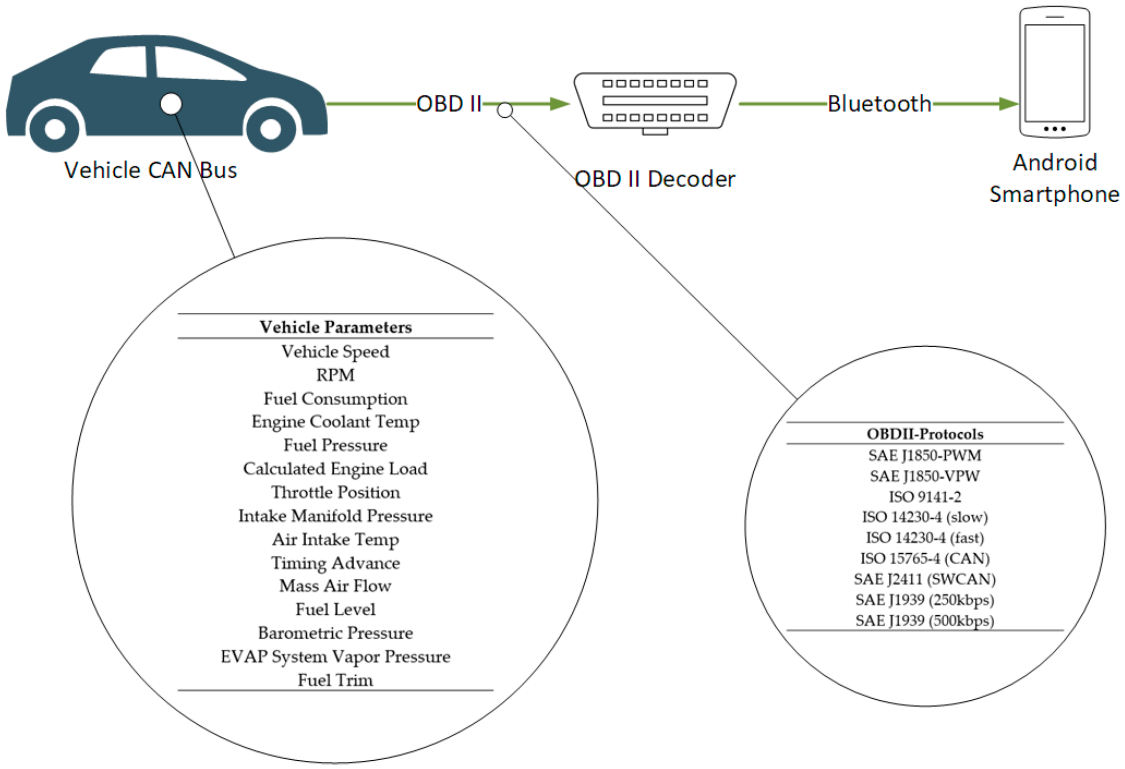


Figure 10. In-car equipment layout, extracting data using OBD-II

Source: https://www.mdpi.com/1424-8220/21/14/4704

2.8.1 GPS Latitude, Longitude and Altitude

Due to the phone's cellular GPS signal used to extract the data we can get the exact coordinate values on the map (latitude, longitude and altitude) that hint the vehicle's location, acceleration as well as the movement towards directions and of course the whole trip of the car after connecting the traces together. In more modern vehicles this info can also be obtained from their built-in GPS. Additionally we can get information about the current terrain the car is at, for example a change in the altitude through a small period of time could show that the vehicle is going uphill with whatever this could be linked to (e.g. uphill stresses the engine more and more torque might be desired).

2.8.2 Engine RPM

The engine's RPM is the revolutions per minute the crankshaft of the engine runs at. Usually higher RPM offer more torque and strain the engine more while lower RPM offer less torque and strain the engine less achieving better fuel consumption as well. High RPM also has a great impact on the fuel consumption since the higher the RPM the more fuel injected per minute since more cycles are completed.

2.8.3 Vehicle Speed

As expected the vehicle's speed at a current given time can be extracted. It could be a value in either mph or kmph. Generally higher speeds are correlated with higher gears and lower RPMs and also to unsafe driving in certain contexts. The driver can increase the speed by stepping on the gas pedal.

2.8.4 Engine Torque

Torque is typically measured in pounds feet and is defined as a twisting force. In a vehicle, it translates into the rotational force generated by the crankshaft. Torque is a measure of how much work an engine can do. The more torque an engine can provide the quicker the acceleration and inertia.

2.8.5 Accelerator and Throttle Pedal Values

This feature refers to the position of the gas pedal. When the driver steps on the gas pedal it allows more air into the engine and the ECU (based on the fuel map) sprays more gas into the combustion chamber in order to match the air-fuel ratio and create a combustion fired by the spark plugs. The higher the value the more air is allowed into the engine by the opening of the butterfly valve that the gas pedal controls and thus the more the acceleration/speed.

2.8.6 Forward and Lateral Acceleration

These values refer to the forward and lateral acceleration of the vehicle and are usually extracted from the mobile phone's (or the external device doing the packet capturing) GPS and gyroscope sensors except if the car has built-in ones. The International System of Units dictates that the acceleration is ought to be expressed in N/s^2 but depending on the case it might be expressed in Gs. These values are useful in order to identify maneuvers as well as assess their safety and the driver's style when tackling them.

2.8.7 Selected Gear

Especially useful on manual transmission cars, this feature indicates the current selected gear. The lower the gear the more torque the vehicle is able to output but the lower speed is able to achieve and vise versa (the higher the gear the less torque can be achieved but is able to reach a higher speed). Lower gears offer better acceleration but lower speed, some usual scenarios are the start of the vehicle and overtakes. Of course the limits, the speed and the torque a vehicle can output in a certain gear is dependent on the vehicle's capabilities. Running the vehicle on full throttle in low gears and revving it to high RPMs for prolonged periods of time can increase the engine temps and cause damage to several parts. Moreover in lower gear ratios engine takes more work for a single revolution of the vehicle's wheels meaning more engine cycles and more fuel to burn, so constantly driving on low gears is taxing on fuel consumption.

2.8.8 Clutch and Break Operation Acknowledgements

This feature is similar to the acceleration pedal values extracted, but sometimes can be NaN and acts as an acknowledgement hinting the usage of the break or the clutch pedal respectively. When the driver steps on the break pedal, the break pads grip on the wheel applying breaking force and reducing the speed creating thermal energy. When stepping on the clutch the driver is about to change gear and disconnects the flywheel and the engines power doesn't transfer to the wheels until they reengage it, this leaves the car in a rather vulnerable state. Clutch also has a biting point so knowing the value of the biting point (point of engagement) as well as how precisely they hit this point can also possibly help in driver profiling. These are especially useful data since we get to know the usual force applied on breaks by a certain driver, how safely he engages in a stop as well as how smoothly he is able to change gears and if its safe when he does so.

2.8.9 Engine Coolant Temperature

This value represents the temperature of the engine coolant running through the vehicles cooling system in order to keep the engine running at acceptable temperature levels. It can be given in either degrees Celsius or Fahrenheit. Generally hard, prolonged use of the vehicle and pushing the engine to its limits (overall bad driving behaviour) can make the coolant temperature rise. Of course this is not always the case as this can just hint an engine or cooling system problem like a bad loop or other mechanical issues unrelated to the drivers behaviour.

2.8.10 Calculated Engine LOAD

Beginning 2005, all vehicles that employ CAN communication must also provide a calculated load through the ECU. The calculated engine

load value is calculated by the following formula as also stated by SAE: $\frac{\text{current airflow}}{\text{(peak airflow at WOT@STP as a function of rpm)}} * (\text{BARO}/29.92) * \text{SQRT}(298/(AAT + 273))$ Where: STP = Standard Temperature and Pressure = 25 Celsius, 29.92 in Hg BARO, SQRT = square root, WOT = wide open throttle, AAT = Ambient Air Temperature in Celsius. This value indicates the percent of the peak available torque and is linearly correlated with engine vacuum. It manages to reach 1.0 at WOT (wide open throttle) at any altitude, temperature or rpm for both naturally aspirated and boosted engines.

2.8.11 Fuel Consumption

This is the vehicle's instantaneous fuel consumption at a particular moment. The fuel efficiency of a vehicle is measured in litres per hundred kilometers (L100km). Fuel efficiency is linked to multiple phenomena, many that are based on driving behaviour so it can hint a lot about the driver's profile.

2.8.12 Air/Fuel Ratio

The air to fuel mixture ratio is a fraction giving a final value that depends on the volume of air against the volume of fuel making its way into the combustion chamber. As mentioned in the fuel maps section the air to fuel ratio at a given time can offer us useful info on the current type of driving happening (for example hint if the car is being idle, cruising, or the driver is running with wide open throttle on a highway).

2.8.13 CO2 and Emissions Data

The value that can be extracted concerning emissions depends on the implementations on the car and the standards that it follows based on legislation. Usually we can at least extract certain PID codes or DTCs that allow us to understand if the catalyst system is working or if the engine is running extremely rich or lean therefore show (based on the unusual vehicle behaviour) that the vehicle isn't running on its desired standards. In more advanced cases and in newer vehicles there might be the option to get the actual Lambda/oxygen sensor values and compare data before and after the catalytic conversion taking place on the catalyst. These kind of data are one of the most important that can be acquired as they can be useful in a today's society that has to tackle serious problems related to the emissions. Even though there are standards and legislation that exist users sometimes don't maintain the emission control related parts in their vehicles or even find ways to bypass them for their own reasons. Finding a way to monitor this could be very beneficial as we will later see and discuss further.

2.8.14 Mass Air Flow Sensor Data

Engines employ the MAF (Mass Air Flow) sensor to control the fuel flow. The air flow signal from this sensor is processed by the vehicle's ECU in order to determine how much fuel to inject, aiming to maintain an ideal air-to-fuel ratio.

2.8.15 Intake Manifold Absolute Pressure Data

Similar to the mass airflow sensor and the intake manifold absolute pressure (or MAP for short) this returns analogous values and serves the same purpose. Even though they serve the same purpose they work on different mechanical principles. The unit used to express the fuel flow is Grams per second (g/s).

2.8.16 Short and Long Term Fuel Trim Banks Values

As the ECU attempts to maintain the desired air to fuel ratio it takes advantage of the short and long term fuel trim banks as well as the MAF/MAP and other sensors. As the load on an engine changes, the AFR of the mixture required by the engine changes as well. To keep the AFR as near to the stoichiometric point (or the desired current target), the ECU attempts to continuously modify its fuel delivery schemes. When the oxygen sensors sense an increase in the amount of air coming in the engine it will signal that the engine is going to run leaner thus the short term fuel trim value is going to be positive as the engine will attempt to mix in more fuel to match the target AFR. Vise versa if the mixture is rich the value will be negative. The values from the short term fuel trim will transfer on the long term fuel trim if the ECU detects that there is a continuous variance of the actual AFR from the desired one for a prolonged period in order to proceed to corrections quickly. These values can easily show if the engine is running lean or rich at a specific point in time based on our desired AFR at the moment. Generally for the short trim a 3% variance should be acceptable while the long term should lie around 0%.

2.8.17 Intake Air Temperature

This value represents the the temperature of the air that passes through the vehicle's intake in degrees Celsius or Fahrenheit. If the vehicle is running smoothly without any damage or extreme heat under the hood, the temp of the incoming air should be almost the same as the atmospheric one outside the vehicle.

2.8.18 Time stamp

Finally we can get a time stamp with precision up to milliseconds indicating the exact time the packet was captured from the ECU. This is a relative measure and doesn't correspond to real time. The values start from 0 with the start of the engine and keep counting until they reset when it turns off.

2.9 Fuel Maps

The fuel injection process is a key procedure that impacts engine performance. As we aforementioned combustion happens due to the burning of an air and fuel mixture ignited by a spark plug. The amount of air and fuel that goes into the chamber depends on multiple factors and the ECU is responsible for regulating that ratio in real time. We know as a general rule that the more the driver steps on the gas pedal, the more the acceleration and speed. This happens because the air and fuel mixture changes ratios, with a proper mixture more energy can be released at a certain time during a combustion in order to force the pistons to move the crankshaft. Of course the air and fuel mixture isn't just correlated to the position of the gas pedal.

The ECU collects, interprets and makes adjustment on the AFR based on the data from multiple sensors like MAF/MAP, Oxygen, TPS, VSS, Temperature sensor and many more [57]. Some of the most important features that affect the target AFR and the possibility to keep the engine running smoothly with a certain map are the fuel type, camshaft overlap and duration, engine power, knock threshold, engine speed, engine load, coolant temperature, cylinder wall temperature and the idle stability [80]. Fuel map tuning is one of the most important matters since it affects the power a vehicle can make, its durability, drivability, idle stability, fuel economy, the emissions it produces and its safety on the road. The ECU does these stability correction on the mixture based on a certain scheme.

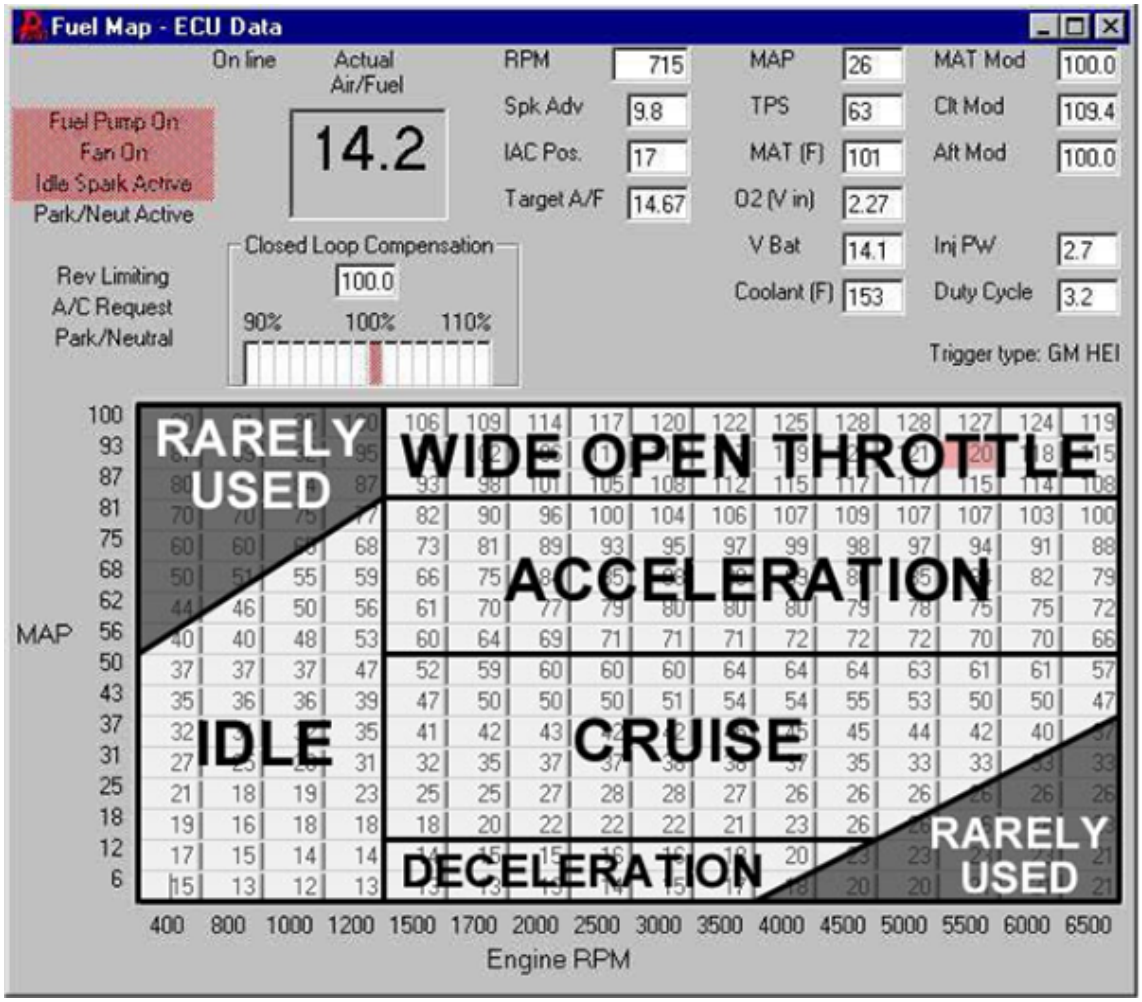


Figure 11. A visualisation of a car's fuel map through a tuning software. Sections on the map show the events where usually a certain value is targeted.

Source: https://help.summitracing.com/what-is-a-fuel-map

A fuel map, also known as fuel table, is basically a table of targeted AFR values based on multiple parameters that affect the running conditions of the engine. The main reason of existence for this map is for the regulation of the AFR (which indicates the mass of air and the mass of fuel in the mixture) during the different loads and circumstances the vehicle is going through. It accomplishes this by adjusting the pulse width (PW) of the fuel injector. The table on its X axis usually represents the Engine RPM while the axis Y the engine LOAD in percentage that we previously discussed. Each column in the table represent the target AFR based on the current conditions. Many fuel maps are also colored to identify when we get a rich or lean mixture which is something we will explain soon.

As we can see in the picture 11 some parts of the table are labeled. These labels correspond to the kind of driving that usually takes place when we have such conditions. For example in RPM lower than 1000 where we also have a very small LOAD value the car is probably idling. In the right middle down portion of the map we have the cruising targets with moderate RPM and LOAD, and on the middle top we have the acceleration portion

since the LOAD gets higher as we try to gain speed. The wide open throttle regions refer to when the driver has fully stepped on the gas pedal that keeping the throttle completely open on the exact opposite side of the map we have the deceleration. The top left and bottom right edges of the map are indeed rarely used since it means that we either reached a maximum speed with very low RPM or that we are at a very high speed and we let go of the throttle. Knowing the current AFR can hint the type of driving going on in a typical vehicle at a current time.

For clarification, the engine LOAD % for naturally aspirated engines is normally the same as your TPS (throttle positioning sensor), while the load for force induction engines is typically the same as the Manifold Absolute Pressure (MAP) reading [57]. Generally the engine LOAD in percentage is simply calculated by the following formula:

$$\text{Engine load } \% = \frac{\text{Airflow }_{\text{current}}}{\text{Airflow }_{\text{max}}} \times 100 \tag{2.1}$$

There is a condition where during a combustion the mixture is able to be completely burned without any losses offering optimal results that we will discuss. This happens only when the AFR is equal to what we call stoichiometric ratio. For gasoline the stoichiometric ratio is 14.7:1, meaning that to completely burn the mixture, we need 14.7 grams of air for every gram of fuel inserted. For different kind of fuel the stoichiometric ratio also differs since their chemical structure is not the same. When the mixture burns the following reactions happens to release the energy:

$$25O_2 + 2C_8H_{18} \rightarrow 16CO_2 + 18H_2O + \text{ Energy} \tag{2.2}$$

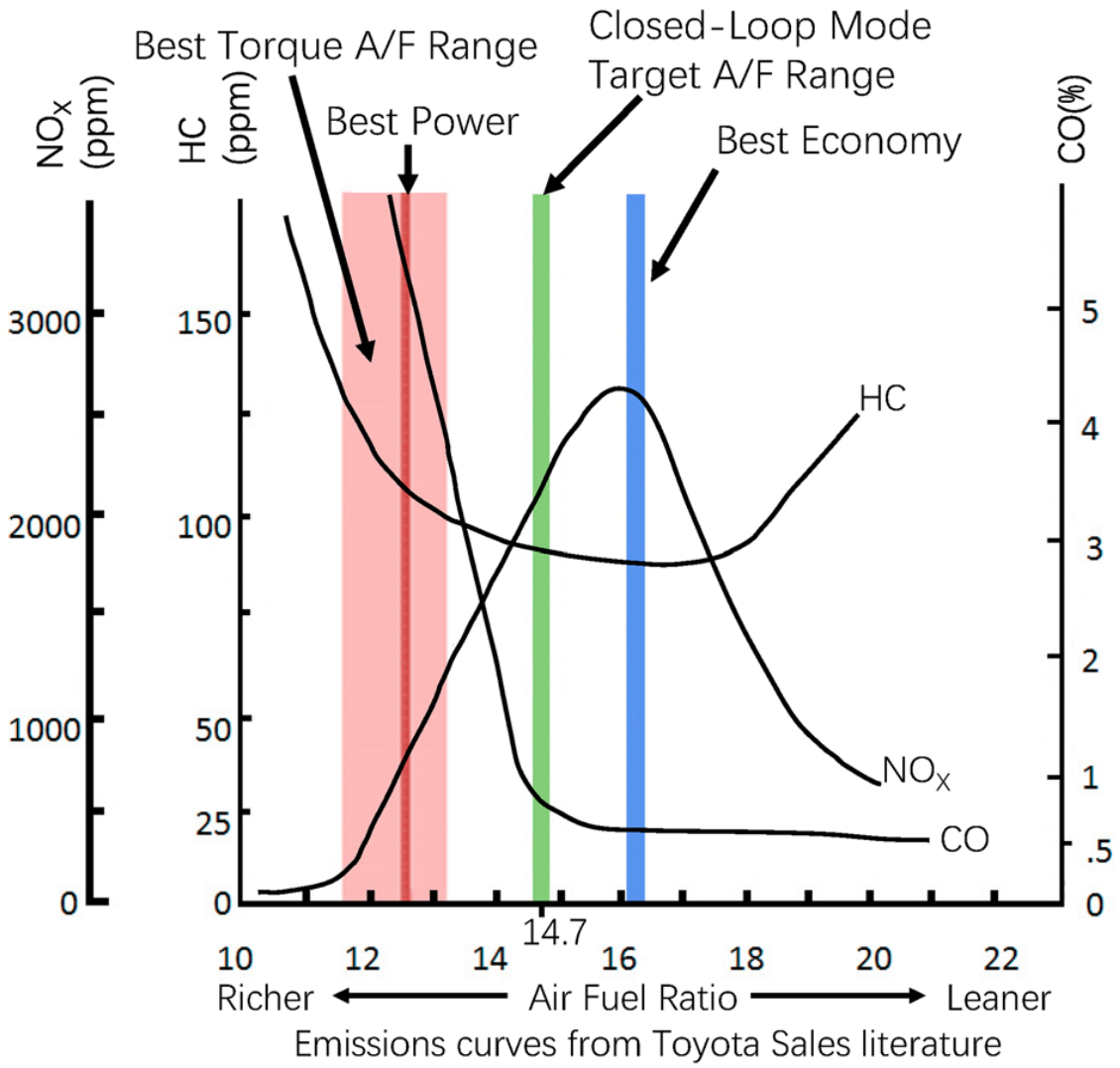


Figure 12. Explaining air to fuel ratio and the effects of running on a rich or lean mixture.

Source: https://link.springer.com/article/10.1007/s13042-018-0863-0

Generally we say that we are running on a rich mixture when the air to fuel ration is bellow the stoichiometric AFR for the fuel we are running because there will be less air mass than the one needed to completely burn the fuel thus we are running rich on fuel. On the other hand when we run on a ratio higher than the stoichiometric we say the opposite which is running lean and it means that we lack mass of fuel and we insert too much air in the combustion chamber.

Emissions are an important matter linked to fuel maps and the mixture's ratio type (lean - rich). The graph on figure 12 depicts the emission gasses produced by burning gasoline at various AFRs. HC corresponds to hydrocarbon, NOx to nitrogen oxides referring to nitric oxide (NO) and nitrogen dioxide (NO2) and finally CO refers to carbon greenhouse emissions (carbon dioxide and monoxide). We can see that both HC and CO emissions maximize as the mixture gets richer while NOx peaks around AFR 16 and has a bell distribution. HC rises again at approximately AFR 17 and rises as the mixture gets all

the more leaner while the NOx falls. Greenhouse emissions remain at low levels, around .5% as long as the mixture remains lean. This info is very important for when we are trying to design concepts and programs attempting to minimize emissions.

Apart from emissions, running rich or lean has certain advantages and disadvantages that we should also take into consideration when tuning a map. If we ignore the emissions for a moment we can see that we can get the peak power of an engine with a rich mixture as indicated by the red region in the graph, it ranges approximately from 11.5 to 13 with best depicted around 12.5. This is due to the fact that a rich combustion burns faster thus creating pressure in the chamber quicker, the opposite applies for the leaner mixtures where combustion is slower. On the other hand the leaner the mixture, the better the fuel economy as we burn less fuel fuel per combustion. Based on the graph we achieve best fuel consumption around AFR 16.2. The stoichiometric AFR is the green line as is 14.7. Additionally to the above when running on a rich mixture the engine temperature is more manageable and cooler as the evaporation of the fuel assist to heat absorption of the cylinders, again the opposite is valid for lean mixtures. Running lean or rich is generally correlated to the following conditions:

Running Rich	**Running Stoichiometric**	**Running Lean**
Best Power	Good Emissions	Best Fuel Economy
Cooler Temps	Good Fuel Economy	Hotter Temperatures
Worse Fuel Economy	Balanced Power	High NOx Emissions
High HC & CO Emissions		

Table 2. Results of Running an Engine on Rich, Lean and Near Stoichiometric Mixture

According to several performance car component makers like [29],[55] and other sources as well as the facts presented, we should keep in mind that it may appear that stoichiometric ratio is always the optimal target but that's not really true in all conditions. A fairly rich mixture will generally yield the most power while drivability improves with a moderately lean mixture at cruising RPM. Idle is better with a somewhat lean mixture as well, although an engine with a big camshaft will idle better with a slightly rich mixture. Not every car is the same and shouldn't be treated as a black box. There is NO map that can fit for any car and any desirable driving style, that is the reason why there are separate maps focusing on performance, others for economy, safety, following a balanced scheme and so on. Creating an optimal fuel map is not an easy task and it requires a whole lot of experience and knowledge on tuning.

Compiling advice and recommendations from several sources (e.g. [49], [55], [84], [29]) generally the approximate targeted AFR per the aforementioned driving conditions lies around the following values, but this is by no means a universal rule:

Condition	Gasoline AFR	Lambda	Lean-Rich
Stoichiometric	14.7	1	Stoichiometric
Idling	12.5-14	0.85-0.95	Rich
Cruising	14.7-16	1-1.1	Stoich-Lean
Accelerating	11-14	0.75-0.95	Rich
Wide Open Throttle	11.5-13	0.78-0.89	Rich
Decelerating	16-17	1.1-1.6	Lean

Table 3. Driving Conditions and the Approximate Targeted AFR & Lambda Values per Case

Apart from AFR, the Lambda value is another method to interpret the air/fuel combination. It is symbolized by the Greek letter λ. Lambda is a percentage that specifies how much richer or leaner the air-fuel ratio is compared to stoichiometric. It is usually preferred over AFR since with a simple glance we are able to know if the mixture is lean or rich and precisely how much. A Lambda of 1.0 indicates that the engine is operating at a stoichiometric AFR. Numbers greater than one indicate a lean combination with an excess of oxygen, whereas numbers less than one indicate a rich mixture.

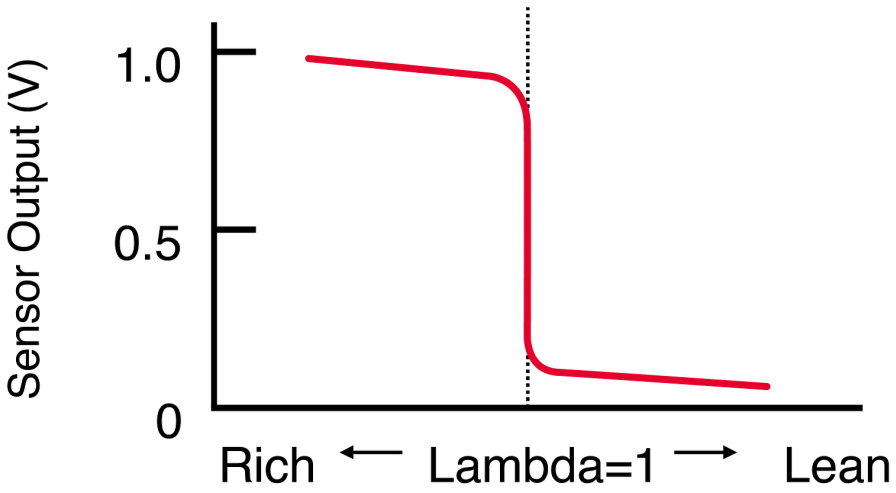


Figure 13. Typical O2 signal from Lambda sensor.

Source: https://www.denso-am.eu/news/air-fuel-ratio-sensors-and-oxygen-sensors-whats-the-difference

We can calculate the Lambda value by dividing the current/actual AFR to stoichiometric one. For example lets take the value of the actual AFR the engine is running seen on picture 11 which is 14.2. If we divide it by the stoichiometric AFR of 14.7 we will get $14.2/14.7 \approx 0.96$. As this is percentage we get that we are lying around 96% and this

means we are running ever so slightly rich as we can see from the graph on figure 13. A Lambda to AFR calculator is provided at [82] for better understanding.

This value is named like that as it is related to the Lambda sensor, also known as the exhaust gas oxygen sensor (EGO). It is one of the most important sensors as it is used to detect how much unburned fuel or extra oxygen remains after combustion. After a combustion happens, the sensor creates a voltage signal, as seen in figure 13, that indicates if the mixture that was burnt was rich or lean. If it's rich the voltage on the lambda sensor will be 1V, while on a lean condition it will be near 0V, the curve is extremely steep leaving the stoichiometric region at the center. Based on that corrections will be made with the help of the ECU as mentioned in the previous chapter and will transfer data to the fuel trim banks in order to keep the mixture to the targeted ratio. The sensor can be found in the exhaust manifold. Modern cars may even have 2 of them for advanced corrections. We should know that in case of a data-set analyzation or during data collection is normal for the lambda sensor values to be outliers as the sensor gets accurate readings only when its fully heated [48]

Fuel map optimization is part of a big field in the automotive industry called tuning. Tuning a car can offer great advantage over a stock tune (also known as factory tune). Optimizing an engine for peak performance is a crucial element in eliciting top-notch results from race cars. Through tuning we can achieve better horsepower output, better efficiency and most of all greater safety and drivability of the vehicle. Creating a fuel map could also be seen as a programming problem concerning tables and multiple parameters that have to be taken into account in order to calculate a final optimal number (the lambda or AFR) based on them. Further optimizing motors to achieve that is very important and finding a way that employs artificial intelligence for custom optimal map creation as well as adaptive mapping will immensely benefit the field. We will discuss some nice works concerning informatics and the field of car tuning in the literature review chapter.

2.10 Communications and Modern Additions

As the automotive industry prepares for the next big step following internet of things and smart mobility they create ways for intercommunication between vehicles as well as other "things" that will be taking place in these smart environments. To achieve this, modern additions like sensors and modules enabling telematics are added to vehicles. At this point we should also clarify that telematics is a term referring to telecommunications and informatics while in IoT terminology "thing" refers to an entity in a smart network (e.g. a device, a vehicle or anything smart that can communicate to its connected network). Apart from connection these systems also help a lot in autonomous driving applications. In this section we will refer to some of the most crucial latest additions in vehicles. Before that we will list the most common communications that can take place in a smart environment and are common IoT terminology.

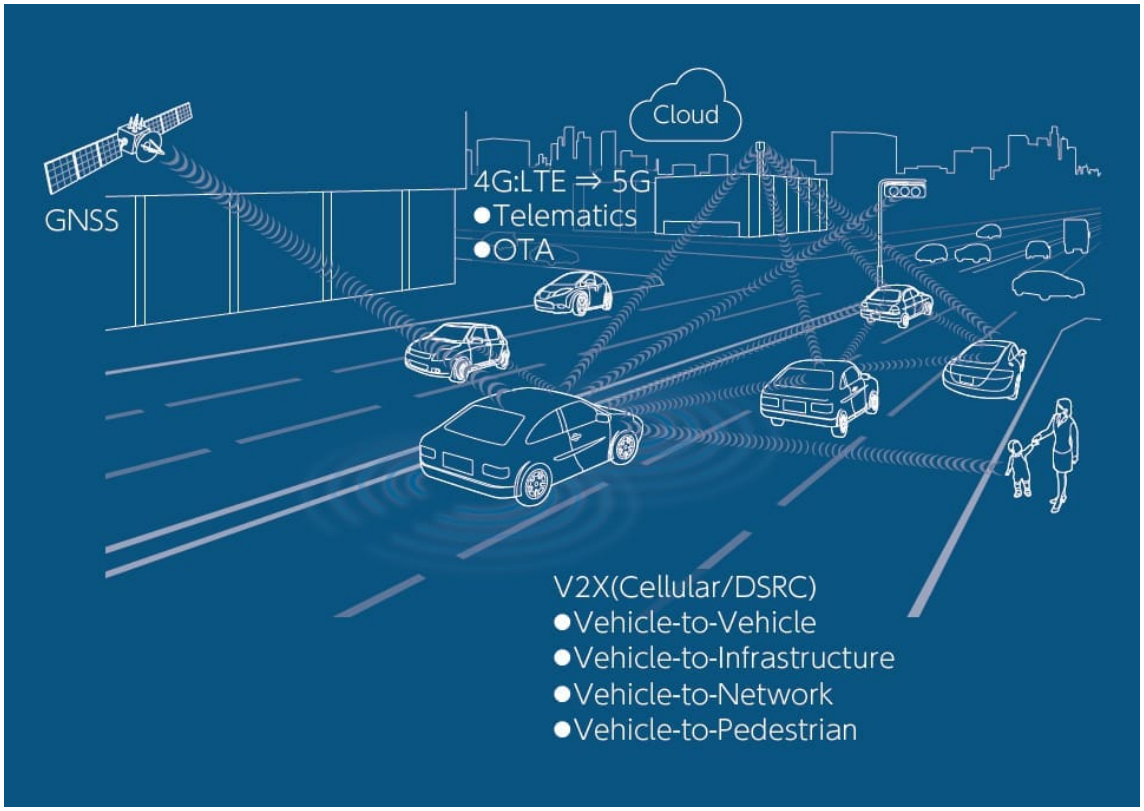


Figure 14. Vehicle to ”things” communications that take place in a smart environment.

Source: https://www.alpsalpine.com/eu/news_release/2020/1015_01.html

2.10.1 Types of Communications

In the future of connected vehicles, following IoT advancements, the aim is for all of the vehicles to interconnect with each other as well as other ”things” in order to share info in a smart way just like humans. Thanks to that traffic accidents will be reduced by eliminating human errors. To achieve the vision of a connect vehicle network the following types of communication will be taking place which have their own names.

- **V2X: Vehicle to Everything** refers to a communication framework that enables vehicles to exchange information with various entities in their surroundings. It encompasses vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), vehicle-to-pedestrian (V2P), and other forms of communication, allowing for enhanced safety, traffic efficiency, and connectivity in transportation systems.

- **V2I: Vehicle to Infrastructure** communication allows vehicles to communicate with traffic lights, road signs, and other infrastructure, enabling optimized traffic flow, improved navigation, and enhanced safety features.

- **V2V: Vehicle to Vehicle** communication enables cars to exchange information about their position, speed, and direction, enhancing safety by providing real-time

awareness of nearby vehicles.

- **V2D: Vehicle to Device** communication enables vehicles to interact with smartphones, wearables, and other devices, providing seamless integration, personalized settings, and enhanced user experience.
- **V2P: Vehicle to Pedestrians** communication aims to improve pedestrian safety by allowing vehicles to detect and communicate with pedestrians, providing alerts and warnings to prevent accidents
- **V2H: Vehicle to Home** refers to the exchange of information between electric vehicles and home energy management systems, enabling seamless integration and control of power flow between the vehicle and the home, thus making electric vehicles able to serve as a backup power source for homes during outages.
- **V2N: Vehicle to Network** communication establishes a connection between vehicles and cellular or Wi-Fi networks, enabling services such as real-time traffic updates, remote vehicle monitoring, and data exchange for intelligent transportation systems.
- **V2G: Vehicle to Grid** communication facilitates the bidirectional flow of energy between electric vehicles and the power grid, enabling vehicle-to-home energy transfer, energy storage, and grid stabilization.
- **V2C: Vehicle to Cloud** communication allows vehicles to connect to cloud-based services, enabling features such as over-the-air updates, remote diagnostics, and personalized services.
- **V2E: Vehicle to Emergency** services communication enables vehicles to communicate with emergency services, automatically sending location and crash data in the event of an accident, improving emergency response times.

2.10.2 VANET

Future vehicles will coexist in a Vehicular Ad-hoc NETwork (or VANET for short) which is a wireless network framework that enables vehicles to establish dynamic and self-organizing communication links with each other and roadside infrastructure. An illustration to help better understand the concept can be seen on 14. VANET employs wireless technologies like Dedicated Short Range Communications (DSRC) or cellular networks, along with protocols such as IEEE 802.11p or LTE, to facilitate communication, these will be taken care of by a TCU (Telematic Control Unit) installed in future cars. VANETs support communication of vehicles with all of the other ”things” found in the network. E.g. Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communications as well as all the aforementioned communication types, allowing for real-time information exchange.

In the context of networks, an ad-hoc network is a temporary network that is set up quickly and without a pre-existing infrastructure. It allows devices to connect directly to each other without relying on a central router or access point. Ad hoc networks are useful in situations where a regular network is not available or practical, such as in emergencies or when devices need to communicate in a decentralized manner. They can be created using wireless technologies like Wi-Fi or Bluetooth, allowing devices to share information and communicate with each other without the need for a fixed network setup.

Vehicles in VANETs serve as mobile nodes that form a network capable of adapting to changing network topologies and environmental conditions. Through V2V communication, vehicles share essential data like position, speed, acceleration, and braking status, promoting cooperative driving, collision avoidance, and traffic safety. V2I communication enables vehicles to exchange information with roadside infrastructure, including traffic lights, road signs, and toll booths. This communication supports traffic management, traffic signal optimization, and dynamic route guidance, improving overall traffic efficiency and reducing congestion.

Nonetheless, VANETs face challenges. Ensuring communication reliability is crucial due to the dynamic nature of vehicular networks and potential obstacles that can obstruct wireless signals. Scalability poses another challenge as the network must handle a large number of vehicles while maintaining efficient communication as the network size increases. Servers able to handle the countless request of vehicles will be a high cost operation. Privacy and security are also major concerns, given the sensitive nature of data exchange in VANETs. Preserving data privacy and establishing secure communication mechanisms against malicious attacks remain active research areas to ensure the reliability and trustworthiness of VANETs in real-world implementations.

2.10.3 DSRC & C-V2X

DSRC stands for Dedicated Short-Range Communications. It is a wireless communication technology primarily designed for V2V and V2I communication. It operates in the 5.9 GHz frequency band (usually between 5.85–5.925 GHz) and utilizes a variant of Wi-Fi called IEEE 802.11p, also known as ITS-G5. The DSRC standard is basically an ad-hoc modification of the IEEE 802.11 attempt on at lowering the packet size to be delivered over radio channels as much as possible in order to make it fit for fast and reliable communications on road infrastructures.

DSRC enables vehicles to exchange information in a short-range, high-bandwidth manner, facilitating real-time communication and collaboration between vehicles and roadside infrastructure. This technology plays a crucial role in enhancing road safety, improving traffic efficiency, and enabling advanced driving applications. DSRC serves as the foundation for various applications and services. Vehicles Equipped with DSRC can share vital data, including speed, position, acceleration, and more, with other vehicles and infrastructure components. This allows for the seamless exchange of information

related to road conditions, traffic congestion, and potential hazards. It can assist several safety systems like, collision avoidance systems that leverage real-time vehicle-to-vehicle communication, intersection safety mechanisms that enable vehicles to coordinate movements, cooperative adaptive cruise control that optimizes driving speeds based on traffic conditions, and emergency vehicle alerts that promptly notify nearby vehicles of their presence. Later on we will see some related messages transmitted through DSRC.

Even though DSRC is more widely used today, a new technology called Cellular Vehicle-to-Everything (C-V2X) has also shown up. C-V2X leverages existing cellular infrastructure such as LTE and 5G already used by mobile phones, compared to DSRC which uses Wi-Fi (specifically the IEEE 802.11). It uses a 3GPP (3rd Generation Partnership Project Standards organization) standardised 4G LTE or 5G mobile cellular connectivity. Additionally C-V2X operates on SC-FDM while DSRC on OFDM with CSMA. DSRC's range is typically around 300 meters while C-V2X seems to have quite wider range coverage, but at this moment there aren't many researches claiming that the 300 meter range won't be enough for future applications. On the other hand DSRC can transmit much quicker and has around half the latency compared to C-V2X. Generally DSRC is considered to be much more safe and reliable thus will be used for safety critical communications and exchange data with RSUs (road side units). DSRC has been studied since early 2000s and it is operational and has been deployed in several cars, in the USA from General Motors, Europe from Volkswagen and in Japan from Toyota. C-V2X just started to have deployments in 2021. C-V2X will be able to communicate with the cloud as as well as pedestrian devices like smartphones and mostly be used to send larger amounts of data irrespective of the delay, thanks to its cellular capabilities. It seems that C-V2X will gain more traction and might take over the communications DSRC takes care of. Currently there are pilot trials taking place to test its capabilities. [10], [67], [23], [85], [86]

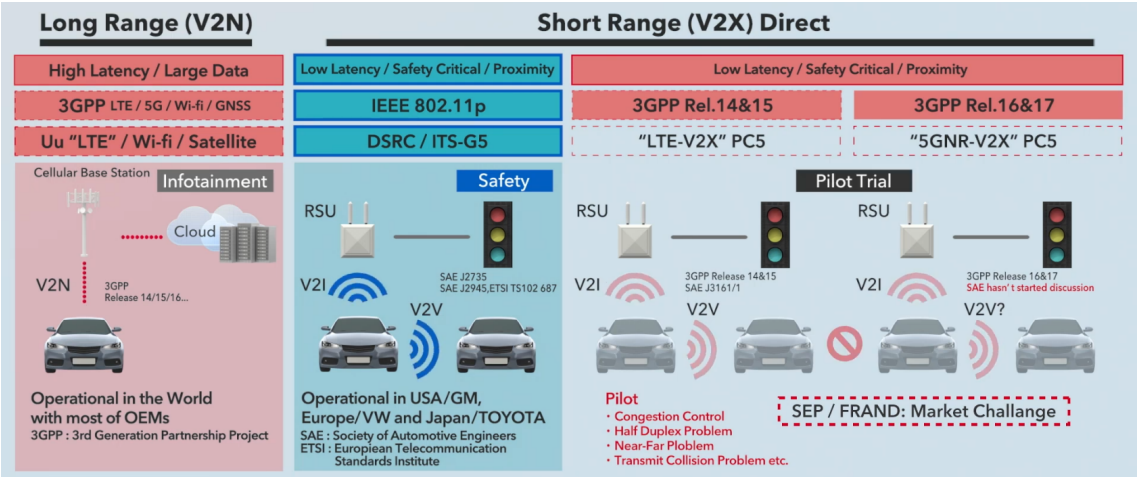


Figure 15. Current state of DSRC and C-V2X as well as the possible implementations and use cases.

Source: https://youtu.be/SYpHtCpdJ1o

C-V2X has some advantages such as extended communication range, improved scalability, and integration with existing cellular infrastructure. Whether it will be fully adopted by continents like Japan and Europe which already mostly use DSRC is still a question. The problem is that that these 2 standards cannot communicate with each other as they use different technologies and standards even though they plan to serve the same purpose. The automotive industry faces a dilemma on whether to continue to use DSRC or choose C-V2X. According to [85] the inability of older cellular technologies like 2G and 3G to communicate with LTE or next-generation 5G NR-V2X (New Radio-V2X) is a fundamental problem and one of the reasons why cellular technology cannot be effectively utilized for safety applications, thus suggesting that DSRC should still be on focus. Maybe devices able to use both standards depending on the situation will be used initially. Later on we will see where most of the industries around the world turn towards.

2.10.4 ITS / Vehicle Communication Messages

To achieve better safety, efficiency and enable communication and coordination between vehicles, infrastructure, pedestrians, and other entities in the VANET ecosystem V2X communications relies on the exchange of messages. These messages play a crucial role in facilitating various applications and services aimed at improving transportation safety, efficiency, and overall mobility.

For clarification purposes we will explain what the words ITS and C-ITS are since they usually come up when referred to the subject since these V2X messages are also referred to as ITS or C-ITS messages. C-ITS means Cooperative Intelligent Transport Systems and is a subset of ITS (Intelligent Transportation Systems). C-ITS focuses on the use of communication and information technologies to enable cooperative behavior between vehicles, infrastructure, and other road users. It involves the exchange of real-time data and messages between vehicles and infrastructure units to improve safety, efficiency, and mobility on the road.

There are numerous types of ITS messages, we will only mention some of the most important ones to understand the incentive:

Basic Safety Message (BSM): A fundamental message in ITS that provides essential information about a vehicle's position, speed, acceleration, heading, and other basic parameters. It is typically used in V2V (Vehicle-to-Vehicle) communications for applications such as collision avoidance, cooperative maneuvers, and situational awareness.

Cooperative Awareness Message (CAM): Exchanged between vehicles to share their current status, including position, speed, heading, size, and other relevant information. It allows nearby vehicles to have a comprehensive awareness of each other's presence and movements, enabling cooperative behavior and safer driving.

Intersection Collision Avoidance Message (ICA): These type of messages are used for intersection safety applications. They provide information about the vehicle's

approach to an intersection, its intended path, and other relevant details to support collision avoidance, signal optimization, and intersection management.

Traffic Light Phases and Timing Message (SPaT): SPaT messages convey the current status of traffic lights, including signal phase (e.g., green, yellow, red) and timing information. These messages enable vehicles to adapt their driving behavior based on the traffic signal status, improving traffic flow, reducing congestion, and enhancing safety at intersections.

Road Hazard Warning (RHW): RHW messages are used to notify nearby vehicles about road hazards such as accidents, construction zones, debris, or adverse weather conditions. These messages help drivers and automated systems to proactively adjust their routes, speeds, or behaviors to avoid potential dangers.

Over the Air Message (OTA): These messages are used to update and configure software or firmware on connected vehicles. They enable the seamless and secure delivery of software updates, patches, and configuration changes to ensure optimal performance, security, and functionality.

Infrastructure to Vehicle Information Message (IVIM): This message includes data about the general environment for example road signs, such as speed restrictions or information regarding road construction. IVIMs are used to digitalize roadside traffic signs.

Message Assistance for Perception (MAP): MAP messages similar to IVIM are transmitted by infrastructure units and contain detailed information about the road network topology, including lane geometry, speed limits, road attributes, and road restrictions. This data aids vehicles in situational awareness and path planning.

Collective Perception Message (CPM): They are V2X messages that exchange perception data between vehicles and infrastructure. They enable vehicles to share information about their local environment, including detected objects, road conditions, and more. CPMs enhance situational awareness, allowing vehicles to make informed decisions and adapt their behavior.

Maneuver Coordination Message (MCM): These type of messages are used to coordinate maneuvers between vehicles. They allow vehicles to communicate their planned maneuvers, such as lane changes or turns, to nearby vehicles and infrastructure. MCMs optimize traffic flow by providing awareness of upcoming maneuvers, facilitating smoother interactions

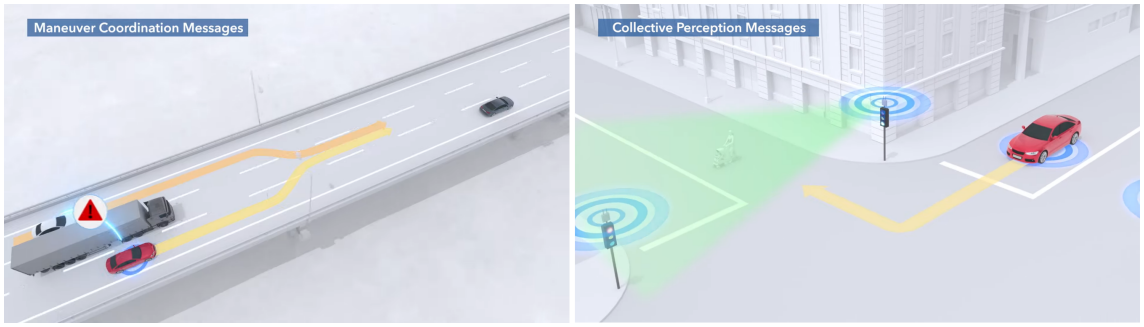


Figure 16. Illustration of the use cases and impact of the CPM and MCM messages

Source: https://youtu.be/SYpHtCpdJ1o

For instance, in the above scenario of a collective perception message the traffic light / RCU was able to detect a mum and her children passing, something that the red car through human eyes might have not be able to see. The intelligent traffic light will transmit the CPM to the red car and thus knowing that pedestrians are crossing the road it will proceed with safety. On the example of the maneuver coordination message the two cars (red and white) that are unable to see each other due to the truck taking the middle lane will be able to commit a safe overtake and realise their existence thank to MCM.

According to C-ROADS and Car 2 Car Communication Consortium [22] on a 2023 publication concerning the data layer, the messages can have the following structure:

Access Layer Header	GeoNetworking Header (including security)	Basic Transport Header	Facility payload (e.g. CAM)

Figure 17. General packet structure for C-ITS messages

Source: [22]

They also proposed the two following formats:

In the first option we have an Ethernet II portion, next GeoNetworking including security if applicable, then the basic transport protocol and finally the main payload depending on the type of the message.

ETH	Geonet	BTP	Facility Payload

Figure 18. Frame Format Option 1 for C-ITS Messages

Source: C-ITS Cross-Border Testing: PCAP Exchange Specification

In the second proposed option the frame starts with a Radiotap Header, then the IEEE 802.11 frame (QoS), next a LLC header (Logical Link Control) containing control information that helps manage the data transmission process (typically source and

destination addresses, control bits, and error checking information). After the LCC the packet continues with the Geonetworking, the basic transport protocol and finally the main payload just like option 1.

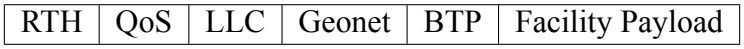


Figure 19. Frame Format Option 2 for C-ITS Messages

Source: C-ITS Cross-Border Testing: PCAP Exchange Specification

2.10.5 Communication Spectrum Allocation

To ensure public road safety and smooth operation of V2X communications in VANET certain frequency spectrum had to be allocated solely for these type of communications. There are current disagreements on the allocation especially in the U.S. while most countries seem to take their own approach and there doesn't seem to be a standard range of frequencies and their use case across all continents of the world. The board 20 shows the spectrum allocations across certain continents.

Generally, the initial idea was to assign the 5.9 GHz frequency band for this type of communications with the spectrum used usually being 5.85–5.925 GHz. Almost all continents have mostly used frequencies of this range except Japan. In Japan it was decided to use to use the range of 755.5 to 764.5 for ITS while 5770 to 5850 MHz will be used for ETC (Electronic Toll Collection) and ETC 2.0 system [28]. Europe, including the United Kingdom will fully utilize the band with frequencies from 5855 MHz to 5875 being used for Non-Safety ITS while 5875 to 5915 MHz being used for safety [34]. The rest of the allocated spectrum will probably be used for rail ITS concerning trains, metros and any transportation media on rails. So in conclusion Europe will dedicate the frequencies from 5855 to 5935 MHz for V2X communication only, avoiding interference and stemming for a safe and harmonized approach.

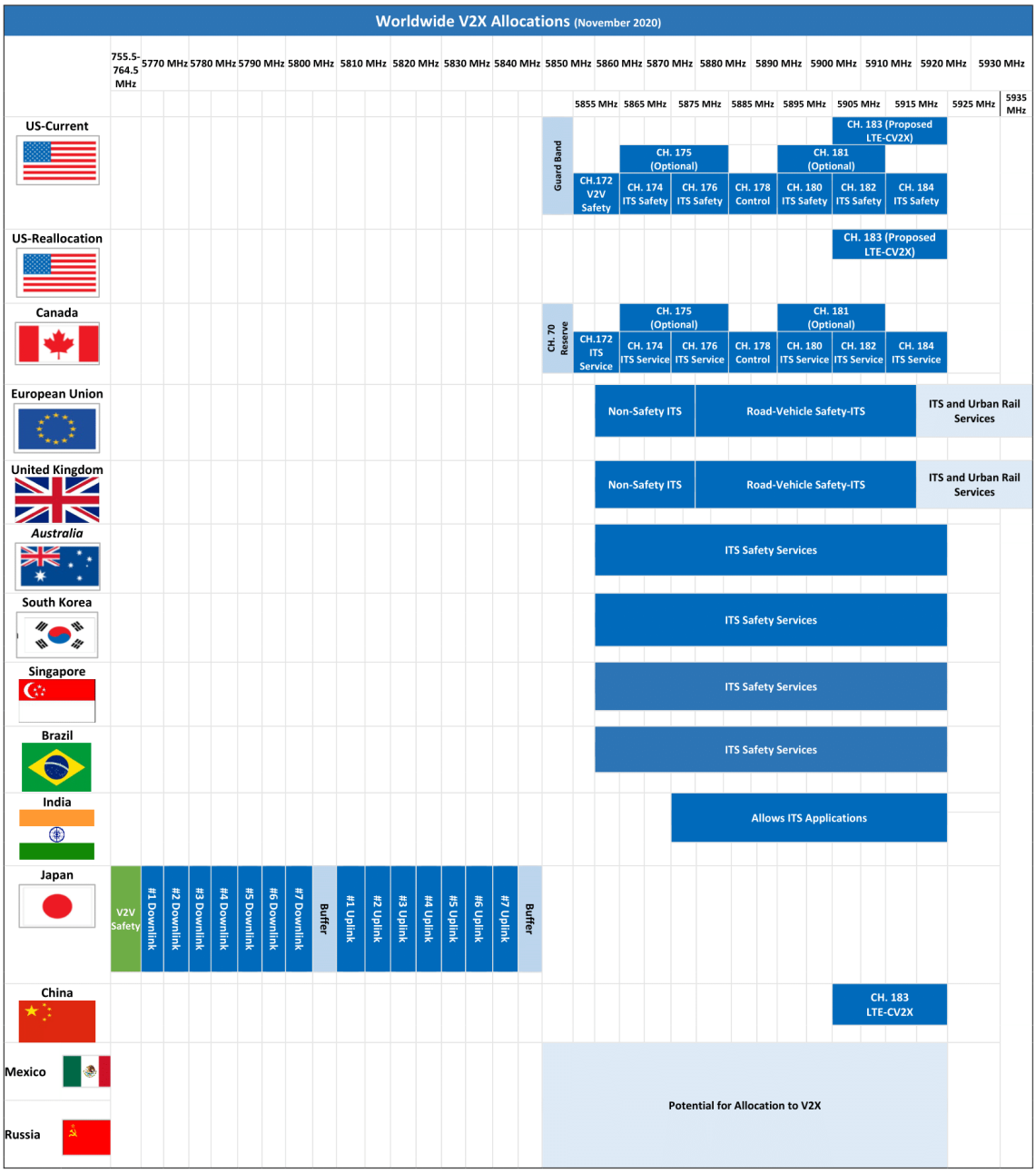


Figure 20. Frequency Spectrum Allocations for ITS / V2X Communications Across Certain Continents

Source: U.S. Department of Transportation

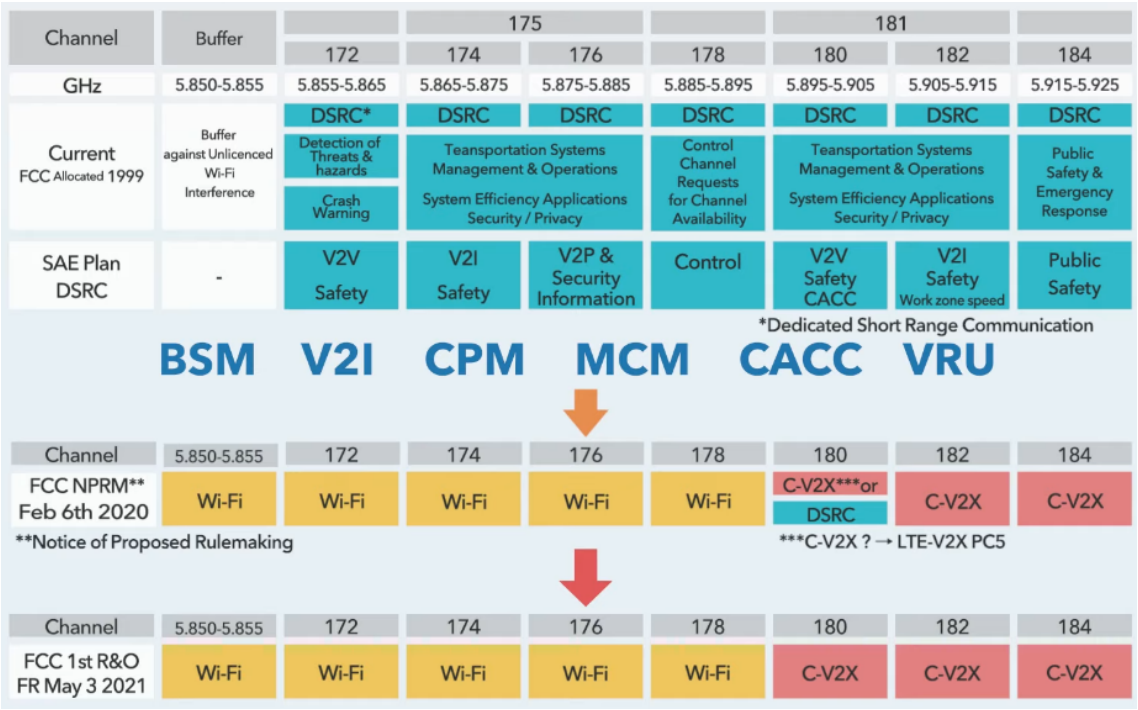


Figure 21. The Initial and the Current Spectrum Allocation in the US (before and after re-allocation) as of 2022

Source: https://www.youtube.com/watch?v=SYpHtCpdJ1o

Despite the general incentive of several organisations including C2CCC, C-ROADS and many others that the whole 5.9 GHz should be solely allocated for V2X communication and ensure uninterrupted operation, U.S. decided to proceed in relocation of the frequency spectrum dedicated for V2X. In figure 21 the re-allocation is illustrated along with SAE's plan for the frequency distribution and what features will each part of the spectrum may cover. Many sources mentioned at [85] and [86], claim that this will cause interference problems and the spectrum will be insufficient rendering the unsafe and unreliable. U.S. seems to have taken seconds though and instead of following Europe's plan turns to plan similar to China's which also has allocated only 5095 MHz to 5925 MHz for the proposed LTE-CV2X scheme not accounting for DSRC. Their plan (as seen on figure 21) seems to be that DSRC can make use of the 5.9 GHz band but share it with Wi-Fi. The channels 180, 182 and 184 will be used by C-V2X. V2X Supporters (reliable source endorsed by C2CCC) mention that "The FCC did not explain any reimbursement method for switching from DSRC to Cellular-V2X", "At the moment, there is no definition for C-V2X" as of the Q4 of 2022 [85], [86]. Though U.S. seems to turn towards C-V2X technologies that also make use of cellular communications thus not being fully reliant on the radio frequency spectrum this still raises concerns for a fair reason why and it doesn't promote the harmonization of the incentive.

2.10.6 Driving Automation Levels

The idea of autonomous driving is not new while we've already seen some semi-autonomous cars on the public roads with Tesla making the idea buzz. Since we will also refer to sensors, devices and the role of artificial intelligence in autonomous driving it will be useful to know the 6 Levels of Driving Automation as established by SAE and standardized by ISO under SAE J3016 which defines the SAE Levels from Level 0 (no driving automation) to Level 5 (full driving automation) in the context of motor vehicles and their operation on roadways [9].

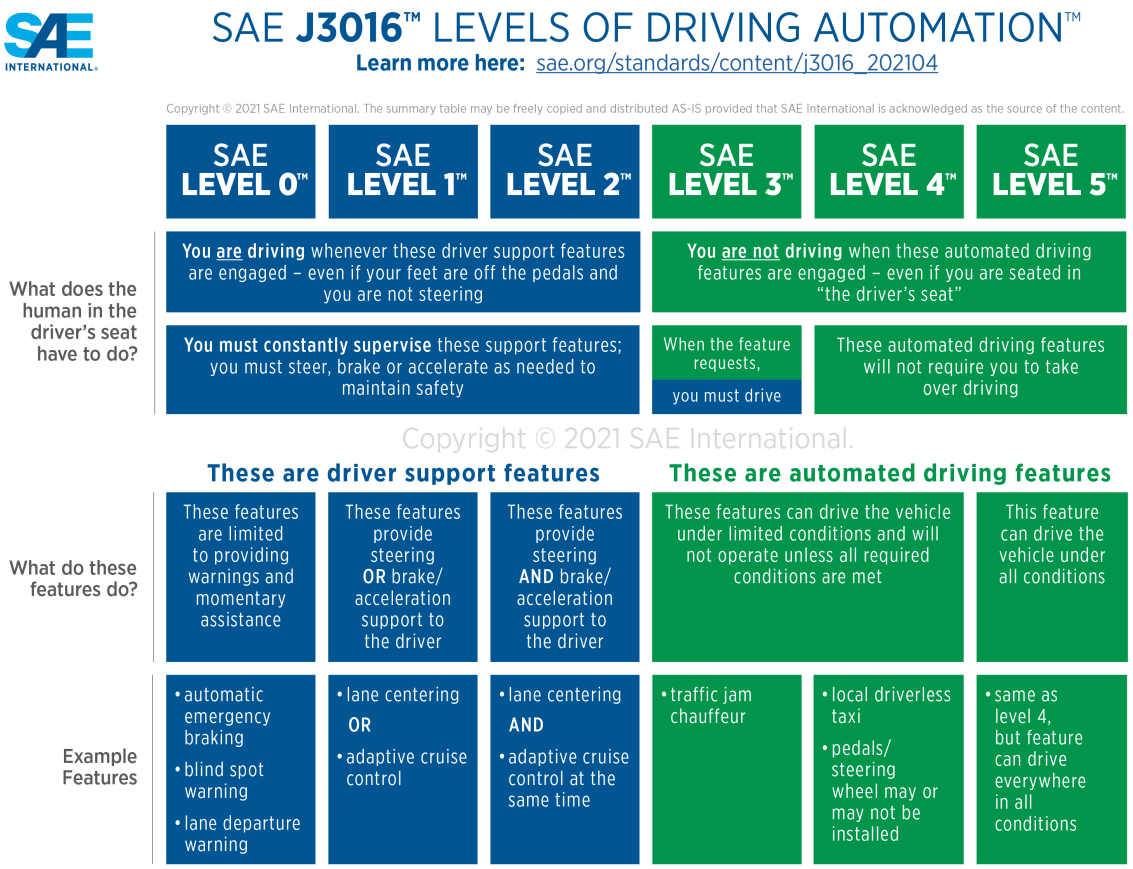


Figure 22. The 6 SAE Levels of Driving Automation from SAE Level 0 (no driving automation) to Level 5 (full driving automation) in the context of motor vehicles and their operation on roadways.

Source: https://www.sae.org/blog/sae-j3016-update

We should keep in mind and as highlighted by NHTSA (National Highway Traffic Safety Administration) that the highest level of driving automation seen in modern commercial vehicles is just up to level 2 [17]. Although as of 2022 some level 3 vehicles seem to have made their way to the market specifically from Mercedes-Benz which was the first company to bring level 3 driving automation vehicle both to EU and US [16]. NHTSA

suggest that vehicles will feature perfect lane keeping assist, adaptive cruise control and traffic jam assist as of 2025. Indeed technology has gone very far with cruise control being a given while we see several safety features such as collision detection on modern vehicles working perfectly. The ”future” era of automated safety is predicted to start around 2025+.

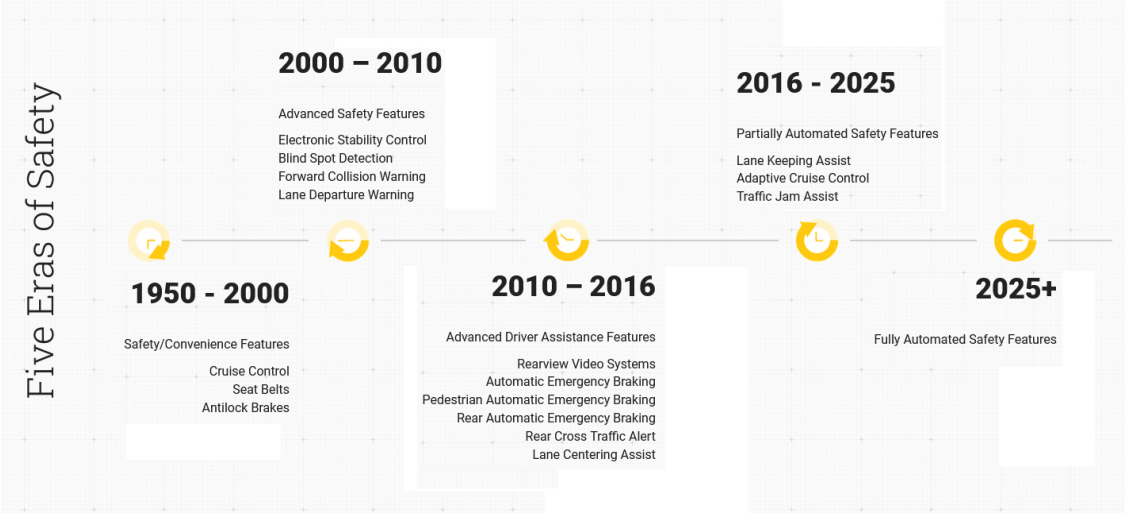


Figure 23. The Five Eras of Safety, graph made by NHTSA

Source: https://www.nhtsa.gov/technology-innovation/automated-vehicles-safety

Additionally milestones of future mobility safety according to NHTSA , can be seen at figure 24, while NHTSA also reports that future addition to the Euro NCAP programme will include tests to vehicle related to assessment of ADAS (Advanced Driver-Assistance Systems), driver impairment and cognitive distraction systems as well as V2V, V2I and V2X communications [4].

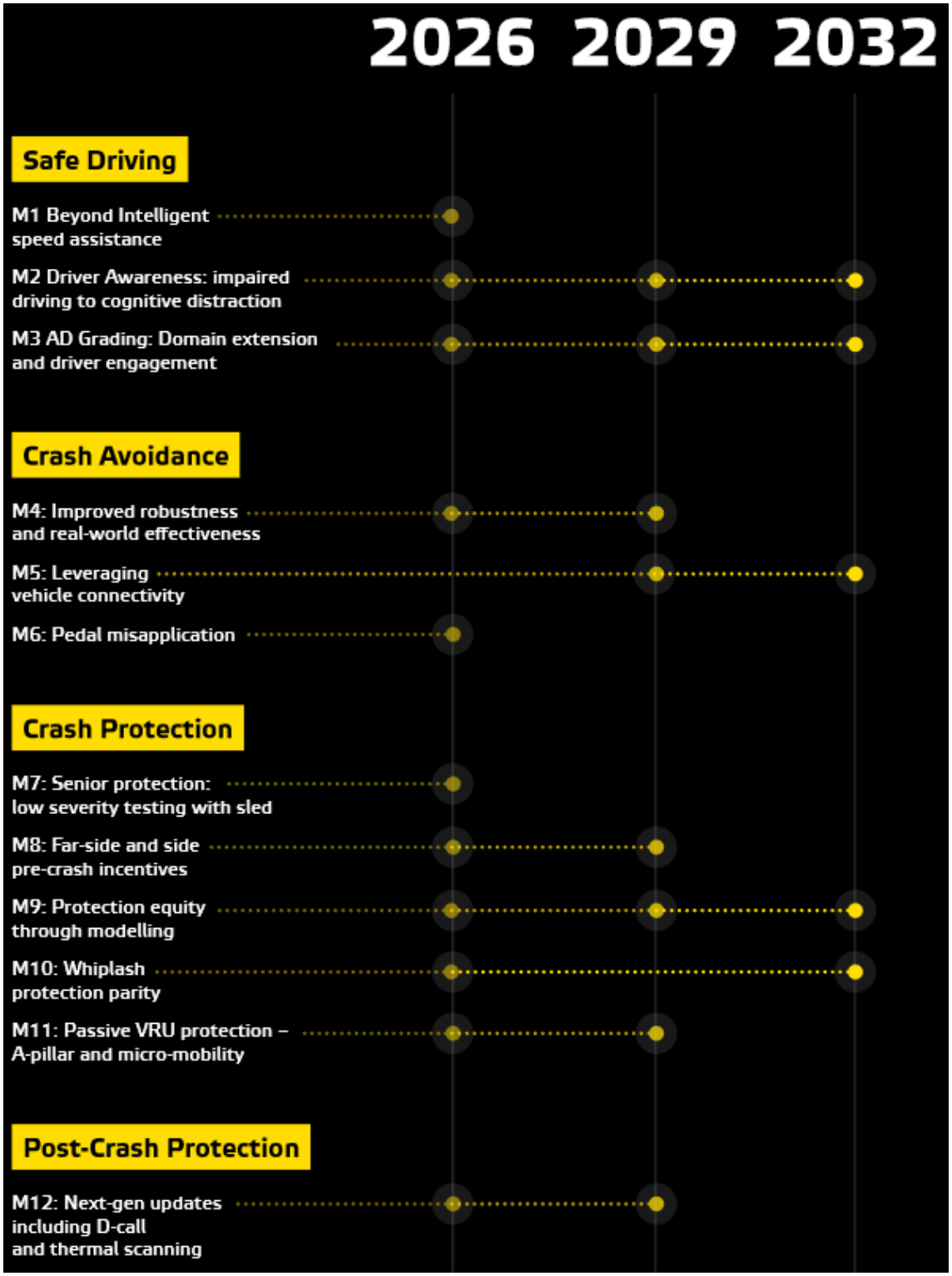


Figure 24. Milestones for the Future of Safe Mobility by NHTSA

Source: https://cdn.euroncap.com/media/74468/euro-ncap-roadmap-vision-2030.pdf

2.10.7 TCU

Modern vehicles will (and some already do) include a telematics control units (or TCUs) in their systems. TCUs or TCMs (telematics control modules) are embedded systems/micro-controllers that enable wireless communications between things like the ones described above. TCUs will also be able to communicate through CAN and receive telemetry data like the ones mentioned in the ”possible extracted data” section. Then they will be able to share them to everything in the environment like other vehicles, devices, the cloud and so on, through cellular networking aiming to optimize traffic flow as well as safety on the roads. The user will also be able to have access to the telemetry data through mobile or web apps and of course the vehicle’s infotainment system. Moreover TCUs will incorporate features like automatic eCall (emergency call) and allow for quick roadside assistance. This also implies and its known that TCUs will implement (or at least have access to) the vehicle’s microphones and speakers offering voice detection and other features supported by machine learning making the infotainment system more useful than ever.

The telematics control unit will be able to handle multiple types of communications and will also take care of memory and battery management in modern BEVs/EVs (electric vehicles). They will take advantage of 5G networks to communicate with things but other technologies as well like DSRC, Satellite, LTE, 3G/4G while Wi-Fi and Bluetooth will also be useful for other operations like bulk cost-effective software updates. By adding more modems and processors to the vehicle, data transmissions will become more dependable, efficient, and quick while improving connectivity to the cloud, infrastructure, and other cars.

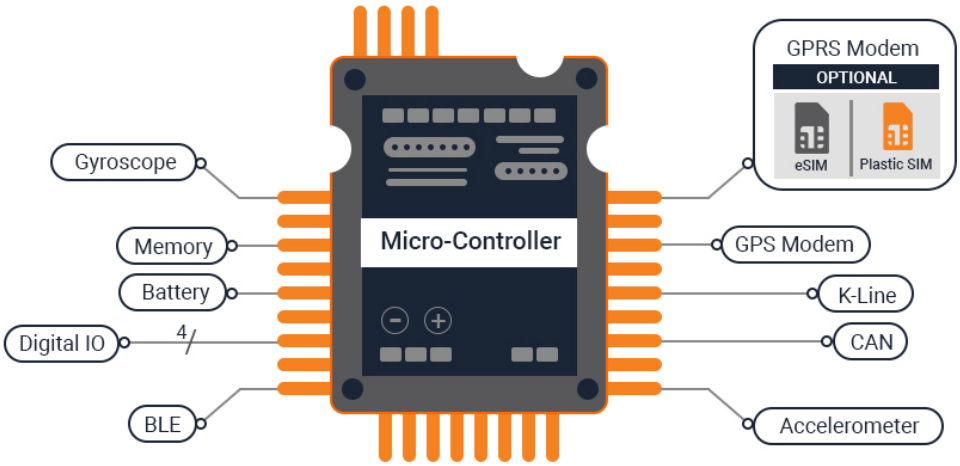


Figure 25. Technology architecture of a Telematics Control Unit

Source: https://www.embitel.com/blog/embedded-blog/tech-behind-telematics-explained-how-does-a-vehicle-telematics-solution-work

Regarding its architecture, a TCU usually consists of the following components [88], [54]:

- A **micro-controller** or a microprocessor or field programmable gate array (FPGA). It will consist of a gyroscope sensor for measuring or maintaining orientation and angular velocity, a GPS/GPRS modem, an accelerometer and a CAN-BUS reader that is able to communicate with the vehicle's ECUs and retrieve information.
- A **Global Navigation Satellite System** (GNSS) module for exact position tracking.
- A **Central Processing Unit** (CPU).
- A **mobile communication unit** supporting a wide range of communication methods like Cellular, 5G/4G/LTE, Wi-Fi, Bluetooth etc..
- A built-in **battery module** to facilitate integrated power management that can also be used as a cost-effective backup option to retain the clocks' info and allow access to telemetry data even when the vehicle is turned off.
- A **Bluetooth module** for easy interconnection with the user's various devices and other close range things in the network.
- **A** Microphone or an array used for hands-free operation of certain features with voice based commands. It will also support for media playback within the vehicle through output devices.

- A **General Purpose Input/Output** interface (GPIO) system, can be both analog and/or digital.
- A **Memory Unit** to save data for future use or share later in the occurrence of an unreliable connection or passage though mobile-free zones. This module can also be useful for more sophisticated telematics functions such as speech recognition that require such functions.
- Finally, there is a **GPRS module** enabling data connectivity and, occasionally, voice interaction with remote devices. To facilitate connection with these remote devices via the cellular network, the GPRS module may include a SIM or an e-SIM card as an addition to the GPRS modem.

2.10.8 Sonar

Sonar stands for so(und) na(vigation) (and) r(anging). Sonar is installed in modern vehicles for the detection of nearby objects in the vehicles field. To achieve this sonar emits ultra-sonic sound waves (inaudible to the human ear) and measures the time difference between the emission of the ultrasonic pulse and the reflection that will echo back to to the sensor once it hits an object. Thanks to that the sensors understand whether an object is near or further away based on how much time it will take for the sound to return. The more time it takes for the sound to return the further away the object.

Sonar is a low cost and very reliable sensor and it is used predominately in marine applications with the reason behind it being that sound can travel very fast in water thus offering great and fast detection. On the other hand, in land applications where the sound travels much slower, sonar has a major drawback which is its range/distance that it can cover to detect objects. Sonar sensors used in cars are used to detect objects within a 3 meter radius. Additionally, sonar is not able to identify exactly what an object could be rather just acknowledge its existence. That's why the main applications of sonar in cars is for parking assist, blind sport detection and detection of immediate surroundings. It is used in cooperation with other object detection and identification sensors and devices.

2.10.9 Radar

Radar which stands for ra(dio) d(etection) a(nd) r(anging) covers some of sonar's disabilities. Radar is an essential component for modern vehicles and is usually installed at the front, rear and sides of the vehicle. The working principles are similar to sonar's but instead of sound waves radar makes use of radio waves which are much more suited for land applications. Radar measures the delay between the emission of the electromagnetic pulse and its reflection back to the sensor.

Radar is capable of detecting objects from a much further distance (even 50 meters or more) and because radio waves have long wavelengths they are able to penetrate certain mediums (e.g. water droplets) and perform reliably even under poor weather conditions

like rain, fog or snow. Just like sonar, radar is perfect for detecting an object's exact position as well as it velocity while distinguishing moving and non-moving objects but it can't identify the object. Another drawback of radar is that it is susceptible to noise and interference and that it can also confuse highly reflective objects that could be small with bigger ones that are less reflective. Again, because of the above, radar sensors' use is limited to tasks like collision warning, parking assist, blind spot detection as well as adaptive cruise control. It is usually used in combination with other more advanced sensors like LiDAR and cameras.

2.10.10 LiDAR

LiDAR along with cameras are the main protagonists in the self-driving ecosystem since they are the ones deemed capable of collecting data fit enough for this task. LiDAR as a term is meant to be a combination of Light and Radar but the term itself means Li(ght) D(etection) A(nd) R(anging). LiDAR solves problems mentioned for sonar and radar as it makes use of lasers to scan and create a 3D model of the surrounding world. It usually sits at the center of the vehicle's roof and is able to create this 3D model by emitting hundreds of thousands of laser pulses in a radial pattern. The sensor registers these pulses as they get reflected from the things they hit. Based on the delay between the light emission and the time it takes for it to reflect back to the sensor, the LiDAR unit is able to create a very accurate 3D representation of the surrounding world by performing complex graphical calculations of the data received.

Unfortunately LiDAR sensors are very big and way more expensive compared to the rest while their power consumption is also higher compared to other sensors that can be used for self-driving cars. Another disadvantage is that because it uses light it is not able to ”see” through mediums like fog, water, snow or even high sun angles and reflections, thus rendering it useless in poor weather conditions. A radar can be used in conjunction with LiDAR which is able to handle such cases. But probably the biggest disadvantage of both sonar, radar and LiDAR is that they are actually unable to identify things, preserve color and actually ”see” things just like a human eye would. They cannot understand road signs, traffic light signals or get the status of an object (e.g. red light, speed limit sign etc.). To do that we would need something that resembles the human eye, and for that we didn't have to look further than cameras.

On the other hand LiDAR is able to generate data that don't require huge processing power in order for them to be useful, and it is able to inform the vehicle immediately and very accurately about it's surroundings including the object sizes, distance and velocity. This is an advantage over cameras that would be useless without great computational power and artificial intelligence to identify the data (in this case images) received. That's the reason why most of automotive makers prefer to use LiDAR over cameras as their primary sensor and instead may use cameras supported by AI in order to interpret the objects' status.

2.10.11 Cameras

Cameras are a mandatory addition to modern cars since 2018 in the US and since 2022 in the EU, while almost all autonomous vehicles incorporate camera systems either as their main or secondary sensor for autonomous driving. As aforementioned cameras are able to resemble the human eye, this correlation/metaphor is very important; we have to understand that our already existing network is built around/relies on visual feedback, cameras allow us to read exactly that in a much more humanly fashion. This could get us closer to our goal which is making the computer understand how the driving network works.

Cameras work in a universally known way, light passing via the lens of the camera reaches the image sensor and changes its voltage. Then the image sensor's output signal is processed within the camera to generate an image. Cameras with the help of artificial intelligence and the recent advancements in neural networks are not only able to detect objects in an image but also identify what this object exactly is, what it signifies and what is its status. Cameras as our eyes, and neural networks resembling our way of thinking is a great metaphor that could be used for this approach.

Of course cameras eliminate the main disadvantage of the rest of the sensors which was lack of ability to identity an object's status but they are limited by a certain factor which is artificial intelligence. While thanks to AI cameras are able to identify objects and their statuses, there is the serious danger of miss-identification of certain objects and phenomena. Yet there are no, and there cannot be 100% accurate models that will predict and identify with no misses ever. Of course this is not a problem and it is acceptable for a relatively low margin of error to exist, but there are known fatal accidents caused by AI model's failure to complete certain tasks like object and status identification. The main problem of cameras right now is the lack of a well trained model ready to tackle the countless situations that a vehicle may find itself on the roads. This renders the camera option more unreliable when compared to the other sensors which offer more precise readings and are less susceptible to errors caused by the AI model's judgment. We could say that the biggest disadvantage of this approach is its accuracy. Apart from that, we should also mention that image processing is not an easy task and cameras are also susceptible to conditions like bad weather since existence of fog, rain or snow will worsen the image's clarity and quality.

LiDAR seems to currently be dominant on the market with most of the big automotive makers embracing it as the main sensor responsible for autonomous driving related tasks in their future vehicles. On the contrary there are some others that believe in the cameras' and AI's ability as the best possible approach; with the main supporter of the idea being the current largest EV manufacturer in the world, Tesla, and CEO Elon Musk referring to LiDAR as "A fool's errand" while adding that "Anyone relying on LiDAR is doomed. Doomed!" [2], [37], [76]. Weather LiDAR or cameras will be the future is still a question. Maybe a combination of the two will offer the optimal result. There were situations where

using additional sensors like LiDAR could save lives and there probably is a reason that the majority currently uses it. Of course there are also countless situations where AI has saved lives and we mustn't neglect that. We should embrace advancements in the field of AI that aim for the peoples safety and better well being. We should also highlight that many accidents were also caused due to driver's absent mind from the wheel thinking that their vehicle's autopilot mode offers fully autonomous features and requires no attention. In these cases we can't and we shouldn't blame it all to a computer. Remember that up until the writing of this work there aren't any fully autonomous SAE Level 4 and Level 5 vehicles available to the public.

Chapter 3

Literature Review & Current Trends

There are several fields in vehicles where computer and information science has aided the automotive industry, from the creation of simple comfort features (e.g. cruise control) to enhanced security and efficiency (e.g. advanced driver-assistance system, drowsy detection systems, collision detection). There are many works showcasing novel technologies and concepts to be employed in future vehicles including the use of artificial intelligence for recognition of certain phenomena like driving patterns as well as for self driving vehicles and for the field of engine tuning. In this section some important works and current research will be compiled that also highlight the state of the art and ways that fields of IT (like algorithms, security, AI, HCI, IoT, networking and more) attempt to improve the current state of vehicles on the road. I should clarify that this is just a glimpse of what information technology is able to do and there are countless works on several fields. This review is limited. The focus here is on works that i was able to have access to and caught my interest with their approach but also mainly concerning artificial intelligence as it was the initial incentive of this thesis, but also because AI will play a major role in the future of vehicles and driving. Finally through research i showcase the current trends and what are the main focus subjects of the leading automotive companies and their R&D departments as well as what they want to achieve by researching them.

3.1 General Works on Artificial Intelligence and OBD Data

We extensively mentioned and described how an ECU works, the modern and conventional vehicle's sensors, and how we are able to extract useful real-time data. Thanks to OBD many great works and data-sets were published. Most ECUs in cars (especially older ones) act in an algorithmic manner with code already embedded into them rather than act based on an AI model principle. With the current advancements on artificial intelligence we are able to create models that are able to offer novel features or optimize current ones that rely on OBD-II data. Using data solely extracted through OBD is important as it is the least invasive way to the privacy of the driver thus rendering possible

future implementations easier to happen. OBD data would be easy to be transferred through cloud and cellular infrastructures a feature that would be even more ideal for smart city scenarios.

Some of the ”trendy topics” at this current time that are very likely to be implemented more and more in future vehicles are driver identification, driving style and profiling recognition, as well as risk assessment. The frequency of automobile thefts is steadily rising despite the advent of new technologies to deter auto theft. This is a major matter as thanks to AI applications in cars we are not only able to enhance security and add theft protection features to vehicles but it can also aid to computer interference when certain phenomena that occur are detected by the ECU in order to increase efficiency and driving safety. Additionally, recognition of driving patterns might hint further information as we will see. Driving behavior recognition and analysis is critical for assessing road safety.

3.1.1 Driver Identification

Starting with the impressive findings of a 2016 article by a research team conducted by some Stanford University members along with some member of the Volkswagen Electronics Research Laboratory and AUDI AG. The article has an eye catching title which is ”Driver Identification Using Automobile Sensor Data from a Single Turn” [58]. Indeed in this study the researchers were able to provide a technique employing artificial intelligence and a certain classifier to identify a driver from a group of people using sensor data obtained only during turns, which itself is quite impressive. We should understand that this is a classification task between drivers assisted by certain features extracted from the vehicles used in the test and which in the end constitute a driving style. The idea is to use these variations in driving styles to identify a distinctive ”signature” for each driver, which may be anything from minor changes to the steering wheel’s tilt during turns to how firmly one presses the gas pedal and more. Computers thanks to AI are quite good in detecting even small but consistent differences as we will see.

The data-set used in this research was created by AUDI AG and Audi Electronics Venture using anonymous data collected from drivers who were requested to operate customized Audi A3 model cars with integrated data loggers, and capture devices stored a timestamped dump of the CAN-bus communication. The driving of the automobiles took place in public roads at Ingolstadt, Germany from a selected group of drivers. The researchers note that the most frequent turn in the data-set was the one made every morning by the drivers as they picked up their car from the Audi parking lot in Ingolstadt where the begging of each logging session started. The final data-set contains sensor readings from several turns, repeated several times by multiple drivers to avoid an over-fitting effect. Specifically contains data from 10 cars, 64 drivers, 2,098 hours of driving and 110,023 km covered. Each session was lasting approximately 8-10 seconds and each record is labeled with the driver ID in order to train the AI model. The classifier was created with the intention of identifying unique driving behaviors, which can be spotted in the data even

on such a small road segment. The data-set contains time-stamped readings per every 0.1 seconds from the following 12 sensors that were explained thoroughly in the previous chapter (Steering wheel angle, Steering velocity, Steering acceleration, Vehicle velocity, Throttle position, Gas pedal position, Engine RPM, Torque, Brake pedal position, Lateral acceleration, Forward acceleration, Vehicle heading). To increase the performance of the classifier a synchronization technique was also applied to the data as different turns require varying amounts of time in different sessions alignment between the timing of the data was needed for a fair comparison. The classification/recognition of the drivers is possible thanks to the aforementioned data. Even while our driving may appear to be similar to others', it nevertheless differs. In the paper, for example, we can see that driver 1 began turning the wheel earliest, driver 2 turned the wheel the furthest at the apex of the turns, and driver 3 maintained wheel turning last. These are a few examples of distinctive traits that make each individual different.

Their final classifiers accuracy managed to reach an average of 76.9% for a single-turn prediction between two drivers and was ranging from 55% and 93.5%. For the same classification task but between five drivers the results were less promising averaging at 50.1% and ranging between 33.2% and 70%. It is also referred that they made use of the random forest classifier. Even though this is quite impressive coming from such a short road section, and the researchers themselves deem their results promising, i would say that there is still great way for something like this to be implemented on everyday cars on the market, apart from its application for triggering comfort features based on the detected driver, since these percentages seem rather low if it was to be used for something critical. Some drivers where harder to classify than others and researchers suspect that this occurred due to inconsistent driving patters or patterns that were extremely similar to another driver. In this case recognition of the driver's mood and other factors could assist this venture as the driving style can also be affected by them.

Turn ID	Turn Type	Prediction Accuracy (# of sessions per driver)			
		$n = 2$	$n = 3$	$n = 4$	$n = 5$
1	Urban, non-major road	72.0%(34)	58.7%(31)	49.3%(30)	41.0%(29)
2	Urban, non-major road	75.0%(24)	64.0%(22)	64.0%(20)	54.6%(19)
3	Merge onto busy road	69.5%(24)	48.3%(19)	39.0%(17)	33.4%(12)
4	Merge off busy road	62.0%(17)	56.3%(17)	50.3%(17)	45.6%(17)
5	Merge onto highway	55.0%(21)	52.3%(15)	57.5%(12)	48.2%(4)
6	Merge onto highway	79.5%(17)	57.0%(17)	60.5%(16)	49.5%(16)
7	Urban, major road	67.5%(17)	56.0%(16)	60.5%(13)	56.8%(8)
8	Urban, major road	87.0%(16)	51.3%(12)	47.0%(8)	33.2%(6)
9	Turn onto bridge	83.5%(18)	60.0%(15)	35.0%(11)	41.0%(11)
10	Rural turn	82.5%(17)	74.0%(15)	65.8%(14)	62.4%(13)
11	Rural turn	93.5%(16)	56.7%(15)	63.2%(13)	70.6%(12)
12	Rural turn	96.0%(13)	77.7%(12)	70.2%(11)	64.8%(11)
	Urban/highway average	72.3%	60.0%	51.5%	44.8%
	Rural average	90.7%	69.4%	66.4%	65.9%
	Average across all turns	76.9%	59.4%	55.2%	50.1%

Table 4. Prediction Accuracy For Each Of The Top 12 Turns. The n Represents the Number of Drivers. Table from [58].

The researchers provide clear result tables of the classifiers' performance across different areas, turns, and number of drivers. Researchers observed that the three best-performing turns (by a wide margin) are those that occur in rural areas (especially 10, 11, and 12). A possible explanation they give for this phenomenon is that in such areas less possible barriers exist, such as pedestrians or other automobiles thus resulting in more consistent readings that are not affected by outside factors.

In addition to that, they tested the importance of each sensor in the identification of the drivers, but it turned out the outcome was quite erratic and inconsistent. They report that there wasn't a single "indicator" regarding the drivers identity but rather a mix of elements that construct the whole profile. Furthermore, this suggests that additional work is required to develop more thorough models that can identify drivers holistically as opposed to only depending on the specifics of each turn which is something that we will take a look in the next articles that happened on a later date.

Regarding the possible applications of the above, apart from auto-theft protection, this would allow for automatic profiling and other automations of comfort features. As an illustration, it would enable the automobile to recognize the driver as soon as the car turns out of the driveway, allowing the car's settings and profiling to be automatically changed to suit the driver's preferences (e.g. temperature, radio station, suspension hardness, mirror location, etc.). Either way their findings are more than impressive and highlight that turns are exceptionally well-suited for recognizing differences between drivers, especially when compared to straightaways.

Another brilliant work on driver identification would be [73] were the researchers proposed a machine learning-based strategy which stealthily and continually updates a drivers profile by extracting info from the built-in car sensors. The paper seems to be an

advancement over [71] which also used the same data-set provided by HCRL (Hacking and Countermeasure Research Lab), available at [60], and it was also used for the the AI/ML based driver classification challenge track in 2018 Information Security R&D data-set challenge in South Korea. Again these 2 works rely solely on OBD data and AI models to provide new unique and important features for vehicles. The data-set consists of real driving data from a KIA soul driven between Korea University and SANGAM World Cup Stadium for about 23 hours total from 10 different drivers while logging data through the OBD port every second. It consists of 51 features which i think is one of the biggest reasons their findings managed to exceed expectations and reach a very high accuracy. The features are listed and explained at [73] but some of them were also thoroughly explained in the theoretical background chapter. The data-set was labeled from A to J based on which driver was driving at the time. This is one of the greatest data-set i was able to find freely online and with such a wide feature list.

Both bring to attention the rising problem of auto-thefts that take place in our modern society with many security experts warning about the phenomena of relay attacks and key-less access [92], [36]. One common car theft technique involves breaking into the vehicle and connecting a laptop to the OBD port. This allows the thieves to access the car's ECU and alter packets in order to bypass authentication methods like keys and bio-metrics. Another approach takes advantage of social engineering and owners are deceived into installing malicious software on their smartphones that sometimes are used as an authentication media. [71] mentions that bio-metric methods like passwords and fingerprinting are not accurate or versatile enough for security issues in connected cars. Instead, both articles suggests using behavioral characteristics, such as analyzing the driver's specific driving patterns, as an alternative method for authentication. By considering factors such as vehicle interval, acceleration, speed, brakes, and steering angle, this approach offers a reliable way to authenticate the driver's identity in connected car systems.

The researchers on [73] made use of 5 different machine learning algorithms/classifiers (compared to [71] which used 4) in order to identify which driver was behind the wheel per session. On both papers this classification task was accomplished through WEKA, a collection of machine learning tools often used in data mining for scientific study which is also freely available at [93]. Generally most of accuracy readings on [71] reach or even exceed 99% with the best for the work being the random forest classifier while the authors report that in the early stages of detection MLP and KNN algorithms are not reliable enough. On the other hand [73] made use of J48 and 2 of variations of this algorithm as well as Random Tree and Rep Tree algorithms. Their results exceeded expectations with their accuracy readings for all drivers constantly reading over 99% in the best cases as well. This goes to show that a wide feature set might benefit this task as even small differences can identify a different driving style.

For example if we look at the following figure 26 we can spot differences in the

values recorded for every feature depending on the different driving style. Some are more prominent while other less but either-way we are able to classify the drivers based on such differences in their driving style. Someone might use more fuel, or make the transmission run hotter, steer the wheel more aggressively or push on the gas to a certain degree every time. There are countless differences and the wider the data-set the more specific we can be about them. We can also examine the correlation between these values.

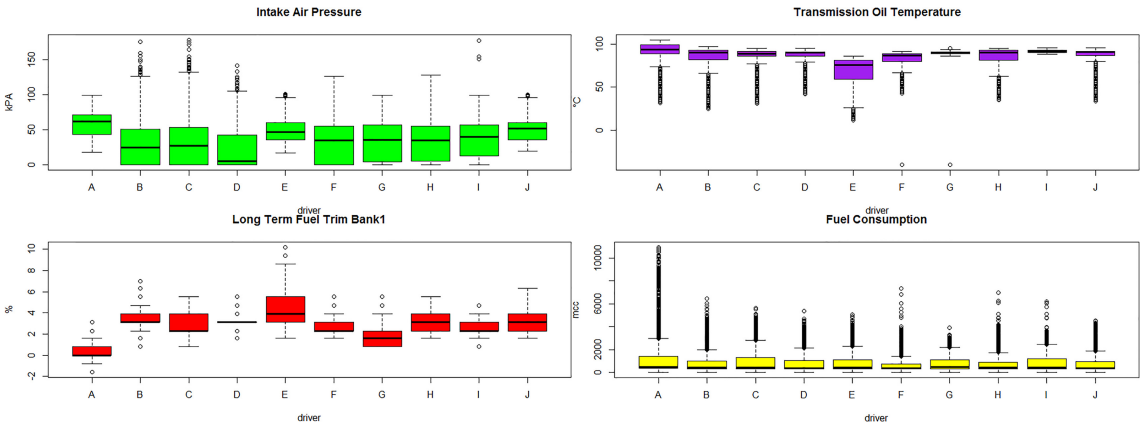


Figure 26. Box plots for the Fuel Consumption, Intake Air Pressure, Long Term Fuel Trim Bank 1 and Transmission Oil Temperature features for the ten different drivers considered in the experiment of [73]. The differences in driving style are prominent even with a look at the plots.

Source: “Human behavior characterization for driving style recognition in vehicle system” Fabio Martinelli et al.

A feature selection process also took place to find out the most prominent features. It came out that the ones fit best to identify the drivers were the Intake air pressure, Engine soacking time, Long Term Fuel Trim Bank 1, Torque of friction, Transmission oil temperature, and the Steering wheel speed. This is good to keep in mind for future research and to compare it with the best performing features of other papers.

[73] gives new insights proposing some possible concepts of application but also performs a more in depth analysis to the features when compared to [71]. The work generally takes a supervised learning approach to the problem which includes two steps, the learning and the prediction. To achieve this, first data are collected from the OBD port then the machine computes whether the features acquired match a registered driver of the car. The first practical application would be for driver identification where the vehicle will send the driver-related feature set extracted through the port to the app and through analysation if it passes the similarity threshold it will allow for its smooth operation. On the other hand if it recognizes that the driver’s behaviour doesn’t match the actual owner’s features then it will notify the owner for the possible car theft. In addition to that i would suggest other measures like enabling the car’s limb mode which sets a cap to the maximum speed and features of the car, and i could also suggest a geo-location signal for the ECU

with GPS support.

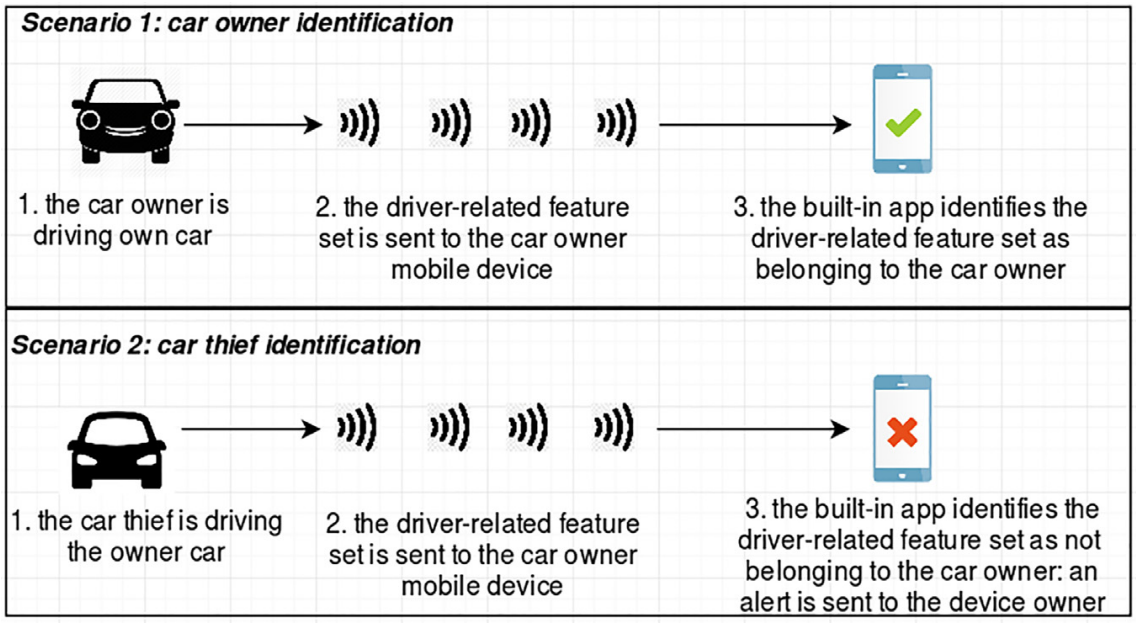


Figure 27. Application scenario of an AI supported driver identification app for car theft protection as proposed on [73].

Source: "Human behavior characterization for driving style recognition in vehicle system" Fabio Martinelli et al.

The second scenario illustrates the usage of such app in a car insurance company proposals for driver accident policies, which is a topic previously referred. By taking advantage of this approach car insurance companies may be able to keep anonymized records of their insured drivers and vehicles in their servers that were extracted from the vehicle's ECUs and sent over through the network. Then they will be able to perform data analysis and check whether the driver was the registered owner or not. Apart from that this approach would generally be useful just for checks on the well-being of the car and the provident maintenance of the vehicle as well as the driving style taking place before an accident.

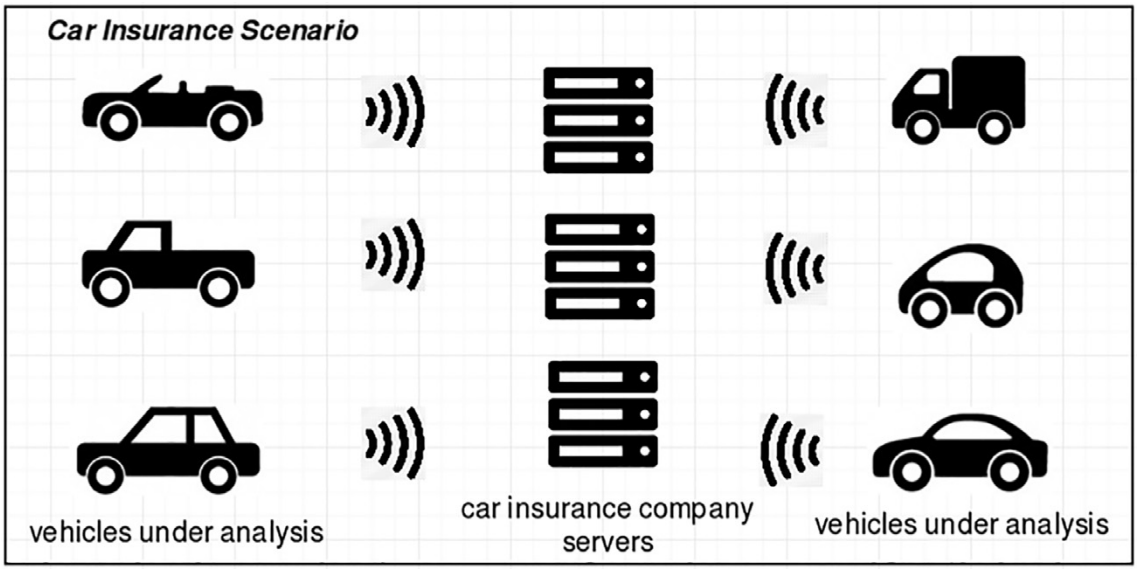


Figure 28. Application scenario of an AI supported driver identification app for insurance companies as proposed on [73].

Source: "Human behavior characterization for driving style recognition in vehicle system" Fabio Martinelli et al.

Even though the results of these papers are extremely positive and stem for future applications the authors of [71] say that the similarity-based method necessitates ample data for driver identification (e.g. KNN), while the algorithm utilizing driver-specific threshold values exhibits strong performance even with limited initial data. Thus, they highlight that a more advanced machine learning approach is necessary for effective auto-theft detection, surpassing the limitations of the similarity-based method.

I believe this kind of research is extremely important and exciting while it offers an alternative perspective to conventional security measures like cryptography and malicious software detection and disinfection. The plan is that an authorized driver will be recognized by classification algorithms, while an unauthorized driver that creates a bellow threshold accuracy on the algorithm will not and will then trigger safety mechanisms. Apart from that their promising results and highly accurate models suggest a possible future implementation that can very much change the life of many car owners suffering from such attacks just like the recent KIA "challenge" grand theft scheme [97]. Another work using the same data-set published exactly on May 19 2023 (near the finish of this dissertation) and attempted a similar classification task. The authors of [70] using this 51 feature data-set from HCRL used some of the features of the set and derived them to match their incentive. Their goal was to classify the 10 drivers of the set based on their driving quality, they labeled the driving of every driver from poor to excellent. This judgment was based on the influence on driving score that they offered in each of the derived features. For example on the average fuel consumption they labeled it a high negative driving score while on the average speed a positive moderate, on average gear a positive high influence

and so on for the rest of their selected features. This would mean that a driver that has a good fuel consumption and drives in moderate speeds and high gears would be good. They even have a reving instance feature calculated by ”IF REVV_ENGINE = TRUE increment REV_INSTANCES” stating ”A good driver should not unnecessarily rev the engine in our model these instances also negatively affect the score.”.

I disagree with their ranking scheme and its one of the reasons i didn’t conduct a test this way myself which was an initial idea for this thesis. Let’s say for example the driver is on an uphill road and the gear engaged is first but also the engine revs high because it tries its best to cope with the roads conditions. Just because the driver is on uphill he is considered a bad driver? Then their model will for sure classify a good driver as a bad one. This is not a machine learning mistake but rather a concept mistake that i have to point out. If extracted data simulating bad and good driving were extracted and labeled from experts then there would be no problem in training such model but in this case there are logical mistakes. Of course a driver revving the engine high could be bad and generally is a racing characteristic but not always. Same applies for average gear and speed, these are features that depend on the roads conditions. For this case i would recommend the application of fuzzy logic. In future work i would like to work on such data-set and create my own by capturing real data and get them labeled by experts and mechanics also participating in the collection of it. The data-set is more fitted for driver identification and behaviour analysis but either way the authors of [70] using supervised learning for their approach managed to reach 99%, 99%, and 100% accuracy using SVM, AdaBoost, and Random Forest algorithms respectively.

In a more modern 2022 study authors of [35] made use of deep learning networks in combination with swarm algorithms to make this classification task more sophisticated. Their approach even though more complex didn’t yield any better results than the previous paper with their average accuracy lying at 83.43% across the 3 online data-set that they used for their tests that can be found online.

Authors of [79] propose an automobile theft countermeasure leveraging driver identification and attempt to create a concept highly possible to be employed in real life scenarios and vehicles. Again they make use of AI for driver identification just like previous articles. Their tests made use of a 4 driver data-set where 1 would be the real driver and the rest are considered thieves. The average accuracy they managed to reach was 0.884. They expect their system to be implemented in an IVI (In-Vehicle Infotainment system) and that a driver will initiate the training of the model for half an hour after the purchase of the new vehicle. They also report that the data collection would happen through Bluetooth and the OBD-II port which i find rather inelegant for a feature implemented in a modern vehicle, i believe it should use a more stealthy way that asks the user to insert an OBD dongle to read data, it could use a way to directly read from the ECU by using CAN Lines. Additionally they would make up for the lack of computational power of the in-vehicle systems with an independent computer server where the vehicle would connect through a telematics channel. Again this will require the

existence of modern TCU as explained in chapter 2. The same applies for previous articles with similar concepts. Finally I'll have to mention the lack of unsupervised learning in most of the articles i read so far (even ones not mentioned here).

Again the reason that i focus so much on these works on my review is because it was the original incentive of this dissertation to perform a similar classification task and because they also promote privacy through anonymity in a concept applicable to anyone and every car, without relying on a vast technological equipment upgrade. There are several other works that employ many more sensors and additional measures but some further from today's reality. We can act on internal combustion engines and improve our every day lives even before the EV era which is yet unknown if and when it will arrive and EVs will be completely established.

3.1.2 Driver Safety

Most of the accidents on the roads occur because of human error. With the help of technology multiple safety features were added to cars and it is one of the top priorities even until this day to enhance existing ones and in the near feature introduce new ones. The following papers show some possible safety features that can/will be added in future vehicles.

Drowsiness detection as well as attention detection will be one of the most anticipated features to surely make its way in future vehicles while some already employ such features based on several inputs. Due to ADAS and the rise of autonomous driving people tend to forget they are on the wheel and doze off even if their vehicles are not fully autonomous. Such safety features are deemed of very high importance.

In the articles [32] and [30] authors review the prospects and recent developments in drowsiness detection. The methods discussed for detecting and assessing the level of drowsiness are applicable to SAE autonomous driving levels 0 to 3 where the driver's attention is fully required.

Methods	Measurement Information	Measurement Target	Measurement Method	Measurement Index	Advantages	Disadvantages
Contact method	Biometric information	Heartbeat, pulse wave, aspiration, brain wave, myoelectric, eye movement, etc.	Heart rate monitor, pulse wavemeter, electroencephalograph, electromyograph, nystagmus, etc.	Heart rate, chaos analysis, alpha wave, theta wave, muscle action potential, vestibular oculomotor reflex, etc.	High drowsiness detection performance can be obtained .	Driver behavior adversely affects the reliability of the designed system.
Non-contact Method	Vehicle behavior	Steering pattern, distance between lane and vehicle, speed, distance between vehicles, etc.	Steering angle sensor, white line recognition camera, laser radar, etc.	Steering frequency, meandering rate, steering volume, monotonous steering	Estimates can be obtained in a way that is unobtrusive to the driver.	The accuracy of detection and estimation depends on road conditions and the environment. It is useful only when the driver is holding the steering wheel.
Non-contact Method	Driver's graphic information	Open rate of eyes, blink, pupil, voice, and expression	Camera, microphone	Opening and closing rates of eyes, number of blinks, time of closing eyes, pupil fluctuation, chaos analysis of speech sound, drowsy categorization by expression, etc.	Intuitional index and easy-to-understand, high accuracy.	Different lighting conditions may disrupt the detection performance .

Table 5. Approaches for detecting driver's drowsiness as seen on [32]

Especially [32] has done an exceptional job on finding both info on the approaches as well as the implementations and the accuracy of them even in the ones applied to actual cars, mainly from Japanese auto-makers. As seen on the table 5 created by [32]

the detection can take place based on 3 types of data. The first is biometric information which usually acquired by a heart rate monitor or electromyograph etc., these are generally less elegant and attractive when installed in a car so its the least used way but offers high drowsiness detection that is based on the drivers biometric info like heart rate. Another way would be though OBD data and the vehicle's vision sensors that monitor the vehicle's behaviour. The steering pattern as well as the distance between the roads white lane and the other vehicles are giveaways about the drowsiness level of the driver and can be identified through machine learning. Finally we have another much used information type (usually used in cooperation with the vehicle behaviour data as they are both obtained in a non contact method) is the driver's graphic information. This info is acquired through cameras as well as microphones. The opening and closing rates of the eyes, number of blinks, pupil fluctuation and distance of certain points of the eye can help in identifying drowsiness. A driver being vocal is also a good indication that he is paying attention. Each method has it's own disadvantages

Based on [32] most of Japanese car manufacturers (incl. Toyota, Honda, Subaru, Mazda and Nissan) seem to use methods of non-contact devices to extract data for this feature. All the info gathered is based from publication or press releases claiming these facts and the current approach of each company. From the company leaders, Toyota, Subaru, Nissan use (or will use) graphic information to trigger warnings when closed eyes or side glances occur. In addition Toyota apart from warning stops the car when the driver is not in a good posture or does not respond to warning. Subaru also uses vehicle behaviour info on different cases (not in conjunction with graphic). Subaru, Mazda, Honda, as well as non-japanese manufacturers like Volvo and Jaguar use the same approach and will display warning through the infotainment system of the vehicle. After reading this info i was quite surprised on the fact that only Toyota out of these manufactures proceeds to the shut down of the vehicle in this emergency case. None of the companies have reported accuracy of their systems probably because of marketing concerns as well as patent and confidentiality constraints. Through the literacy review of recent work at [32] and [30] the accuracy across multiple works seem to vary between 70 and 99%. Hopefully commercial cars use well trained models. I should also note that works mentioned on [32] using multiple methods in conjunction didn't achieve very high accuracy and were rather in the low spectrum but this could be due to implementation and lack of rules in the rules of when each capturing will play the major role in the decision.

The authors of [30] also refer to the various ways the classification of a drowsy or not driver can happen, providing ample citations (over 100) while they also illustrate the framework of this in a picture 29. The classic machine learning cycle occurs, through the collected data a feature extraction is performed, then feature transformation can take place while feature selection happens to increase accuracy selecting the best traits for the task. Classification happens with the use of algorithms and classifiers acting after being trained with data. Then based on the classification results we get a decision output of whether the

driver is drowsy or not and then the car based on that may initiate it's alarm or proceed to appropriate actions that vary from vehicle to vehicle.

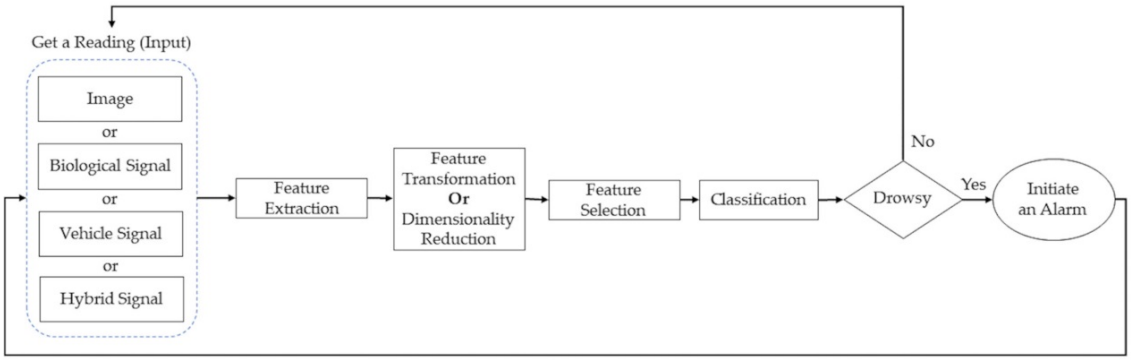


Figure 29. Driver drowsiness detection systems data flow.

Source: https://www.mdpi.com/1424-8220/22/5/2069

On [30] the authors refer to the challenges the drowsiness detection systems face while also referring to certain companies. One major challenge which occurs on both image, biological and car sensor data approaches is that most of these system are trained and tested on simulations and not real conditions thus rendering them less ready to tackle real life scenarios. For image based classification the biggest challenges are the driver's movement as well as facial characteristic and objects covering the driver's face like eye-wear. For the biometric data approach the data are usually too noisy while the hardware setup complexity is also very high. The vehicle based approach which is the cheapest and less intrusive seem to have the least disadvantages so far but the road's conditions can confuse and the precision of whether the driver is drowsy or not is not that great. Again in such a case, same as the LiDAR vs cameras discussion i believe that a combination of cameras and vehicle data approach will be the most implemented one, while i find biological based data harder to extract properly while maintaining a good marketing approach, creating vehicle's appealing to buyers.

Authors of a 2021 article [101] were able to detect drivers' risky behaviour like sudden acceleration, sudden breaking as well as sudden right and left turns. The data-set used was consisted solely out of accelerometer and gyroscope data and was labeled according to the mentioned risky actions. Their final data-set consisted of 60 features that were based on statistical values calculated using the gyroscope and accelerometer extracted values from an algorithm the authors developed. This also comes to highlight that calculating the statistical values might improve accuracy as a similar technique took place in previously mentioned papers. The authors also make use of sliding windows to smooth the data.

A specialty on this paper is the use of fuzzy logic, since they were able to get feedback from police officers that assigned a risk score for each dangerous behavior they created membership functions and fuzzy rules. Based on two "modules" as they call it in the paper the MLM (Machine Leaning Module) and the FLM (Fuzzy Learning Module) they were

able to both identify risky behaviour and offer a risk driving score to the driver based on the number of risky moves performed.

The MLM module was trained and tested with widely used machine learning algorithms in behavior analysis. They used a plethora of algorithms/classifiers including C4.5 Decision Tree, Random Forest, Artificial Neural Network, Support-Vector Machine, K-Nearest Neighbor, Naive Bayes, and K-Star. The models on this work too were created using WEKA. The accuracy ranges between the algorithms with the lower bound being 93% achieved with naive Bayes while they managed to reach an astounding 100% accuracy with the K-star algorithm! These results are extremely promising and stem for a real life implementation for detecting risky behaviour. The possible applications are countless especially considering speeding tickets or even asking for driver license updates based on excessive risk scores.

The FLM module is responsible of assigning a risk driving score to the driver based on the number of risky moves performed. In extend each risky move has a value of importance (as judged by officers when given certain scenarios), that because of the fuzzy logic is not static and varies per context of the situation. After calculation the FLM with return a score ranging from 0 to 100. The authors provide several graphs illustrating their thoughts. The picture 30 visualizes the framework that would be behind a future app making use of this proposal.

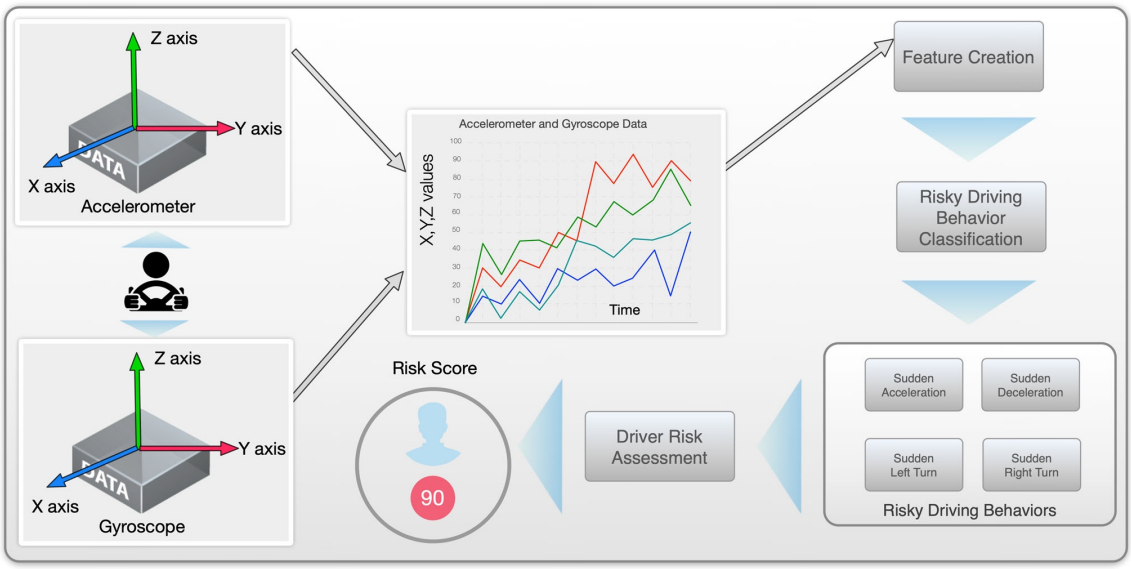


Figure 30. The risk behaviour assessment system's architecture as developed from [73].

Source: "Driver's black box: a system for driver risk assessment using machine learning and fuzzy logic" A. S. Yuksel & S. Atmaca

The authors thoroughly ran tests concerning the window size and the number of features and concluded that reducing the number of features only affect the accuracy negatively while the optimal window size for the statistical features was found to be that

of 14 seconds. They add that accuracy is dependent in the quality of features extracted.

The article discusses the integration of research findings into real-time crash warning systems to prevent accidents caused by aggressive driving behaviors. By actively detecting and recording risky behaviors, these systems increase driver awareness and promote safer driving. Classification and instant feedback can be used for real-time monitoring if shorter time intervals are used to not make processing hard. Additionally, the article proposes using the system to simulate traffic accidents using additional sensors like GPS and allowing traffic officers to analyze driving behaviors and identify the cause of accidents on the roads. The potential of gamification in promoting safe driving behaviors is also mentioned as an avenue for future research which calls for another field of economy and information technology called game theory.

Another article using the same data-set got published later next year [77] where the authors tested additional algorithms like logistic regression, SVM and multi-layer perceptron as classifiers for this task. They concluded that the best classifier (at least in their work) was SVM which reached an accuracy of 99.4%.

More notable works about applications of artificial intelligence and OBD-data can be found in the additional bibliography.

3.2 The Future: Focus Subjects of Leading Automotive Companies and Their R&D Institutes

The focus subjects of leading automotive companies encompass a wide range of key areas that drive innovation and shape the future of the automotive industry. These companies dedicate significant resources and expertise to push the boundaries of technology, design, sustainability, safety, and connectivity. By focusing on these subjects, automotive industry leaders strive to meet the evolving needs and demands of consumers while staying ahead of the competition. From electric and autonomous vehicles to advanced safety features, cutting-edge infotainment systems, and sustainable manufacturing practices, these companies lead the way in shaping the next generation of automobiles. With an unwavering commitment to excellence and a relentless pursuit of advancement, the focus subjects of leading automotive companies pave the way for a transformative automotive landscape that merges performance, sustainability, and convenience.

Before we continue ahead, i want to express my love for certain Japanese automotive companies and their openness in their research as well as their forward and open thinking (not that others do not. this is not catholic.). While i searched for papers from American as well as German automotive companies many of them were technical papers behind a paywall prohibitive for a student. In addition to that i want to highlight the existence of ways to reach out and communicate with certain Japanese companies like Honda and Toyota and their maintenance of dedicated pages for their research institutes where email

addresses open to public and usual Q&A pages can be found along with their recent advancements, news, supported publications and vision. Thank you for your contribution! The most of the following were info compiled from the HRI [18] (Honda Research Institute) and TRI [19] (Toyota Research Institute) but i think to some extent reflect most of the leading automotive companies' focus subjects. Of course other companies like Ford, GM, BMW, Volkswagen, Hyundai, Nissan and Subaru were also researched through data found from multiple sources online as well as their respective sites.

Again this is not a thing that applies to everyone. There are many automotive companies around the world and each and every one has their own R&D department that shapes the future. Whether data and papers will be publicly accessible / easy to find online / maintain a certain site and offer easy ways to communicate does not mean that the brilliance of their work doesn't reflect. Additionally ALL the big automotive companies including American, German, Korean, and Japanese have websites with latest news covering inventions technology, on going trials and so on. But TRI and HRI, have a dedicated page and even share or list scientific work and papers rather than simpler news articles. After all this section is to showcase the trends and research fields that are currently in the scope of the companies, not the companies themselves even though they are used to offer examples for better understanding of each subject.

3.2.1 Energy & Materials

Self-healing materials: Car manufacturers are exploring the development of self-healing materials, such as polymers or coatings, that can automatically repair minor scratches or damages on the vehicle's exterior, reducing the need for manual repairs. Not many applications of such materials have appeared yet but some early adaptation examples would be BMW's self-healing grill that could be found in news [3], [21]. The grill was able to "revive" itself from minor scratches.

Energy harvesting technologies: Research is being conducted on technologies that can harvest and utilize energy from sources such as vibrations, heat, or sunlight to power various vehicle systems, reducing reliance on traditional energy sources and increasing overall efficiency.

Advanced energy storage solutions: Batteries will play protagonist role as already seen in the upcoming EVs. Research is focused on developing more efficient and higher-capacity energy storage systems for electric vehicles, such as solid-state batteries or advanced supercapacitors, to increase driving range and improve overall performance.

Energy Management: An emerging problem is integrated energy management for buildings and e-mobility (electric or fuel-cell vehicles), in which automobiles may be utilized to balance energy flows. The key objective is to strike a compromise between the drivers' flexibility and the comfort expectations of the building's occupants. Reportedly [20] HRI-EU employs digital twins (digital copy of the real world), simulation models of cars and buildings, to develop and test energy management systems in diverse

scenarios and conditions. Exploring various control architectures, from simple rule-based approaches to model predictive control (MPC), and utilize adversarial and multi-objective optimization algorithms to investigate and enhance the robustness and performance of controller solutions.

Toyota has taken a great leap on this field with focus on

- Developing closed-loop methods for scientific discoveries.
- Making simulation-guided synthesis of novel materials possible.
- A thorough data-driven strategy to improving battery manufacture.
- Using systems thinking to drive strategic carbon neutrality decisions.

Toyota and many other companies have been researching advanced materials and manufacturing techniques to reduce vehicle weight, make it less loud and improve fuel efficiency. This may involve the development of new lightweight alloys, composites, or innovative manufacturing processes. Several recent works about inorganic crystals' structure can be found on TRI's website which are utilized for battery materials enabling energy storage and release. They also provide strength and durability in structural components, like steel, aluminum alloys, and ceramic composites used in engine parts, chassis components, and heat shields. So this suggest further utilization of the structure of inorganic crystal's from Toyota.

TRI has also created 2 open source projects that can be found on GitHub embracing the open software approach. The first is BEEP [61] which is a set of tools designed to support Battery Evaluation and Early Prediction of cycle life and the second is CAMD [75] which provides a flexible software framework for sequential / Bayesian optimization type campaigns for materials discovery.

3.2.2 Human Interactive Driving

Human-Interactive Driving: Human-Interactive Driving refers to the interaction between human drivers and advanced driving technologies, such as autonomous vehicles or driver-assistance systems. It focuses on creating seamless and intuitive interfaces that enable effective communication and collaboration between humans and automated systems. Human factor research utilizes principles from human psychology and physiology to optimize human-machine interaction. This involves designing interfaces that align with cognitive ergonomics and continuously monitoring the user's situational, emotional, and belief states. By doing so, the system can select the most suitable behavior in real time, ensuring maximum benefit for the user based on their current situation.

User Experience: A key aspect of Human-Interactive Driving is prioritizing the user experience. Interfaces and control systems are designed to be user-friendly, intuitive, and easy to understand, enabling drivers to interact with automation features effortlessly. Clear

communication and feedback mechanisms are crucial for building trust and ensuring a smooth driving experience. Future vehicles will be operable both by voice, gestures and other media closer to our human nature. In the very distant future maybe even through neuron detection.

Transitioning Between Automation Levels: The importance of facilitating smooth transitions between different automation levels, allowing drivers to take control or hand off control to the automated system seamlessly. This requires well-designed interfaces that provide clear information about system capabilities, limitations, and current operational status.

Driver Monitoring: Human-Interactive Driving emphasizes the need for driver monitoring systems to ensure the driver's engagement and readiness to take over control when necessary. For example DDD systems as previously mentioned can be used to detect driver attentiveness and intervene if the driver becomes disengaged or incapacitated while classifying and understanding a drivers behaviour through powertrain data can allow for corrective moves and tuning of the vehicle for a personalized user experience to fit or guide/correct the drivers behaviour to the best possible.

Overall, Human-Interactive Driving focuses on designing safe, efficient, and user-friendly driving experiences by integrating advanced technologies while considering the human factor in the driving process to achieve seamless collaboration of machines and humans while making mobility available to anyone.

3.2.3 Robotics

Robots are an integral part of the future and smart cities where mobility will play a major role. According to HRI-US their robotics program intends to incorporate avatars and autonomous intelligent entities into collaborative networks, allowing robots to cooperate with humans. They believe robots will broaden human capacities and improving quality of life by supporting human's physical, mental, and emotional activities offering more time for humans to socialize and create connections.

Toyota will use a plethora of robots in their Woven city project to enhance peoples' lives, so that's another reason. On TRI's website another 2 open source projects concerning robotics can be found. Drake which is a C++ toolbox for analyzing the dynamics of Toyota's robots and building control systems for them, and Punyo, a design for a soft bubble gripper that allows for robust and perceptive manipulation.

Car companies also prioritize robotics due to the fact that it assists their supply chain. Robots are employed in various areas of car manufacturing, including hazardous or physically demanding tasks, enhancing safety by replacing human workers in potentially dangerous environments while improving efficiency and reducing errors in the process.

Each company focuses on robots for various reasons the following list show the some of the main incentives of some popular automakers:

Toyota: Toyota has been investing in robotics research through its subsidiary Toyota

Research Institute (TRI). They focus on developing robots for various applications, including healthcare, household chores, and mobility assistance.

Honda: Honda has been involved in robotics research for many years. They have developed advanced humanoid robots like ASIMO and are working on robotics technologies for enhancing mobility and assistance in daily life.

Hyundai: Hyundai has established the Hyundai Robotics Lab to explore the application of robotics in various fields, including manufacturing, logistics, and healthcare. They aim to develop intelligent and efficient robotic systems for industrial and service sectors.

Ford: Ford has been exploring robotics applications for automotive manufacturing processes. They have developed collaborative robots, or cobots, that work alongside human workers on the assembly line to improve efficiency and safety.

BMW: BMW has been involved in robotics research, particularly in the area of automated production processes. They utilize robotics for tasks such as vehicle assembly and logistics within their manufacturing facilities.

General Motors: General Motors (GM) has been utilizing robotics extensively in their manufacturing processes for years. They have developed advanced robotic systems for tasks like welding, painting, and assembly in their production plants.

Volkswagen: Volkswagen has been actively researching and implementing robotics in their manufacturing processes. They utilize robots for tasks such as assembly, material handling, and quality control to enhance production efficiency and precision.

3.2.4 Artificial Intelligence - Autonomous Driving

We already analyzed most of the tasks that artificial intelligence will be undertaking in mobility. This includes computer vision, identification of certain phenomena, driver assistance systems, robotics, autonomous driving an so on.

According to HRI-US, Honda envisions future vehicles as living companions. They are made to keep humans safe by understanding their emotional and physical requirements and make for a private moving place for humans to live a pleasant existence.

Toyota seems to also be thinking the same if we take a look at the Woven city project as well as the autonomous driving automobiles released in the Japanese roads during the 2021 Olympics [81]. TRI also focuses on Human-Centered AI aiming to promote carbon neutrality and innovate future products and technologies by predicting preferences and increasing design creativity.

Some even research the ethical considerations that raise, such as the allocation of responsibility between humans and machines in complex driving situations. Determining liability and addressing ethical dilemmas, such as potential conflicts between safety and individual preferences, are crucial aspects that need to be addressed as these technologies evolve. I believe that the field of game theory can also assist this venture.

Additionally with the help of AI, companies strive to implement fully autonomous

safety features enhancing both safety and efficiency on the roads. By integrating technologies like collision warning systems, adaptive cruise control, lane-keeping assistance, Driver Drowsiness Detection systems (DDDs), advanced driver assistance systems (ADAS) it helps prevent accidents, reduce human errors, and optimize driving behaviors for better fuel efficiency and traffic flow.

3.2.5 V2X Communications & Smart Grid

Automotive companies conduct research on Vehicle-to-Everything (V2X) communications and Smart Grid technology to achieve multiple objectives and most of all get closer to an implementation of the future ecosystem of VANET as explained before. By exploring V2X and Smart Grid technologies, automotive companies aim to enhance vehicle safety, efficiency, and contribute to a smarter and more sustainable transportation ecosystem. Most if not all of automotive companies already perform research related to the subject as the legislation and competition also pushes them forward. We showcased multiple technologies that are still improving and being tested as well as many concepts and state of the art applications and hardware concerning mobility that will play a major role.

3.2.6 Virtual & Augmented Reality

Car companies invest in virtual reality (VR) and augmented reality (AR) technologies for multiple purposes. These technologies enhance the design and development phase by enabling designers and engineers to visualize and test virtual vehicle prototypes, resulting in early identification of issues and cost-saving design modifications. Furthermore, VR and AR elevate the customer experience by offering immersive and interactive car purchasing experiences, allowing customers to virtually explore various configurations, features, and options to make well-informed decisions. It is also utilized in training technicians, who can learn and practice intricate repair and maintenance tasks in a virtual environment, leading to enhanced efficiency and minimized errors. Future cars are said to also have AR dashboards and other VR and AR related hardware as well as software.

3.2.7 Sustainable Mobility and Alternative Fuels

Automotive companies are actively researching sustainable mobility solutions, including alternative fuel options such as hydrogen fuel cells, bio-fuels, and synthetic fuels. They explore ways to reduce emissions, improve fuel efficiency, and promote environmentally friendly transportation options as they attempt to achieve a carbon neutral profile.

An alternative fuel apart from electricity that made its backup to the foreground is hydrogen. Toyota has been a pioneer in hydrogen fuel cell technology, with the commercial release of the Toyota Mirai. The company’s CEO Akio Toyoda even went as

far as to confirm that the company's main focus is the improvement of hydrogen powered vehicle and fuels despite the current electrification efforts [24]. This shows his determined spirit and strong belief in this alternative fuel that we might see more in the future. Toyota is committed to developing sustainable technologies to reduce environmental impact. Their research includes advancements in hybrid and electric vehicle technology, fuel cell vehicles, and the use of renewable energy sources for transportation. Several other companies including Hyundai, Honda, and Mercedes-Benz have also embraced the idea of hydrogen fuel and also conduct important research on sustainable mobility and alternative power sources.

3.2.8 Quantum Computing

Quantum-enhanced simulations: Quantum computing can be used to perform highly accurate and efficient simulations of various aspects of car design and performance. For example, it can simulate the behavior of complex materials used in battery systems, enabling car companies to optimize battery performance, charging times, and overall efficiency.

Quantum machine learning: Quantum computing has the potential to enhance machine learning algorithms used in autonomous driving systems. By leveraging the unique properties of quantum systems, such as superposition and entanglement, car companies can develop more powerful algorithms for object recognition, decision-making, and predictive modeling. This can improve the safety and efficiency of autonomous vehicles.

Quantum cryptography and cybersecurity: Quantum computing can also play a role in enhancing the cybersecurity of connected cars. Quantum cryptography offers advanced encryption methods that are resistant to attacks from quantum computers. By leveraging quantum-resistant encryption algorithms, car companies can ensure the security and privacy of vehicle communications and protect against potential cyber threats.

It's important to note that while quantum computing holds great potential, it is still an emerging field, and practical implementations in the automotive industry are currently limited. However, research and development efforts are underway to explore these and other potential applications of quantum computing in cars.

Some of the companies researching quantum computing are:

Volkswagen Group: Volkswagen has established the Volkswagen Quantum Computing Competence Center (VWQCC) to explore the potential applications of quantum computing in the automotive industry. They are focusing on areas such as traffic optimization, material simulations, and machine learning algorithms.

BMW Group: BMW has partnered with several research institutions and companies in quantum computing research. They are particularly interested in utilizing quantum computing for materials research, optimization problems, and data analysis to enhance their vehicle development processes.

Toyota: Toyota has been actively researching quantum computing in collaboration with various academic institutions and research centers. Their focus areas include optimizing vehicle design, improving fuel cell technology, and enhancing traffic flow management using quantum algorithms.

Daimler AG: Daimler, the parent company of Mercedes-Benz, has been exploring quantum computing applications through collaborations with research institutions. Their research areas include optimizing manufacturing processes, battery technology, and traffic management.

Ford: Ford has engaged in partnerships with universities and research organizations to explore quantum computing applications in vehicle design, manufacturing, and supply chain optimization.

Honda: As mentioned at HRI-US website Honda aims to make advancements in quantum sensing and computing by developing novel qubit technology. They seek to leverage quantum mechanical effects to improve measurement precision for sensors and enable more powerful computations for quantum computers, using their expertise in nanomaterial synthesis and core technologies.

3.2.9 Software

Software has become a significant aspect of today's vehicles while many software firms are entering the car market. Cars make use of software a lot in the back-end (e.g. ECUs) but also even more in the front-end, as sophisticated infotainment systems are a must for the attractiveness of a modern car. These systems rely heavily on software to provide intuitive user interfaces, seamless integration with smartphones and other devices, voice recognition, and access to a variety of entertainment and connectivity options. Car companies invest in software research to ensure their infotainment systems are user-friendly, feature-rich, and compatible with emerging technologies. Over-the-air updates of cars' firmware will also be a thing, and as we mentioned, cars nowadays are computers on wheels so focusing on software is only natural to ensure success in the future.

In addition to all of the above we have seen many cars having software-bounded features with users/drivers having to pay to unlock them even though the hardware for a feature is already installed in their vehicle. An example of such approach was seen recently as BMW started running a subscription based service with a monthly fee for unlocking the heated seats feature in their vehicles despite the heating mechanism being already installed [95]. It seems that with the increasing integration of software and connectivity, car companies are exploring new revenue streams and business models. Subscription-based services might be a norm if the market pushes forward to it while in-vehicle app marketplaces and data-driven services that leverage the wealth of data collected from connected vehicles will also arise.

All the above mentioned focus subjects, research projects and advancements, demonstrate automotive/mobility companies' ongoing efforts to explore innovative

technologies and solutions that have the potential to transform the automotive industry. While these developments may not yet be widely applied, they hold promise for future advancements in vehicle design, functionality, and sustainability. Mobility will surely play an even more major role in our future societies and these set goals and ongoing research already show the possible shape of this future.

Chapter 4

Toyota's Woven City Case Study

After looking at multiple advancements including vehicles in IoT and understanding the way cars work and their future i think it is beneficiary to also examine the part "mobility" will play in the future and how a future smart city is visualised to be. In this case study we will take a look at Woven City, the dream smart city that Toyota builds and unlike other initiatives, is focused on "mobility" and is being built with human well-being in mind. Examining the Toyota Woven City project will offer insights and better understanding into how advanced technologies and sustainable practices can shape the cities of tomorrow. There isn't much bibliography available involving Woven City as it is still an ongoing project but here i compile information from the most important ones referring to it yet as well as Toyota's official announcement and analyze its current state and vision.

4.1 Introduction

The project begins with Toyota's transformation from an automotive company to a mobility company, meaning much more than a simple car manufacturer, and as an umbrella term the company embraces application of Toyota's technologies in multiple fields that relate to anything moving and makes an opening to the market. In May 2015 Toyota announced the mobility team concept and in 2016 TRI-US was established. November 2017, President Akio Toyoda underlined that the car industry was facing a significant transition that occurs only once every 100 years and that this time it happens due to the effect of CASE. Thus major focus of the company (as well as one of the reasons behind the city) was announced to be Connectivity, Autonomy, Shared Mobility and Electrification, or as they call it, CASE. Finally, on 2018 Toyota officially announced their transformation to a mobility company [25]. Following the transformation of the company, the ambitious initiative of the Toyota Woven City project was announced at the Consumer Electronics Show (CES) in Las Vegas in January 2020 [94].

In February 23, 2021 the groundbreaking ceremony for Woven City was held announcing the grand beginning of the project [45]. Construction work started early 2021

with the city being build from the ground up. A 175-acre site repurposed from the closing of the former Higashi-Fuji plant site of Toyota Motor East Japan was used. Site preparation work finished as planned starting February 2021 and finishing October 2022. To clarify and create a timeline, as of today the Woven City is still under construction with Phase1 of construction work starting on November 2022 and plans of completion of Phase1 in summer of 2024. In 2025, with Phase1 completed, initial trials will take place in the city [26]. The city will be located at the base of the unique and beautiful Mountain Fuji.

The name "Woven City" is meant to reflect the interconnectedness of its components and the diverse range of technologies and services that will be integrated seamlessly into daily life. As seen on the picture collage at 31 the city is even planned to be constructed to even look "Woven". According to Toyota, Woven City is meant to be an exploratory mechanism, an integrated system of various elements, all working together to weave the future fabric of life [91].



Figure 31. Picture Collage Illustrating the Concept of Toyota's Woven City

Source: https://global.toyota/en/newsroom/corporate/31171023.html

At CES Toyota shared their thoughts about the vision of the creation of a prototype city, designed to be a living laboratory for researchers, scientists, and companies to test and refine advanced technologies. They wanted a place able to handle every research activity that TRI and other research departments of Toyota wanted to conduct, but instead of a simulated environment (which as we mentioned creates several problems in AI models used for real life applications) they wanted to elevate their research to a real-life connected city offering them real data from real scenarios.

The city aims to redefine urban living by integrating cutting-edge solutions in mobility,

sustainability, and connectivity embracing IT. Entering at Woven City's official website [91] their vision and ultimate mission can be seen. Toyota wants to expand mobility, enhance humanity and engage society while their statement is to "Build the Future Fabric of Life in a City as a Test Course for Mobility".

The city is not yet inhabited as it is not yet completed, but Toyota reports that the community will initially consist of roughly 360 individuals, primarily elderly people and families. The population will then gradually grow to 2000. Among them of course will be Toyota personnel and researchers allowed to test and develop technology related to a wide range of areas including automated driving, personal mobility, robotics, and artificial intelligence [94] in real-world settings. The vision is for the city to be a living laboratory where citizens can live play and participate in their future. The main subjects of the "living laboratory" can be seen in picture 32.

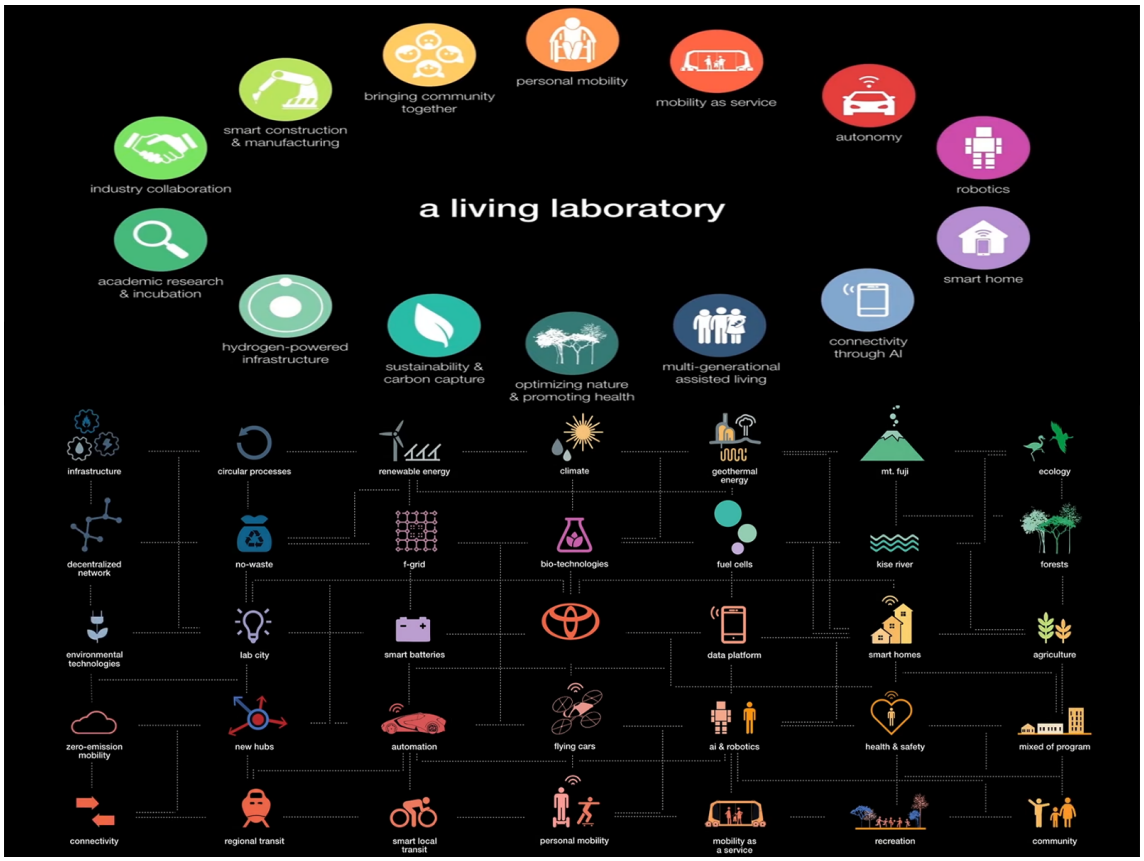


Figure 32. Subjects Involving Toyota Woven City, its Vision and the Interconnections

Source: https://www.youtube.com/watch?v=NME7pGh-7rk

The project will demonstrate a human-centered approach to community development and it is seen as an important step for Toyota in shaping the future of mobility and urban living. By creating a real-world environment to test and refine these technologies, Toyota aims to accelerate their development and deployment on a larger scale.

4.2 Objectives

The Woven City project is driven by Toyota's commitment on creating a better future for mobility and urban living. It seeks to address the challenges faced by cities worldwide, including congestion, pollution, and the need for sustainable solutions. By providing a controlled environment for experimentation and collaboration between researchers, scientists, and companies with the residents that will provide instant feedback and share their ideas. Woven City aims to drive the development of practical applications and solutions, showcasing a holistic approach to urban planning that can enhance urban mobility, sustainability, and quality of life.

To summarize the goals and objectives and according to Akio Toyoda's words "At Toyota we embrace the 17 sustainable development goals of the United Nations… and we hope the Woven City will provide a unique opportunity to create technology that will help achieve these goals." [99], [42]. The United Nations Sustainable Development Goals are a set of 17 global objectives (as seen in picture 33) about social, economic, and environmental challenges that we should face in order to achieve a more equitable, sustainable, and prosperous future for all the people and the planet. The Woven Planet in any update article in Woven City's website concerning crucial implementations and features also mentions in which of these categories it contributes.



Figure 33. The 17 Goals of Sustainable Development by United Nations.

Source: https://sdgs.un.org/goals

CEO Akio Toyoda in his message about woven city also added that he would like to add an 18th goal to the above which is ”Happiness, Because no matter where we live, happiness is something we all desire, and we all deserve...” [42], [99]. Generally Woven Planet markets the city’s purpose as ”Well-being for all” [100]. In Japan, the term ”Smart Community” is more commonly used than the term ”Smart City” [72]. A smart community integrates advanced technologies and social systems, enhancing energy efficiency, promoting the use of unused energy sources, and enhancing mobility aiming for the general well-being of the society rather than just the ”smartification” of a city of things. It seems that Woven City is really aiming for a smart community rather than just a smart city.

Of course there are opinions voicing that since residents don’t have a say in the initial design of the city and no power over the technologies implemented in the city this makes the city stray from its goal [64]. Though i don’t completely agree with that as Toyota initiated their plan about the city and from time 0 of the announcement of the project, they rolled out the welcome mat literally inviting anyone that is able to help to get in touch and contribute to the project [94]. Apart from that, it is clear that Toyota wants to stay ahead of the competition and having a whole smart city as an open laboratory for conducting research on the aforementioned fields will help progress Toyota’s creations which is also a desirable goal stemming for the well-being of the company as well as humanity. Of course some might think this just sounds like good marketing, and i too await to hear meaningful research findings and happiness reports of citizens living in the city. The general incentive though, the proof of concept, the quick construction plans, as well the employment of already existing cutting edge technologies make me rise high hopes!

4.3 Infrastructure Design & Features

At Toyota’s CES presentation, CEO Akio Toyoda said, “We plan to build a fully connected, digitalized, and carbon-neutral smart city.”. Toyota commissioned the Danish architect Bjarke Ingels founder and creative partner of Bjarke Ingels Group (BIG) of architects, designers and builders to come up with the city’s infrastructure design based on Toyota’s ideas. Woven City’s infrastructure strives to create an environment in which the creation of new inventions can take place in a timely manner to alleviate societal problems. It will be a programmable city built in a grid-like pattern with the entire city’s operation being woven into a single grid.

The Toyota Woven City is guided by several key design principles:

Connectivity and Communication: The city is built upon a robust and interconnected communication infrastructure. It enables seamless communication between various components, including autonomous vehicles, smart homes, public facilities, and personal devices. This connectivity enables a more efficient and integrated urban environment.

Sustainable Infrastructure and Green Spaces: The project places a strong emphasis

on sustainability and aims to be carbon neutral. The city's infrastructure will be designed to prioritize sustainability. It will incorporate renewable energy generation and will be powered mainly through hydrogen fuel cells. Additionally big green spaces with futuristic design as well as the climate near Mt. Fuji (as seen in picture collage 31) will be encouraging communication between citizens and allowing harmonious coexistence offering a nice and unique blend between nature and technology. With advanced systems supported by AI the city plans to minimize its environmental impact.

Advanced Mobility Solutions: The Woven City aims to revolutionize mobility by testing and refining autonomous vehicles within a controlled environment. These vehicles leverage advanced sensors, machine learning algorithms, and connectivity to navigate the city safely and efficiently.

Intelligent Infrastructure & Robotics: The city's infrastructure will leverage advanced technologies such as sensor networks, data analytics, and artificial intelligence. This intelligent infrastructure enables real-time monitoring, predictive maintenance, intelligent parking systems, efficient resource management, and personalized services that enhance residents' quality of life. Moreover the smart homes that will be inhabited will be equipped with intelligent systems that adjust lighting, temperature, security preferences and other devices based on individual needs. Residents can interact with the city through mobile applications, smart devices, and voice-activated assistants, accessing personalized services and real-time information.

Safety & Monitoring of the Well-being: Through clever designing and splitting of the traffic on different kinds of roads, Toyota plans to reduce accidents and allow for better monitoring. Additionally through smart house systems the well-being of the residents can be monitored. E-pallet vehicles with aids and people ready to offer medical help will also stroll around the city. In this living laboratory safety is being the major priority.

4.3.1 Infrastructure Design & Layout

Through their forward thinking and unique design but also thanks to the ground up making of the project that allows for such dreamy creations, the Woven City attempts to solve many modern problems simply by its infrastructure, that cannot be solved otherwise in an easy manner in the conventional cities.

The big question of our today's societies is **"Why do we still build cities for cars?"**, and why not for humans? Cities nowadays are extremely dense with everything and nothing on a single connected road system. More and more people buy cars to speed up their commute and move to centralized locations (leaving villages and calmer areas) in order to find better opportunities. Of course as each on of us in our society switches to privately owned vehicles as their main commuting way congestion on the roads increases. As the speed of vehicles falls to walking speeds due to the congestion we build even more roads to feed the "vehicle hungry" society. As we build more roads those become congested too because people see it as an opportunity to buy a car for faster commuting

once again. By making more roads we reduce the places people can use to spend leisure time and take nature walks while we also increase the distance of our commute as business buildings are forced to move further from the cities' centers to accommodate for road space. As the number of vehicles increases, parking also becomes a huge problem with parking places needing to be built and use even more space.

Today's cities are extremely focused on roads on vehicles rather than mobility. Mobility is different than cars. Mobility refers to the ability of individuals and goods to move within a given area or between different locations. It encompasses a broader concept of transportation that includes various modes of travel, such as walking, cycling, public transit, shared mobility services, and private vehicles. On the other hand, cars are a specific method of transportation which typically refers to private automobiles. We don't necessarily need cars to satisfy mobility.

Increasing mobility is one of the many major problems. Woven City plans to solve it with MaaS, CASE and it's smart infrastructure. It will be splitting the commute between 3 different types of streets that will be connecting with each into a woven grid of 3x3 city blocks each framing a local park or courtyard as seen in picture 34. One is dedicated to fast-moving traffic of fully autonomous, zero-emission vehicles (blue color) like the aforementioned e-Palette, one to pedestrians with personal mobility vehicles (pink color) like bicycles and the Toyota i-talk, and finally one solely to pedestrians (yellow colors) offering a secure and comfortable atmosphere for leisurely strolls and nature walks. In every road trees create the necessary distinction between people and vehicles. Thanks to this separation accidents will also be reduced getting closer to the "zero accidents on roads" target.

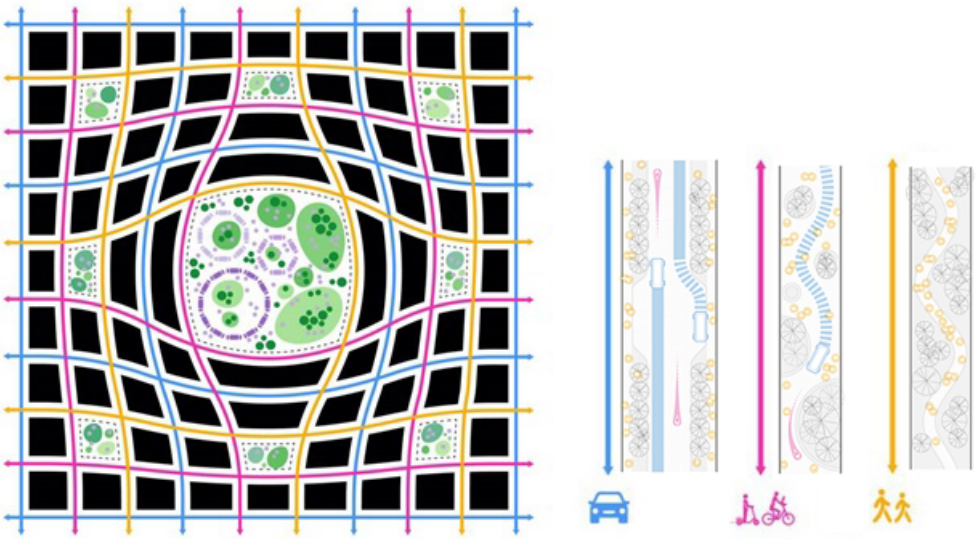


Figure 34. The 3 types of roads in the Woven City and their use cases (distinguishable by color). The streets will be interwoven with each other.

Source: BIG

Community areas are also an essential part of the city's planning. Natural, open areas across the city and the huge central park and plaza are intended to encourage the community to assemble for social gatherings. Toyota believes that human interaction will play a crucial role in the city's ecosystem and through this promotes communication and well-being [40]. Additionally it is said, according to BIG, that depending on the mobility media used, every part of the city will be reachable within about 2 minutes from the city center as seen on picture 35.

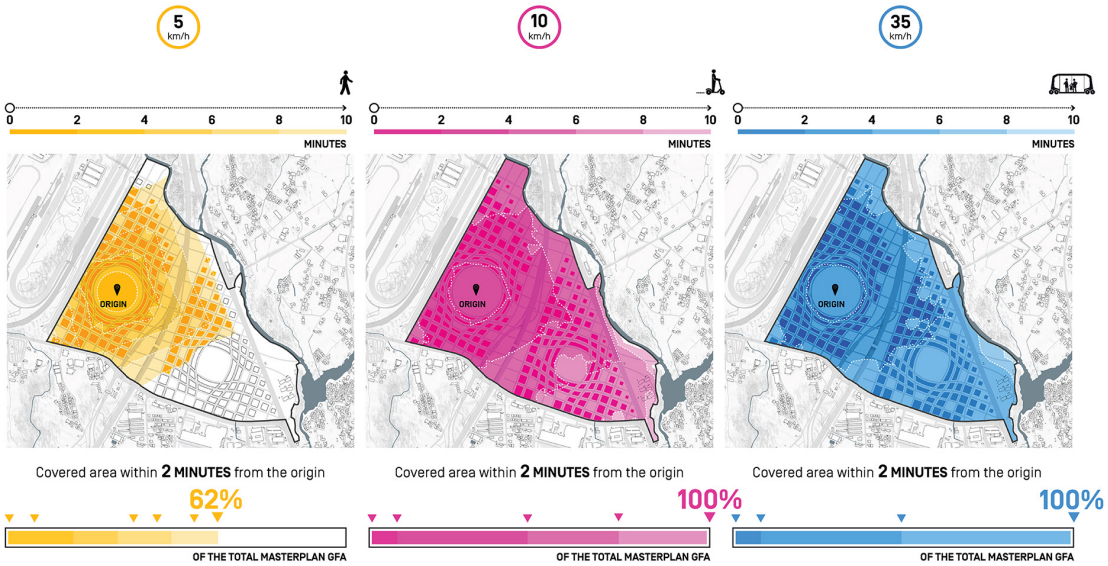


Figure 35. Accessibility times based on mobility media used in Woven City.

Source: BIG

Apart from the surface, many important tasks of the city will be taken care of in the underground. There will be the smart grid underground network with several pathways connecting across the whole city and up to the surface. This underground network will contain the hydrogen fuel cells powering the city, stormwater filtration systems, and through the pathways Micro Palette (small autonomous mobility robot-vehicle, explained later) will take care of the transportation of goods delivering them directly inside the houses intended to receive them.

4.3.2 Mobility Media

In Woven City only fully autonomous, zero-emission vehicles will be allowed [40], vehicles not satisfying the condition will be parked in a certain space outside the city and Toyota can provide suitable ways of mobility to the visitors or residents. A fleet of self-driving vehicles will cover many needs apart from commute. Toyota already has several mobility innovations said to take place to assists the city's venture [90].



Figure 36. The Toyota C+walk T & i-Walk concept, Micro Palette, Sora and LQ (From left to right).

Source: https://www.toyota-europe.com/about-us/start-your-impossible/mobility

Some of them planned to be deployed on the city are:

e-Palette

The e-Palette was announced at 2018 CES and is the vehicle we know the most about so far as it was even released to the public roads of japan during the 2020 Olympics [81]. The e-Palette is an SAE level 4 autonomous, electric, and customizable mobility platform developed by Toyota specifically for Autono-MaaS. It is essentially a modular, self-driving vehicle that can be adapted for various purposes [41]. It has a low floor/cube shape and features a flexible and spacious interior design that can be configured based on specific business needs, and even big outward facing displays (protected by glass) as seen in some models.

In the Woven City concept it will be used as the main multipurpose vehicle for tasks including transportation enabling for shared rides (MaaS), delivery services, mobile offices, and even retail experiences. Picture 37 shows an e-Palette and some possible modifications. Several e-Palette vehicles will run through the high speed roads of the city but can also come inside the town and be purposed as mobile retail units. It can be anything from a pizza shop, a work office to even a hotel accommodation or a first aid supply vehicle.



Figure 37. Various specifications of e-Palette Concept.

Source: https://global.toyota/en/newsroom/corporate/20546438.html

According to [46] Toyota as an emerging provider of mobility hardware and services to businesses, is focused on creating new and attractive features for partners that will help them to expand their value chain and improve customers' lives. Toyota through APIs will allow for the control and the collection of data (simillar to OBD, e.g. speed, location, battery info) from the e-Palettes by third companies owning e-Palette vehicles. To achieve this, APIs will utilize Toyota's proprietary Mobility Services Platform (or MSPF) used to create a suite of connected mobility solutions [46].

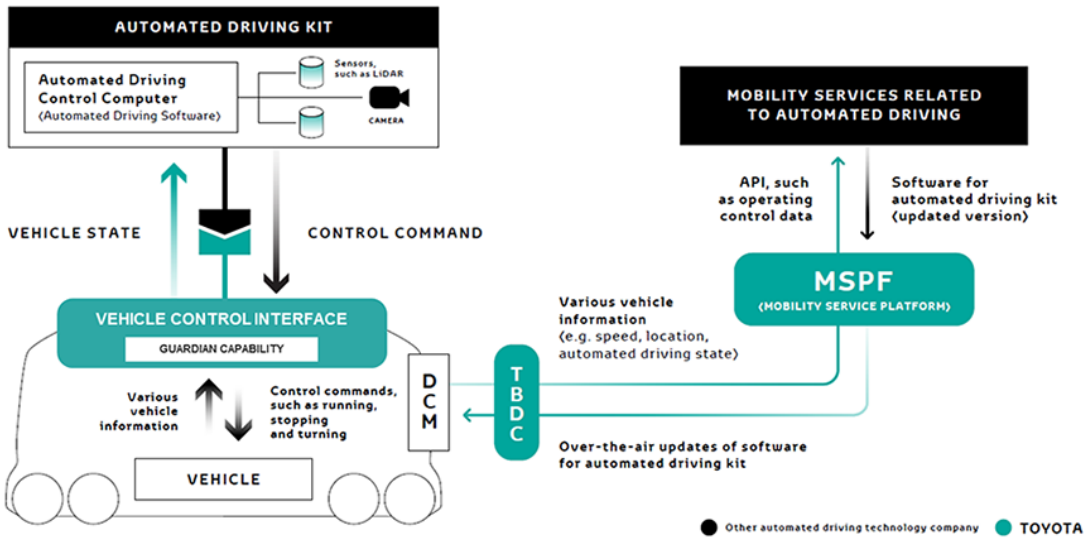


Figure 38. MSPF in MaaS business using e-Palette Concept

Source: https://global.toyota/en/newsroom/corporate/20546438.html

The suite includes e-Palette's open vehicle control interface as well as a collection of software tools that enable partners to install their own autonomous driving system and vehicle management technologies. Toyota's Guardian technology will operate as a safety measure to assure proper operation when a partner company's autonomous driving system is deployed [46]. To have this capability, the e-Palette utilizes a Data Communication Module (DCM), arguably similar to a TCU, in order to collect vehicle information, which is then stored in the Toyota Big Data Center (TBDC) via a global communication platform as seen on figure 39. This vehicle data will be used by the e-Palette Concept to enable a choice of financing alternatives as well as high-level maintenance in collaboration with Toyota dealers [46]. It seems like Toyota will be able to generated a huge amount of data even through vehicles not owned by the company and that programmers will be able to have access to that data through API calls which is a rather simple and much used concept.

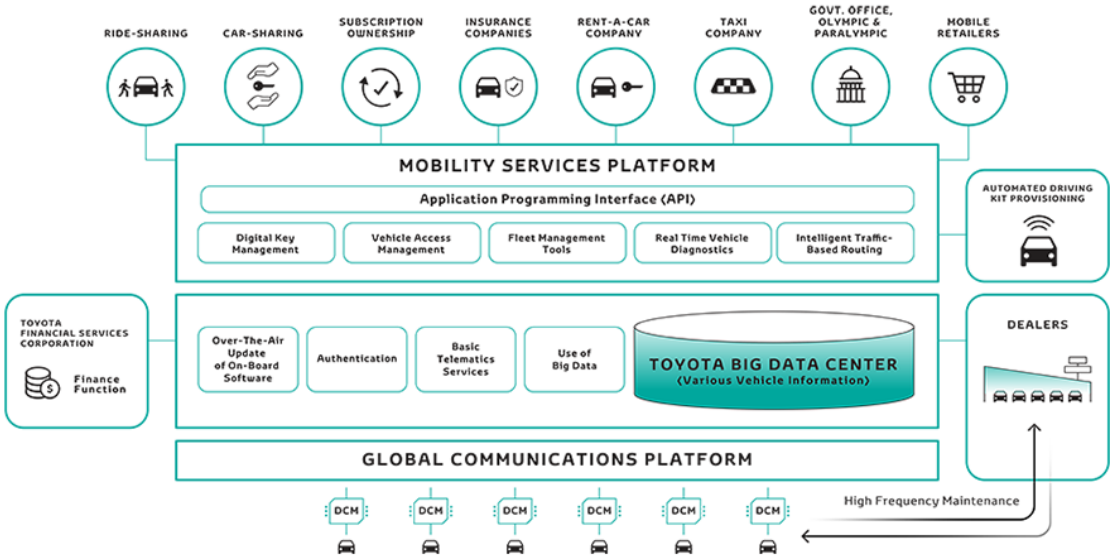


Figure 39. Mechanism of Automated Driving by the open vehicle control interface of Toyota E-Palette

Source: https://global.toyota/en/newsroom/corporate/20546438.html

Micro Palette

The Micro Palette is a little autonomous cargo carrying robot designed to do big things despite its size being similar to a big suite-case, as seen on picture 36. According to [90], whether making convenient door-to-door package deliveries or helping with the move of warehouse inventory, the Micro Palette can do it with a ”smile”. ”Humanity” is an essential part of its behaviour, allowing it to deliver with heart and feeling to customers. Micro Palettes will be ruling the underground of the city taking care of cargo work as well as in-house delivery of household necessities through the interconnected underground grid that has ways to the surface.

i-Walk & C+walk T

i-Walk is a compact personal mobility device occupying similar space as a pedestrian. It utilizes AI technology to understand the user through conversations with an AI Agent and data from sensors, enabling it to provide safe guidance when needed. It has advanced safety measures, including warning the driver and taking avoiding actions in potentially dangerous situations [56]. It has three wheels and an adjustable wheelbase, offering stability during movement and stops. It even features a front facing screen. C+Walk T is also a compact electric three-wheeler designed for short-distance travel in urban environments. It is intended to make it easier and safer for those with mobility difficulties to go about their daily life. Woven City residents are meant to use them as a way to commute in the slow mobility vehicle roads of the city and use it as commute for short day-to-day routes.

Sora

Named from the water cycle (sky, ocean, river, air), the Toyota Sora is a hydrogen fuel cell bus designed for public transportation, showcasing Toyota's commitment to sustainable mobility. It utilizes advanced fuel cell technology to convert hydrogen into electricity, emitting only water vapor as a byproduct. With a spacious interior and a capacity for up to 79 passengers, the Sora focuses on high-energy efficiency, incorporating regenerative braking and intelligent power control. It also incorporates advanced safety features, including pre-collision systems, lane departure alerts, and adaptive cruise control. It is equipped with a variety of sensors and cameras for enhanced safety and maneuverability. As part of Toyota's vision for a hydrogen society, the Sora aims to reduce emissions, air pollution, and fossil fuel dependency in the public transportation sector, promoting a sustainable and clean energy future.

LQ

The Toyota LQ is a concept vehicle that utilizes cutting-edge technology to establish an emotional connection between the driver and the car, based on the development theme of "learn, grow, love." It features automated driving capabilities and an advanced AI-powered interactive agent called "Yui," which learns from the driver and provides a customized mobility experience. The name "LQ" represents Toyota's aspiration to inspire the future development of vehicles that strengthen the bond between the driver and the car [90].

The interior of the LQ is designed with comfort and connectivity in mind, featuring a spacious cabin and advanced infotainment system. The car utilizes biometric sensors to monitor the driver's condition and provide a safe and personalized driving experience. In terms of sustainability, the LQ is an electric vehicle powered by a next-generation solid-state battery, offering improved range and efficiency. It also incorporates lightweight materials and aerodynamic design to maximize energy efficiency.

Even though the above mobility options are still in the development process and seem too futuristic, the future is near thanks to Toyota as according to [27] and [46], they have already partnered with companies interested on using the fleet for their workloads with some early adopters being Amazon, DiDi, Pizza Hut, and Uber.

4.3.3 Hydrogen and Alternative Energy sources

Toyota being one of the strongest believers of hydrogen [24], [39] has also made clear that electricity generated by hydrogen powered fuel cells (generating electricity through an electrochemical reaction between hydrogen and oxygen) will be the main energy supply of the city. The hydrogen cells will be located in the underground tunnels of the city and it is a great cost-effective alternative to batteries as storage of hydrogen is way less expensive. As Toyota has carbon neutrality as one of the city's goals, it will also utilize solar (trough solar panels on the roofs of the housings) and geothermal energy.

Toyota has also signed signed a joint agreement with ENEOS to collaborate on CO2-free hydrogen production and utilization at Woven City [98], [43]. They will work together, along with Toyota's subsidiary Woven Planet, to construct a hydrogen refueling station near Woven City and research an efficient hydrogen supply and demand management system. Electrolyzers will be installed (used for electrolysis, which involves using electricity to split water molecules into hydrogen and oxygen) in the hydrogen station which will produce CO2-free hydrogen using renewable energy and supply it to both Woven City and Toyota's fuel cell electric vehicles (FCEVs) which might bring supplies to the city. Additionally, they will explore the integration of Woven City's Community Energy Management System (CEMS) with ENEOS' hydrogen Energy Management System (EMS) to optimize hydrogen production. The hydrogen refueling station is scheduled to start operating before the opening of Woven City in 2024-2025.

4.3.4 Housing

The city will feature smart homes and buildings equipped with state-of-the-art technologies. The houses will integrate advanced home energy management systems (HEMS) able to monitor the buildings' energy generation and consumption [65]. Intelligent appliances with sensor-based AI will check on residents' well-being and adapt to their preferences to enhance their lives and digital interfaces will create personalized, energy-efficient living spaces. Robots will coexist with humans and help with routine daily tasks like cleaning, trash disposal, laundry pickup, and even occupant health monitoring.

To minimize its ecological impact and retain it's carbon neutral goal while staying true to Japanese traditions the Woven's City buildings will be built with carbon-neutral wood while incorporating a blend of robotic manufacturing processes and traditional Japanese joinery techniques [94], [40], [27]. Photovoltaic panels will be installed on the roofs of the housing to accommodate for extra energy as the main power source will be the aforementioned hydrogen fuel cells on the underground of the city. In addition to the above, Toyota intends to integrate native vegetation into the city and implement hydroponic systems as part of the city's infrastructure to cultivate vegetation and produce fresh food for the residents.

4.3.5 Smart City Platform

Toyota realising the rising of various digital services owing to the rapid development of cloud services, IoT, big data, and AI, proceeded in a collaboration with the national telecommunications company NTT (Nippon Telegraph and Telephone which is also partially owned by the Japanese government) on an ICT (Information and Communication Technology) R&D Platform for Connected Cars. The collaboration seeks to establish technologies for the creation of a Smart Mobility Society [44].

Both companies have initiated activities related to smart cities in the past, utilizing

advanced technologies to improve efficiency and services. NTT has been collaborating with local governments and companies to solve urban issues and promote smart city initiatives. To maximize the impact of transforming cities into smart cities, Toyota and NTT have decided to jointly build and operate the ”Smart City Platform” that encompasses various domains, including people, cars, houses, infrastructure, and public services. The platform will be initially implemented in Woven City and Shinagawa before expanding to other cities.

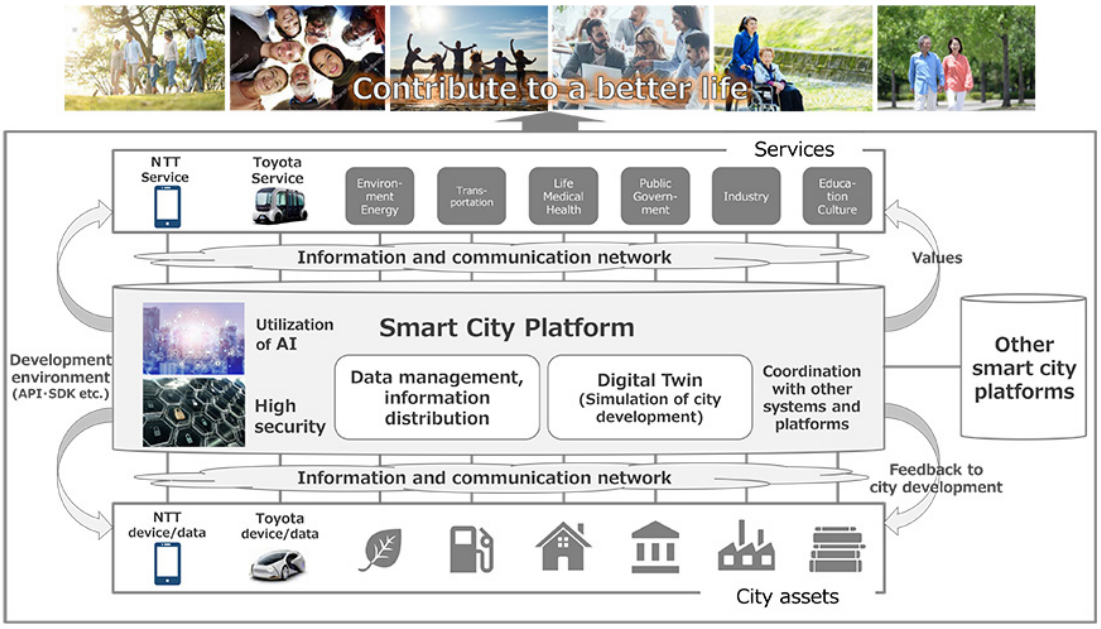


Figure 40. Overview of the Smart City Platform by NTT and Toyota

Source: https://global.toyota/en/newsroom/corporate/32057071.html

An overview of this Smart City Platform can be seen in figure 40. The Smart City Platform serves as a secure foundation for delivering value to residents, businesses, and local governments. According to Toyota’s article about the collaboration [44] the system will consist of:

Smart-city data management and information distribution system: This includes functions for collecting, accumulating, processing, analyzing, and visualizing data. It also serves as an interface for accessing services. The platform facilitates the management and distribution of data relevant to the functioning of a smart city.

Digital twin based on data: The platform incorporates a digital twin, which is a virtual replica of an actual city. This digital twin is continuously updated in real-time with data from the city. It enables urban development simulations and provides feedback on trial results. The digital twin helps in understanding the impact of changes and improvements before implementing them in the real city.

Peripheral functions: Which are functions related to networks, linking with various

devices and hardware, and connecting with different services, systems, and platforms. These peripheral functions ensure seamless integration and interoperability within the smart city ecosystem.

Again devices like smartphones as well as smart vehicles like the e-Palettes will be able to request and send data through API's and SDK as seen on the diagram at figure 40. The system will utilize artificial intelligence for the analyzation of data received and they will probably be stored in Toyota's big data server with high security measures taking place to ensure confidentiality, integrity and authenticity. The system is meant to provide for multiple services like transportation, medical support, education, energy sources and even the government. Feedback after the analyzation of data will go towards the city's assets.

Furthermore, the Smart City Platform is designed to be the "platform of platforms" [44]. It serves as a central platform for individual smart cities, providing a unified interface and infrastructure for managing various services and systems within the city. It also acts as a platform for connecting with other smart city platforms, facilitating collaboration and information exchange between different cities. Overall, the Smart City Platform is a comprehensive framework that manages data, enables simulations, and connects various components within a smart city improving efficiency, sustainability, controllability and contributing to a better quality of life.

4.4 Impact

As the city revolutionizes the concept of mobility, smart cities and urban living it is bound to have a great impact in our society if the project's venture manages to be successful achieving its goals.

Urban Mobility Transformation: By focusing on CASE as well as MaaS (Mobility as a Service), the Woven City has the potential to revolutionize urban transportation. The integration of autonomous vehicles, coupled with intelligent infrastructure and data-driven decision-making, can lead to safer, more efficient, and environmentally friendly mobility options.

Technological Advancement: The project's collaborative environment could drive the rapid advancement of emerging technologies. Through the testing and refinement of autonomous vehicles, AI systems, robots, connectivity and many more.

Enhanced Quality of Life: The integration of IT solutions within the Woven City aims to enhance the quality of life for its residents. Smart homes, personalized services, and seamless connectivity contribute to convenience, comfort, and improved experiences. The city's emphasis on data-driven decision-making can also lead to more efficient and responsive urban services.

Smart and Sustainable Urban Development: Commitment to sustainability serves as a model for future urban development. The integration of renewable energy, advanced

waste management, as well as the unique hydrogen power and carbon neutral approach of the sustainable infrastructure can inspire and influence cities worldwide to prioritize environmentally conscious practices.

Additionally according to authors of [65] which research promotion of eco-policies in Woven city believe that it merits special consideration in the study of eco-policies and eco-cities, and aspires to be a worldwide model, for the following reasons. The city is well-known on a global scale since it is home to Toyota's headquarters. Toyota supports the city's eco-policies, particularly in transportation and industry, by establishing a new mobility car-sharing service system and producing automobiles with low CO2 emissions in order to create a low-carbon society while recent news refer to the Woven City achieving carbon neutrality.

Author of [64] who analyzed Woven City's eco-policies with strategic marketing tools also used in IT has conducted a SWOT analysis on the prospects of the city in promoting eco-policies from a marketing perspective. Keep in mind that this analysis was conducted in year 2019.

	Positive factors	Negative Factors
Internal attributes	Strengths: Toyota City is relatively affluent and internationally known mainly due to the Toyota Motor Corporation. These companies financially and technologically support Toyota City in eco-related themes and eco-events, including the 2015 High-Level Symposium on Sustainable Cities (Toyota City, 2015). The city is also able to subsidize citizens with the purchase of eco-products such as NGCs and smart houses. Toyota City Hall also has a specific department responsible for promoting eco-policy, apart from the department in charge of environment policy.	Weaknesses: Toyota City is not a major city in size, with a population of 423, 000. The city's eco-policy's recognition and impact therefore may be limited, as it is the capital city of the Aichi prefecture compared to major cities' eco-policies, such as those of Kyoto City and Yokohama City. For instance, major broadcasting companies are located in capital cities of prefecture. Also, Toyota City is a car dominant society because of the Toyota Motor Corporation's presence. The full implementation of a car-sharing system like Ha:mo or the development of public transportation like LRT are difficult because the majority own cars (Ito, 2017).
External attributes	Opportunities: The environment and sustainability have been hot global issues. Various international conferences on these issues have been held, such as the 1992 UN Conference on Environment and Development in Rio de Janeiro, the 2002 World Summit on Sustainable Development in Johannesburg, and the 2012UN Conference on Sustainable Development Rio+20. Conferences of the Parties (COPs), an international convention where all world states discuss environment and sustainability issues, also take place every year. The UN Sustainable Development Goals set to be achieved by 2030, consist of addressing many issues regarding the environment and sustainability (United Nations, 2015).	Threats: Environmental issues do not seem to be a major concern for Japanese citizens, compared to other issues such as health care, social welfare, education, community development, culture, art, and sports. (Pekkanen, 2006). According to Nagasaka (2007), the number of memberships in Japan's environment-related organizations is smaller than other countries, such as the US, UK and Germany. For instance, the US National Wildlife Federation, the UK National Trust, and the Nature Conservation Society of Germany have at least a few million members respectively. In contrast, Japan's largest environment-related organization is the Wild Bird Society of Japan with 50, 000 members followed by WWF with 40, 000 and the Nature Conservation Society of Japan with 10, 000.

Table 6. SWOT Analysis of the Toyota Woven City in promoting eco-policy as seen on [64]

According to the SWOT analysis, Woven City, known for its affiliation with Toyota, benefits from financial and technological support from the company in eco-related initiatives. The city also offers subsidies to its residents for purchasing eco-products and has dedicated departments promoting eco-policies. However, as a relatively small city, with very low population compared to major counterparts like Kyoto and Yokohama, Woven City's impact and recognition in eco-policies may be limited. Additionally, the

prevalence of car ownership poses challenges for implementing car-sharing systems or developing public transportation. The adaptation of the MaaS concept might take a while to reach public acceptance as people are used to enjoying having their own personal vehicles. On the bright side, global focus on environmental sustainability presents opportunities for Woven City to contribute, with international conferences and the UN Sustainable Development Goals addressing such issues. Yet, environmental concerns may not be a top priority for Japanese citizens, as memberships in environmental organizations are relatively low compared to countries like the US, UK, and Germany. Issues such as health care, social welfare, education, and community development are equally or more important to the Japanese society which is already one of the most sustainable countries. Modern visions and outlooks of the Woven City plan to show that Toyota will get these needs covered focusing on all the issues the society is concerned about.

4.5 Closing Statement

The Toyota Woven City project represents a pioneering groundbreaking endeavor that showcases the power of advanced information technology in shaping the cities of the future. By integrating autonomous mobility, intelligent infrastructure, and data-driven decision-making, the Woven City aims to transform urban living, enhance sustainability, and improve the quality of life for its residents.

Of course there are also several challenges that the project will be facing along the way. One of the hardest difficulties to tackle i believe will be the adaptation and public acceptance of CASE (especially Shared Mobility and Autonomy) as well as the concept of MaaS. There are several reasons why people are still hesitant to the adoption of the idea and not excited about a future around it. People are accustomed to owning and driving their own vehicles, which gives them a sense of freedom and control over their transportation. The idea of giving up personal ownership and relying on shared mobility options might be seen as a loss of convenience or flexibility even though Woven City makes it look like paradise.

Individual cars as we know them might cease. Following CASE principles shared mobility will be the main way of getting to places but in my personal opinion that's not necessarily bad whatsoever. Of course only if this can cover the needs of today's societies. The e-Palette concept promotes connectivity, integration and a universal repurposable fully autonomous vehicle stemming for the vision of what future mobility will be about. Future vehicles will be very much programmable even with ways as simple as APIs and SDKs offering third parties access to data from Toyota's big data server but also immediate control over the vehicle and enable monitor of its health.

Additionally there are trust and security concerns from the concept of data collection and sharing of data with third parties through systems like the smart city platform. People are right to raise concerns about the sharing of personal transportation data, such as

travel patterns and even payment information as the e-Palettes will have capabilities to record anyone and everything while AI technology will be able to analyze this kind of data. Regulatory concerns also arise about the matter as well as the development of safe autonomous vehicles and other emerging technologies. I hope Toyota and other collaborators as well as the government will take care of these matters through their work to ensure public safety, privacy and provide transparency with technology complying to the human rights.

Apart from that the Woven City's success will also depend on its scalability and ability to be replicated in different contexts. A single city wont have a huge impact, enough to create a breakthrough but if we are able to incorporate the whole ecosystem in multiple contexts then that would be a huge success. Toyota's forward thinking, their innovations, the idea of "platform of platforms" as well as the infrastructure design proves that this city is being built to change the whole world not just the Higashi-Fuji Plant.

Personally i want and believe to the project's success. I await to hear meaningful research findings and happiness reports of citizens in the city. From an overall look the quick advancements and speedy construction process make this dreamy project which has the potential to shape the future of cities and revolutionize mobility very much believable. I am really excited about it and the future of mobility and put trust in Toyota's prowess. While challenges lie ahead, the project's successes and lessons learned will serve as a catalyst for IT-driven urban innovation, inspiring cities worldwide to embrace cutting-edge technologies and create smart, connected, and sustainable urban environments.

Chapter 5

Discussion, Conclusions & Future Work

5.1 Recap & Discussion

Today's automobiles are being revolutionized and their purpose is re-envisioned thanks to information technology. Mobility as we know it will completely transform. The work explored the intersection of mobility, cars, information technology, smart cities and societies, as well as the Internet of Things (IoT). Applications, concepts, and state of the art informatics related to mobility, cars, and smart cities within the IoT framework were investigated thoroughly while showcasing the interdisciplinary nature of the field and the future of humans and mobility. Through comprehensive compilation of info from a wide variety and abundance of reputable sources as well as through commentation about the current advancements, concepts, emerging trends and future possibilities, this dissertation contributes valuable insights to researchers and enthusiasts alike.

A comprehensive overview of engines, sensors, standards, concepts, and mechanics from an IT perspective was provided. The goal was to offer a simplified yet in-depth understanding of topics concerning automotive technology focusing on IT scientists who may not be familiar with the field. It could also be helpful to the ones in the automotive industry with limited knowledge on the IT advancements on the field. We discussed the current and the possible future state of the industry, including concepts, standards, and hardware employed in vehicles. Additionally, we delved into the architecture of automotive electronic systems and mechanics, highlighting methods for extracting, interpreting, and analyzing car data. Through a dedicated case study to Toyota's Woven City the work shifted towards mobility solutions, connected vehicles, the car's position in the society, and smart city infrastructure as well as the exploration of mobility's future.

The research aimed to explore the integration of IoT technologies and concepts to enhance mobility systems, urban living, develop sustainable smart cities and better societies. Along the way state of the art concepts and technologies were highlighted with important recent technological advancements in the automotive field. The future of mobility envisions interconnected vehicles communicating with each other but also other ”things” existing in the smart infrastructures thus creating a controlled and efficient

environment.

This dissertation also highlights the transformative technological shift occurring in the automotive industry and its current state. Cars have evolved into sophisticated computerized systems, with a significant reliance on information technology. The integration of sensors, embedded electronics, advanced ECUs as well as TCUs capable of carrying AI tasks, and the creation of mobility platforms has paved the way for a connected world and implementation of advanced features and automations in vehicles. The focus in the field has shifted from traditional safety measures and mechanical components to prioritize software development and IT/Mobility solutions. This is prominent as major automotive companies re-brand themselves as mobility companies in order to broaden their horizons and instead of simply manufacturing vehicles offer mobility solutions. The current research trends and focuses of mobility companies were explained thoroughly while certain examples were given. Mobility companies' current focus steers towards a wide variety of topics including IT related ones like software engineering, human interactive driving, robotics, artificial intelligence, V2X communication, smart grids, VR & AR and even quantum computing.

Smartphones and Telematics Control Units (TCUs) are expected to be important parts in future mobility solutions. These devices, equipped with advanced sensors and connectivity features, can facilitate various applications, including vehicle tracking, real-time data collection, and integration with smart infrastructure. Intercommunication through VANET such us V2X, V2V and V2I will increase safety by allowing immediate communication between vehicles and other things, stemming for the target of 0 deaths on public roads set by the EU. In the near future (2025+) we expect the upcoming breakthrough to unveil with fully automated safety features, connected vehicles and cities becoming more more smart. Meanwhile technologies like C-V2X and DSRC will keep being enhanced and researched a lot as they are the ones enabling vehicle communications to work. Whether one will be used more over the other in real-life scenarios or whether one might not be used at all after all is still in talks. C-V2X has many advantages, especially since it utilizes the already existing cellular network but it also poses some disadvantages that DSRC covers. There are still talks happening on the spectrum allocation concerning V2X communication with various and fair concerns rising. Regardless of the tech eventually used, safety and harmony should be prioritised in order to make sure nothing malfunctions during real life deployments. Decisions concerning these technologies will seriously affect the future and will be further discussed for sure.

As new platforms for mobility are on the making, they hinted that programming of cars will become much easier with the availability of APIs and SDKs provided by industry leaders. These tools will enable developers to create applications and services that can interact with vehicles, offering customization options, and even control over autonomous driving functions. Additionally, the creation of big data platforms will provide access to vast amounts of automotive data, which can be leveraged for various purposes, such as

optimizing traffic flow and enhancing overall transportation efficiency and safety. By harnessing the wealth of data available from cars and infrastructures, we can unlock countless opportunities for innovation and improvements as illustrated in this study. Advanced data analysis techniques, combined with artificial intelligence and machine learning, enable us to derive valuable insights and develop intelligent transportation systems. This data-centric approach has the potential to transform mobility, making it more efficient, sustainable, and tailored to individual needs.

While data-driven advancements hold immense potential, ensuring privacy and data security is of utmost importance. An anonymized data collection scheme is crucial to protect individuals' personal information while still allowing for valuable insights. Similarly, i believe that the establishment of a neutral network that is open and transparent will help prevent biases and unfair practices in data processing and decision-making algorithms. Monopolies on automotive big data platforms might also become a problem. Moreover, as we rely more on data and AI-powered technologies, ethical dilemmas arise. Responsible and transparent use of AI is crucial to mitigate potential biases, ensure fairness, and address concerns such as privacy infringement and algorithmic accountability. Ongoing efforts in research, industry collaborations, and regulatory frameworks aim to tackle these ethical challenges and promote the development of AI systems that benefit individuals and society as a whole.

The countless sensors present in today's cars as well as the open standard of OBD and CAN-BUS allowed for even individual IT researchers to get into the automotive field and for the release of exciting works. Regarding automotive standards, there have been debates surrounding the OBD-II standard and its potential limitation of use by making it operable only when the car is moving in order to avoid unintended access to third parties. Many advocate for open standards and free access to such standards including OBD-III, the next generation of On-Board Diagnostics but of course safety should be a priority. OBD-III (whether it will appear as OBD-III or telemetry data sharing or anything...) is anticipated to revolutionize mobility and smart infrastructures by offering more advanced real-time diagnostics, the ability to share data over networks like the cloud, and improved integration with emerging technologies. However, legal and regulatory challenges have hindered the adoption and official implementation and standardization of OBD-III, necessitating careful consideration of safety and compliance issues.

From a broader perspective, data plays a vital role in driving innovation in the IT and automotive sectors. Big data, coupled with advancements in data storage, processing, and analysis, offers unprecedented opportunities for improving vehicle performance, developing intelligent transportation systems, and enhancing user experiences. By harnessing data effectively, we can unlock new insights, optimize operations, and create smarter, more sustainable mobility solutions. In our future societies data (later turned to information) will be king and they who own it will go far, so we should be careful with this important resource.

Another thing i want to point out before closing is that, electrification wont necessarily be the solution to the ecological problems our planet faces. In fact, we might be the main reason why. As aforementioned the concept of CASE and Autono-MaaS will revolutionize mobility and will for sure help reduce emissions, the main problem here isn't their creation but their public acceptance.

Electric cars have lower emissions during operation, but the production and disposal of batteries, as well as the sourcing of raw materials have great environmental impact. It is important to consider the full life-cycle emissions of electric vehicles, including their manufacturing and end-of-life stages. To make the incentive count, it is crucial to charge EVs using renewable energy sources such as solar or wind power which are not viable options in many areas. While EVs can contribute to reducing emissions from the city environments moving it to another doesn't solve the problem, addressing climate change requires systemic changes. The current electrification scheme just stems for the decentralization of pollution but doesn't face the problem holistically.

Solving this problem would include improving public transportation, the adaptation and public acceptance of Autono-MaaS and CASE, promotion of sustainable urban planning, the encouraging of active transportation like walking and cycling especially for short distances, and developing integrated multi-modal transportation systems. In conclusion, EVs can help to combat climate change, especially when paired with renewable energy sources, however, a comprehensive solution that includes not just the use of electric cars but also larger reforms in transportation networks and energy infrastructure is required. The adoption of Hydrogen as seen in Woven City in conjunction with Solar energy would very much be a solution for near 0 emissions as showcased.

To also pay my respects to Michalis Kalogerakis i want to mention some of his work through this small spotlight as he has a clever solution to the low emissions and renewable energy topic. Basically, he was able to make himself completely power-independent and achieve getting power ”for free”. Using solar energy from photovoltaic panels he gets ”free” energy to power his house from a renewable source. Happy with the results, he then also wondered how he could make his car move ”for free”. His initial thought was hydrogen and he admits that it is indeed the best fuel in power ratio and that it is a great solution in general (he also has multiple appliances using hydrogen at his residence), but he couldn't easily store it or use it in conventional ICE engines. What he did was make a refinery powered by solar energy from the aforementioned panels where by fermenting sugar beets growing in his garden and then through distillation processes of the molasses he manages to produce a bio-fuel composed from about 14% alcohol with the rest being water [68]. He then uses this fuel to power both his car and sometimes even other things, machinery and devices. This is not just a concept as he has actual proof that this is possible and his home works on this principle. In [69] there is proof of his car, a Citroen C3, moving on this bio-fuel and even ”being able to cook”?! Note that the ICE needs no modification to able to work with this fuel! Keep in mind though he didn't invent the sugar beets to

alcohol concept, but he proposed the ”free fuel” ecosystem. This fuel is pretty ecological without changing much in our current cars but also it is a renewable fuel produced by renewable sources. Whether this is scalable or not remains a question though.

Finally, despite the rise in popularity of pure electric power-trains, vehicle manufacturers are still under intense pressure to improve the ecological performance of their combustion engines to comply with the strict emissions targets imposed, as the global automotive components manufacturer DENSO confirms [47]. ICE engines are not really the problem, they are not dead whatsoever as some people want them to be, even if they eclipse through time, they are, and will remain an integral part of the automotive history as well as an important learning point. I also do not consider upright opinions about electrification saving the world valid for the reasons explained. The video on [31] offers a good perspective on the current state of ICE, and why they are not the only problem.

Big changes take time and there are many practical challenges in mass electrification. The first one would be the autonomy since batteries need charging/refueling more constantly than ICE engines do, but also the charging time is significantly longer with even a car as good as a Porsche Taycan Turbo taking about 22.5 minutes to charge from 5 to 80% [31]. The challenges of creating a widespread charging infrastructure for electric vehicles, particularly in densely populated residential areas as there is a huge lack of space are showcased on [31]. The author also highlights the need for reconstructing parking spaces, installing cables, and conducting regular maintenance. The main problem is that even though EVs wont produce emissions on their own, the electricity they will consume will be (in the vast majority) produced by non renewable sources like the burn of coal and oils which as of 2019 make about 57% of the world’s total energy supply and emit harmful pollutants.

According to the International Energy Agency the use of fuels to produce energy coming from renewable energy sources from 1971 to 2019, a whole 48 years time-span, has only increased a mere 2.6% [62]. All the conferences and meetings and fuzz about the world taking an ecological turn seem to be a lie, a simple facade as nothing turned to actual deeds. So, no, in the very end your BEV is not changing the world, and as a mater of fact electrification is not around the corner and it might never be. It might be hydrogen, or alcohol, hybrids are also offering a solution to our current state, or we will probably continue with ICE for quite a while as we research ways for all the aforementioned major issues to be resolved. What i want to say is that, researching ICEs is not futile. The ”zero” emissions trend on electric vehicles is partially a lie, sometimes seen as a marketing trick. EVs will sure help in the decentralization of pollution from the cities and relocate it somewhere else but they won’t solve our problems, if of course that’s the reason why we switch to EVs and not an ulterior purpose. Again, electric vehicles are not the solution, because combustion engines are not the problem [31]. I love every vehicle and its unique technology whether it is an EV, a FCEVs or using an ICE or whatever elase. The important thing is to make progress for humanity.

Returning to the task at hand, overall, this research underscores the need for continued exploration and implementation of IT & Mobility solutions and addresses the challenges and opportunities in the domains of mobility, cars, and smart cities and societies. By leveraging the power of informatics, we can create a future that is interconnected, efficient, and environmentally conscious. The near future tech that is on the works and was showcased in this thesis proves that the ”unthinkable” future is near thanks to IT. The current advancements in technology and future concepts in Toyota’s Woven City case study that will soon be put to work evince that we really can achieve anything we put our mind into thanks to computers and our thinking. What i want to highlight through this work and i want everyone to take home is that computer science should be for humans, not for machines or cars or roads. While creating and designing our future we should always have in mind the well-being of everyone and everything and how our creations will impact society and the future. Follow a human-centered approach and have as the greatest aim, well-being and happiness, because in the end, that’s all that matters. To be happy. We know we can make anything, but should we if the aim is not ideal? E.g. Woven City approach also shows that we shouldn’t build cities for cars but for humans as explained why in the case study.

With this dissertation i also stay true to the academic program orientation i decided to pick inside my university which was ”Informatics in the Humanities and Social Sciences” which i think is the best one, and i am glad i got into the only university in Greece that has such orientation. The main focus was the study of the impact of new technologies on human thinking, perception, work and creation, on social relations, education, science, political and cultural action, as well as the impact of human presence, cognition and behaviour, individual and group, on the science of information and communication technology itself. This direction responds both to the international reality and to the educational and research needs of the field of information technology.

In the vast realm of possibilities, fueled by the transformative power of information technology, we hold the key to shaping a future where innovation, connectivity, and limitless potential converge to change the world for the better. To quote Akio Toyoda, everything ”is within reach if you just keep climbing”, and this statement couldn’t be more true as the recent advances prove that if we set our mind to something anything is possible and technology will be there to assist our dreams and ideas in becoming reality.

5.2 Future Work, Concepts & Ideas

The future work that can be done in this field is literally unlimited and ever-evolving. In this section ill refer to some of my own future work planned which is working on more practical applications putting to work my knowledge about cars, the way they work, the future, and the vision. One of my favourite fields to work on more would be engine tuning as it is a very exciting one, lets you learn and combine knowledge from multiple fields and

rewards you with a satisfying results as soon as you do it right. The field of tuning does not have many automations in its workflow yet and requires great amount of knowledge about cars while a bad tune can even cause serious damage to a car. I would like to attempt making a machine learning model able to create a better tune / fuel map given a specific car based on reads from sensor data collected from rides as well as dynamo-meter runs following the known tuning process. For this of course collaboration with mechanics and professional tuners is deemed useful as they will be able to guide, and have a say as experts, to what the model should take into account but also provide the necessary tools for this work to be done right.

I would also like to work on the optimization of engine cycles like Atkinson as well as hydrogen cars. One of my initial ideas for this dissertation was to find out if we could achieve better use of the Atkinson cycle by employing ML techniques. For example could we detect the behaviour of the driver through OBD and in conjunction with LiDAR and other technologies detect the road and the car's condition to enable longer use of the Atkinson cycle? (When to switch from Otto-Cycle to Atkinson-Cycle based on ML, since as we know it can only run on certain conditions). I don't know if companies use machine learning in cars already for the Atkinson cycle activation or if it follows algorithmic principles but it would be interesting either ways. The idea of hydrogen cars is also exciting and i would also like to test them out and conduct further research. Looking at Toyota Woven City i feel like the future will be bright and that hydrogen could be viable. Through this inspiring case study i decided to also research more about infrastructure and platform designing.

Furthermore i was thinking of making an app that with the help of AI will help new drivers learn by using it on their first rides. E.g. will give driving scores based on driving behaviour, warnings when dangerous maneuvers, excess speed or breaking take place while also detecting the optimal gear that could be used per time and advice to the new driver as well as many other similar features. This could be possible solely through OBD data extraction but using additional sensors like cameras to warn about posture, warning about possible pedestrians crossing and more will elevate it. Of course, to no surprise i will keep looking at the advancements over VANET and communication technologies while i want to create cheap ways for old cars to gain such features and not lose on the "smart hype". I also have the project of "smaritfying" my family's car (a strong Hyundai Atos built in 1998) in my mind.

Moreover i want to research and elaborate more on the concept of collecting emission related data and track illegal modifications of vehicles on the road in order to create a tax system where taxpayers get taxed relative to the amount of time they use their car, the emissions they create, and the way they maintain it. This way we will also increase safety and aim for greener environments (of course i wouldn't overtax older vehicles just because they don't have money to get a new one). Through an app reading the OBD protocol i envision an interface and platform that will continually capture data related to emissions

(there are ways to estimate emissions even with OBD-II) and based on certain parameters even warn if the car was possibly illegally modified (will check with a ”KTEO” database if the detected modification is legal or not). In the case where illegal modifications are detected (e.g. catalyst removal, which is usually done as it is falsely believed to increase HP) a warning will be sent to the owner’s smartphone issuing an emergency meet to a testing centre for motor vehicles (KTEO) to check it up with a technician. Taxes will be calculated on the amount of time the car spends on the road and on its ecological impact. This will also put pressure to big companies to increase their internal combustion engines’ efficiency and reduce emissions in order to be more competitive in the market. I find the current system of setting standard tax rates unfair in some cases and i think there will be a possibility to update it in the future to be more fair. This will happen with the collection of real-time data through the rise of OBD-III and other similar technologies, i believe this is a thing that will actually happen in the future. Of course we should always take into account and people who can’t afford the latest models of cars and are bound to extremely old models to satisfy daily commute. These people shouldn’t get over-taxed because of that but this is not directly linked to the IT spectrum.

In addition to the above i believe that searching for solutions, or even just slightly enhancing or providing concepts for NP-hard problems like TSP (traveling salesman problem) are much needed and will have an immense impact on the future of mobility. Imagine all of the countless mobility media around the globe delivering cargo, carrying passengers and so on, anything from cars and scooters to drones and airplanes could benefit along with many other fields apart from mobility. Just a simple enhancement and one step closer to the optimal solution, even if it’s not the best, will make a huge change on emissions as well as congestion, the time and energy spent and other factors. The concepts considering the graph approach could also take into consideration special weights on the edges when trying to find the optimal path like battery charging time, people’s needs, road congestion et.c. Quantum technologies may also offer new solutions in the future.

Thinking of it, and looking at the big TXT file stored in my dissertation folder, there are many ideas and tests i couldn’t showcase or conduct due to limitations, lack of advanced high level knowledge on the field of car mechanics, lack of connections with mechanics willing and with deep enough knowledge to help, as well as time constraints regarding the writing of this dissertation. But i am not sad about it since i love mobility and cars and i already have some plans ready regarding cars while research doesn’t stop here! More research will be conducted as i even made new friends from the field of car mechanics through my continuous attempts to increase the work’s impact and even got me acquiring tools and looking at mobility solutions even more. This is just a small piece of work for graduation and even though i couldn’t complete everything i wanted, the work already exceeded expectations and i am satisfied with the result while i also acquired deep knowledge about the subject and honed critical thinking. This thesis already got ”out of hand” (the recommended number of pages was ”at least 80”) but i don’t mind, since every

little thing that i was reading was linked to another that got me all the more excited and i couldn’t stop researching, reading more, writing more and thinking of ways to shed more light as well as spend time envisioning the future of human-centered mobility.

So finally, let me unveil the future of mobility... It will be a tapestry woven with innovation, efficiency, and sustainable progress, where transportation transcends its traditional confines, propelling us towards a connected and dynamic era of limitless possibilities that hopefully i will be there to contribute to.

This is the end of this thesis! Wish you all the best!

Bibliographical References

[1] June 2019. URL: https://www.press.bmwgroup.com/global/article/detail/T0296690EN/bmw-group-enhances-road-safety-by-sharing-anonymised-traffic-data?language=en.

[2] May 2019. URL: https://professional.mit.edu/news/articles/lidar-fools-errand.

[3] July 2021. URL: https://www.repairerdrivennews.com/2020/11/24/bmw-ix-has-special-self-healing-sensor-friendly-grille-high-tech-roof/.

[4] Nov. 2022. URL: https://cdn.euroncap.com/media/74468/euro-ncap-roadmap-vision-2030.pdf.

[5] Apr. 2023. URL: https://en.wikipedia.org/wiki/CAN_bus.

[6] Mar. 2023. URL: https://en.wikipedia.org/wiki/On-board_diagnostics.

[7] May 2023. URL: https://en.wikipedia.org/wiki/Volkswagen_emissions_scandal.

[8] May 2023. URL: https://en.wikipedia.org/wiki/ELM327.

[9] May 2023. URL: https://www.sae.org/blog/sae-j3016-update.

[10] Mar. 2023. URL: https://en.wikipedia.org/wiki/Cellular_V2X.

[11] URL: https://ww2.arb.ca.gov/resources/fact-sheets/board-diagnostic-ii-obd-ii-systems-fact-sheet.

[12] URL: http://fbaum.unc.edu/lobby/_107th/093_OBD_Service_Info/Organizational_Statements/SEMA/SEMA_OBD_frequent_questions.htm.

[13] URL: https://ww1.microchip.com/downloads/en/DeviceDoc/MCP2515-Stand-Alone-CAN-Controller-with-SPI-20001801J.pdf.

[14] URL: http://www.bosch-semiconductors.com/ip-modules/can-ip-modules/x-can/.

[15] URL: https://www.can-cia.org/groups/technical-groups/tc-technical-committee/ig04-lower-layers/sig01-can-xl/.

[16] URL: https://etsc.eu/europes-first-cars-with-level-3-automated-driving-go-on-sale-in-germany/.

[17] URL: https://www.nhtsa.gov/technology-innovation/automated-vehicles-safety.

[18] URL: http://www.jp.honda-ri.com/en/.

[19] URL: https://www.tri.global/.

[20] URL: https://www.honda-ri.de/research/energy-management/.

[21] URL: https://www.news.com.au/technology/motoring/luxury/2022-bmw-ix-review-electric-car-can-self-repair-minor-scratches/news-story/3996306398c4ac7a83c9f686a3f78489.

[22] URL: https://www.car-2-car.org/fileadmin/documents/General_Documents/C-ROADS_C2C_CC_C-ITS_and_CCAM_Data_paper_V1.0.pdf.

[23] URL: https://www.fcc.gov/wireless/bureau-divisions/mobility-division/dedicated-short-range-communications-dsrc-service.

[24] URL: https://www.torquenews.com/1/toyota-ceo-confirms-focus-hydrogen-despite-increasing-electrification-efforts.

[25] URL: https://www.researchgate.net/publication%20364091012_Significance_of_a_smart_city_for_transformation_of_the_business_model_from_an_automaker_to_a_mobility_company_-A_case_study_of_Toyota%E2%80%99s_Woven_City.

[26] URL: https://www.woven-city.global/updates/.

[27] URL: https://digitalcommons.latech.edu/cgi/viewcontent.cgi?article=1059%5C&context=engineering-science-magazine.

[28] 5GAA. URL: https://5gaa.org/content/uploads/2018/07/5GAA_WhitePaper_ITS-spectrum-utilization-in-the-Asia-Pacific-Region_FINAL_160718docx.pdf.

[29] AFR+. *AFR+ basic functionality - understand AFR values, wideband O2 sensors, and fuel trim vs. auto tune modes of our fuel controller.* URL: https://www.afrplus.com/AFRplus-unit-functionality.asp.

[30] Yaman Albadawi, Maen Takruri, and Mohammed Awad. "A review of recent developments in driver drowsiness detection systems". In: *Sensors* 22.5 (2022), p. 2069. DOI: 10.3390/s22052069.

[31] Driving 4 Answers. *Please stop commenting how evs are around the corner and how ice is dead*. June 2022. URL: https://youtu.be/k8CnlL8I4HE.

[32] Toshiya Arakawa. "Trends and future prospects of the drowsiness detection and estimation technology". In: *Sensors* 21.23 (2021), p. 7921. DOI: 10.3390/s21237921.

[33] CAN in Automation (CiA). *History of the CAN technology - CAN in Automation (CiA)*. URL: https://www.can-cia.org/can-knowledge/can/can-history/.

[34] 5GAA Automotive Association. URL: https://5gaa.org/content/uploads/2021/06/5GAA_S-210019_Position-paper-on-European-deployment-band-configuration-for-C-V2X_final.pdf.

[35] Adrian Bosire and Damian Maingi. "Driving signature analysis for auto-theft recovery". In: *The International Arab Journal of Information Technology* 19.3A (2022). DOI: 10.34028/iajit/19/3a/1.

[36] Christopher Boyd and MalwareBytes LABS. *MalwareBytes LABS: Car owners warned of another theft-enabling relay attack*. May 2022. URL: https://www.malwarebytes.com/blog/news/2022/05/car-owners-warned-of-another-theft-enabling-relay-attack.

[37] Matt Burns. *"anyone relying on Lidar is doomed," Elon Musk says*. Apr. 2019. URL: https://techcrunch.com/2019/04/22/anyone-relying-on-lidar-is-doomed-elon-musk-says/?guccounter=1&guce_referrer=aHR0cHM6Ly93d3cuZ29vZ2xlLmNvbS8&guce_referrer_sig=AQAAAJudsDEwLQgnvNrUoQ1lwykTPGbQhiMB_J0zrHoMaYdUnrbIogzRNfDoyhuX5SxzIySiHihOM2cQoOtoJw4Fxk5CQDFm4QrNnixhc9J7v-Pyous2Ue9yernRT6RbTWL2twLRroa4slbfSzeqX7guHDt6SDlG1oTjquRfdQTrSk9.

[38] CAN in Automation CiA. *CAN FD - The basic idea - Can in automation (CIA)*. URL: https://www.can-cia.org/can-knowledge/can/can-fd/.

[39] Joe Clifford. *Are hydrogen-powered cars viable? Toyota's view*. Feb. 2023. URL: https://mag.toyota.co.uk/why-does-toyota-make-hydrogen-cars/.

[40] Joe Clifford. *Toyota to build a hydrogen-powered city of the future*. Jan. 2020. URL: https://mag.toyota.co.uk/toyota-woven-city-hydrogen-power/.

[41] Joe Clifford. *What is the Toyota e-palette?* Feb. 2021. URL: https://mag.toyota.co.uk/what-is-the-toyota-e-palette/.

[42] Toyota Motor Corporation. *Toyota News 122 - within reach if you just keep climbing - Akio's message on Woven City - Toyota Times*. Feb. 2021. URL: https://toyotatimes.jp/en/toyota_news/construction_wovencity/122.html.

[43] Toyota Motor Corporation. *Eneos and Toyota come together to make woven city the most hydrogen-based society: Corporate: Global newsroom*. May 2021. URL: https://global.toyota/en/newsroom/corporate/35298631.html.

[44] Toyota Motor Corporation. *NTT and Toyota enter into Memorandum of understanding concerning business and capital alliance agreement: Corporate: Global newsroom*. Mar. 2020. URL: https://global.toyota/en/newsroom/corporate/32057071.html.

[45] Toyota Motor Corporation. *Toyota breaks ground for "Woven city": Corporate: Global newsroom*. URL: https://global.toyota/en/newsroom/corporate/34827717.html.

[46] Toyota Motor Corporation. *Toyota launches New Mobility Ecosystem and Concept Vehicle at 2018 CES: Corporate: Global newsroom*. URL: https://global.toyota/en/newsroom/corporate/20546438.html.

[47] DENSO. *Air/fuel ratio sensors and oxygen sensors – what's the difference?* Aug. 2022. URL: https://denso-sales.co.za/news/air-fuel-ratio-sensors-and-oxygen-sensors-whats-the-difference.

[48] Heinrich Dueker, Karl-Hermann Friese, and Wolf-Dieter Haecker. "Ceramic aspects of the Bosch Lambda-Sensor". In: *SAE Technical Paper Series* (1975). DOI: 10.4271/750223.

[49] EcmSpy. *ECM Tuning Notes for Buell DDFI and DDFI-2 2nd Edition*. EcmSpy, 2010.

[50] Jim Edwards. *Ford exec retracts statements about tracking drivers with the GPS in their cars*. Jan. 2014. URL: https://www.businessinsider.com/ford-jim-farley-retracts-statements-tracking-drivers-gps-2014-1.

[51] Jim Edwards. *Ford exec: "we know everyone who breaks the law" thanks to our GPS in your car*. Jan. 2014. URL: https://www.businessinsider.com/ford-exec-gps-2014-1.

[52] CSS Electronics. *CAN bus - The Ultimate Guide*. CSS Electronics, 2016.

[53] CSS Electronics. *OBD2 explained - a simple intro [2023]*. Nov. 2021. URL: https://www.csselectronics.com/pages/obd2-explained-simple-intro.

[54] Embitel. *Vehicle telematics: How does a vehicle telematics solution work?* Apr. 2021. URL: https://www.embitel.com/blog/embedded-blog/tech-behind-telematics-explained-how-does-a-vehicle-telematics-solution-work.

[55] Summit Racing Equipment. *Engine basics - air/fuel mixture - Summit Racing Equipment*. May 2020. URL: https://help.summitracing.com/app/answers/detail/a_id/5230/~/engine-basics---air%5C%2Ffuel-mixture.

[56] Toyota Europe. *Toyota Europe: Concept-i WALK*. Mar. 2018. URL: https://newsroom.toyota.eu/2018-toyota-concept-i-walk/.

[57] Dictionary Formula1. *Fuel Maps - Formula1-Dictionary.net*. URL: https://www.formula1-dictionary.net/map_fuel.html.

[58] David Hallac, Abhijit Sharang, Rainer Stahlmann, Andreas Lamprecht, Markus Huber, Martin Roehder, Rok Sosic, and Jure Leskovec. "Driver identification using automobile sensor data from a single turn". In: *2016 IEEE 19th International Conference on Intelligent Transportation Systems (ITSC)* (2016). DOI: 10.1109/itsc.2016.7795670.

[59] Christoph Hammerschmidt. *German car industry plans to close OBD interface*. Apr. 2017. URL: https://www.eenewseurope.com/en/german-car-industry-plans-to-close-obd-interface/.

[60] HCRL. *Driving dataset*. Dec. 2021. URL: https://ocslab.hksecurity.net/Datasets/driving-dataset.

[61] Patrick Herring et al. *BEEP: A Python library for Battery Evaluation and Early Prediction*. en. Jan. 2020. DOI: 10.1016/j.softx.2020.100506. URL: http://dx.doi.org/10.1016/j.softx.2020.100506.

[62] IEA. *Supply – Key World Energy Statistics 2021 – analysis*. 2021. URL: https://www.iea.org/reports/key-world-energy-statistics-2021/supply.

[63] Samsara Inc. *A guide to understanding DTC codes - Samsara IoT Company*. Oct. 2022. URL: https://www.samsara.com/guides/dtc-codes/.

[64] Hiroshi Ito. "Analyzing Toyota City's eco-policy through Strategic Marketing Tools". In: *Asian Social Science* 15.4 (2019), p. 23. DOI: 10.5539/ass.v15n4p23.

[65] Hiroshi Ito and Nobuo Kawazoe. "Assessing and promoting eco-policies in Toyota City, Japan". In: *Policy Design and Practice* 2.1 (2019), pp. 35–52. DOI: 10.1080/25741292.2019.1573451.

[66] J. S. Freudenberg J. A. Cook. *Controller Area Network (CAN)*. 2008. URL: https://www.eecs.umich.edu/courses/eecs461/doc/CAN_notes.pdf.

[67] 19 January. *DSRC vs. C-V2X: A detailed comparison of the 2 types of V2X technologies*. Jan. 2022. URL: https://autocrypt.io/dsrc-vs-c-v2x-a-detailed-comparison-of-the-2-types-of-v2x-technologies/.

[68] Michalis Kalogerakis. *How to ecologically power your life: Michalis Kalogerakis: TEDxChania*. May 2020. URL: https://youtu.be/qQ0QmqkGBNM.

[69] Michalis Kalogerakis. *ΤΡΕΛΑΝΕ ΜΑΣ ΚΑΛΟΓΕΡΑΚΗ ΜΕ ΤΟ ΑΥΤΟΚΙΝΗΤΟ, ΓΕΝΝΗΤΡΙΑ ΚΑΙ ΜΑΓΕΙΡΕΙΟ ΣΟΥ ΠΟΥ ΚΑΙΕΙ ΟΙΝΟΠΝΕΥΜΑ ΚΑΙ ΝΕΡΟ!* Ed. by JosephEditor Papadopoulos. Mar. 2023. URL: https://youtu.be/ZQJkeoX6Utk.

[70] Raman kumar and Anuj jain. In: *Driving behaviour analysis and classification by vehicle OBD data using machine learning* (2022). DOI: 10.21203/rs.3.rs-2353524/v1.

[71] Byung Il Kwak, JiYoung Woo, and Huy Kang Kim. "Know your master: Driver profiling-based anti-theft method". In: *2016 14th Annual Conference on Privacy, Security and Trust (PST)* (2016). DOI: 10.1109/pst.2016.7906929.

[72] Chun Sing Lai, Youwei Jia, Zhekang Dong, Dongxiao Wang, Yingshan Tao, Qi Hong Lai, Richard T. Wong, Ahmed F. Zobaa, Ruiheng Wu, and Loi Lei Lai. "A review of Technical Standards for Smart Cities". In: *Clean Technologies* 2.3 (2020), pp. 290–310. DOI: 10.3390/cleantechnol2030019.

[73] Fabio Martinelli, Francesco Mercaldo, Albina Orlando, Vittoria Nardone, Antonella Santone, and Arun Kumar Sangaiah. "Human behavior characterization for driving style recognition in vehicle system". In: *Computers & Electrical Engineering* 83 (Jan. 2018), p. 102504. DOI: 10.1016/j.compeleceng.2017.12.050.

[74] Fabio Martinelli, Francesco Mercaldo, Albina Orlando, Vittoria Nardone, Antonella Santone, and Arun Kumar Sangaiah. *Human behavior characterization for driving style recognition in vehicle system*. en. May 2020. DOI: 10.1016/j.compeleceng.2017.12.050. URL: http://dx.doi.org/10.1016/j.compeleceng.2017.12.050.

[75] Joseph H. Montoya, Kirsten T. Winther, Raul A. Flores, Thomas Bligaard, Jens S. Hummelshøj, and Muratahan Aykol. *Autonomous intelligent agents for accelerated materials discovery*. en. 2020. DOI: 10.1039/d0sc01101k. URL: http://dx.doi.org/10.1039/D0SC01101K.

[76] Charles Morris. *Elon Musk says Lidar is "A fool's errand," and others are starting to agree*. Mar. 2023. URL: https://evannex.com/blogs/news/elon-musk-says-lidar-is-a-fool-s-errand-and-others-are-starting-to-agree.

[77] Soumajit Mullick and Pabitra Mohan Khilar. "Driver behavior profiling using machine learning". In: *Advances in Systems, Control and Automations* (2021), pp. 165–173. DOI: 10.1007/978-981-15-8685-9_16.

[78] Matthieu Noel. *How car makers are trying to close the OBD port and keep control over the car data?* Oct. 2017. URL: https://www.linkedin.com/pulse/how-car-makers-trying-close-obd-port-keep-control-over-matthieu-noel/.

[79] Kyung Ho Park and Huy Kang Kim. *This car is mine!: Automobile theft countermeasure leveraging driver identification with generative adversarial networks*. Nov. 2019. URL: https://arxiv.org/abs/1911.09870.

[80] Andre Perras. *How to select a proper AFR for your engine*. Dec. 2018. URL: https://www.boostfactory.ca/blogs/standalone-tuning-techniques/how-to-select-a-proper-afr-for-your-engine.

[81] Person. *Toyota to restart self-driving olympic village vehicles with more safety staff*. Aug. 2021. URL: https://www.reuters.com/business/autos-transportation/toyota-restart-self-driving-vehicles-olympic-village-with-more-safety-staff-2021-08-30/.

[82] FTY Racing. *Lambda / AFR Table Calculator*. Jan. 2018. URL: https://ftyracing.com/tech/lambda-afr-table/.

[83] Craig Smith. *The car hacker's handbook*. No Starch Press, 2016.

[84] Mark Stevens. *Proper air-fuel ratio under 6 various conditions (W/ chart)*. June 2022. URL: https://cartreatments.com/air-fuel-ratio-at-various-conditions/.

[85] V2X Supporters. *Current situation of V2X in US and Europe 2021*. Oct. 2021. URL: https://youtu.be/SYpHtCpdJ1o.

[86] V2X Supporters. *Current status of V2X in US and Europe: As of September 2022*. Jan. 2023. URL: https://youtu.be/xh9Y9pJxVwM.

[87] Emmanouil Tatouris. *Toyota Atkinson vs Otto Cycle By Emmanouil Tatouris - AMG Specialist*. Sept. 2019. URL: https://youtu.be/gIP_-K-oxbw.

[88] CarBikeTech Team. *What is Telematics Control Unit & How It Works?* July 2021. URL: https://carbiketech.com/telematics-control-unit/.

[89] Timofey Temlyakov. *Obdii trackers: What future awaits them?* July 2019. URL: https://www.navixy.com/blog/obd-trackers-what-future-awaits/.

[90] *Toyota EU: Mobility*. URL: https://www.toyota-europe.com/about-us/start-your-impossible/mobility.

[91] *Toyota Woven City Official Website*. URL: https://www.woven-city.global/.

[92] Jovi Umawing and MalwareBytes LABS. *MalwareBytes LABS: Tiktok Car Theft Challenge: Hyundai, Kia fix flaw*. Feb. 2023. URL: https://www.malwarebytes.com/blog/news/2023/02/tiktok-car-theft-challenge-hyundai-kia-fix-flaw.

[93] Wekato University. *Weka 3: Machine Learning Software in Java*. URL: https://www.cs.waikato.ac.nz/ml/weka/.

[94] Toyota USA. *CES 2020 Livestream: Introducing the woven city: Toyota*. Jan. 2020. URL: https://youtu.be/NME7pGh-7rk.

[95] James Vincent. *BMW starts selling heated seat subscriptions for 18$ A month*. July 2022. URL: https://www.theverge.com/2022/7/12/23204950/bmw-subscriptions-microtransactions-heated-seats-feature.

[96] Wikipedia. *Atkinson cycle*. Aug. 2022. URL: https://en.wikipedia.org/wiki/Atkinson_cycle#Vehicles_using_Atkinson-cycle_engines.

[97] Wikipedia. *Kia Challenge*. May 2023. URL: https://en.wikipedia.org/wiki/Kia_Challenge.

[98] Inc. Woven By Toyota. *ENEOS, Toyota, and Woven Planet Collaborate to Facilitate CO2-free Hydrogen Production and Usage for Woven City and Beyond*. Mar. 2022. URL: https://woven.toyota/en/news-release/20220323/1y93iGergkoCxKn8DbpN1u.

[99] *Youtube - Woven City: Bringing Akio Toyoda's vision to Woven City*. Feb. 2021. URL: https://youtu.be/p-9X8Z2kJt8.

[100] *Youtube: Woven City - Why are we building Woven City*. June 2022. URL: https://youtu.be/KsjWF-1tFqo.

[101] A. S. Yuksel and S. Atmaca. "Driver's black box: A system for driver risk assessment using machine learning and Fuzzy Logic". In: *Journal of Intelligent Transportation Systems* 25.5 (2020), pp. 482–500. DOI: 10.1080/15472450.2020.1852083.

Additional Bibliography

[102] Abdalla Abdelrahman, Najah Abu-Ali, and Hossam S. Hassanein. "Driver behavior classification in crash and near-crash events using 100-car naturalistic data set". In: *GLOBECOM 2017 - 2017 IEEE Global Communications Conference* (2017). DOI: 10.1109/glocom.2017.8253921.

[103] John D. Hedengren Alan R. Parkinson Richard J. Balling. *Optimization Methods for Engineering Design. The Science of Microfabrication*. Brigham Young University, 2013.

[104] Amir Ansari, Hamidreza Abediasl, Parth Rakeshkumar Patel, Vahid Hosseini, Charles Robert Koch, and Mahdi Shahbakhti. "ESTIMATING INSTANTANEOUS FUEL CONSUMPTION OF VEHICLES BY USING MACHINE LEARNING AND REAL-TIME ON-BOARD DIAGNOSTICS (OBD) DATA". In: *University of Alberta Library* (2022). DOI: 10.7939/R3-4QNT-2997. URL: https://era.library.ualberta.ca/items/dd2443fc-54d8-483b-ae94-f72bccda4737.

[105] *Automotive-driven city of smartness : study of compatibility between Toyota's woven city and its current business mode*. URL: https://koara.lib.keio.ac.jp/xoonips/modules/xoonips/download.php/KO40003001-00002021-3828.pdf?file_id=165145.

[106] Ralph Birnbaum and Jerry Truglia. *Getting to know OBD II*. R. Birnbaum, 2001.

[107] Trabajo Fin de Grado and Roberto Setola. ""EXTRACTION AND ANALYSIS OF CAR DRIVING DATA VIA OBD-II"". In: 2018.

[108] Mohamed A. HAMED, Mohammed H.Khafagy, and Rasha M.Badry. "Fuel consumption prediction model using machine learning". In: *International Journal of Advanced Computer Science and Applications* 12.11 (2021). DOI: 10.14569/ijacsa.2021.0121146.

[109] Feng Han. *A new mapping algorithm for vehicle can bus mapping based on Correlation Method*. Jan. 2022. URL: https://deepblue.lib.umich.edu/handle/2027.42/171757.

[110] Jeff Hartman. *How to tune and Modify Automotive Engine Management Systems - all new edition*. Motorbooks, 2013.

[111] Britt A. Holmén, Mitchell Robinson, Matthew Conger, Karen Sentoff, and University of Vermont. Transportation Research Center. *Light-duty gasoline hybrid-electric and conventional vehicle tailpipe emissions under real-world operating conditions*. June 2014. URL: https://rosap.ntl.bts.gov/view/dot/37029.

[112] Sonali Kangralkar and Rajashri Khanai. "Machine learning application for automotive emission prediction". In: *2021 6th International Conference for Convergence in Technology (I2CT)* (2021). DOI: 10.1109/i2ct51068.2021.9418152.

[113] Md. Abbas Ali Khan, Mphammad Hanif Ali, AKM Fazlul Haque, and Md. Tarek Habib. *A Machine Learning Approach for Driver Identification Based on CAN-BUS Sensor Data*. 2022. arXiv: 2207.10807 [cs.LG].

[114] Byungjin Ko, Lian Cui, Saerona Choi, Byungkyu Brian Park, and Seunghan Ryu. "Field evaluation of vehicle to infrastructure communication-based eco-driving guidance and Eco-Signal System". In: *Transportation Research Record: Journal of the Transportation Research Board* 2672.25 (2018), pp. 123–138. DOI: 10.1177/0361198118797456.

[115] Rigmor Boltinus Larsen.

[116] Wei-Hsun Lee, Teng-Jyun Liang, and Hsuan-Chih Wang. "An innovative and cost-effective traffic information collection scheme using the wireless sniffing technique". In: *Vehicles* 4.4 (2022), pp. 996–1011. DOI: 10.3390/vehicles4040054.

[117] Su Hua Li and Ben Zhao. "Research of in-use vehicle emission management based on on-board diagnostic system". In: *Advanced Materials Research* 586 (2012), pp. 404–408. DOI: 10.4028/www.scientific.net/amr.586.404.

[118] Amy Poh Ai Ling, Sugihara Kokichi, and Mukaidono Masao. "The Japanese Smart Grid Initiatives, Investments, and Collaborations". In: *arXiv* (2012). DOI: 10.48550/ARXIV.1208.5394. URL: https://arxiv.org/abs/1208.5394.

[119] Somayya Madakam, Rajesh M. Holmukhe, and Siddharth Tripathi. "Rising of yokohama, Keihanna, Kitakyushu, and Toyota Smart Cities in the land of the rising sun". In: *Smart Cities* (2018), pp. 243–262. DOI: 10.1007/978-3-319-76669-0_10.

[120] Meenakshi Malik, Rainu Nandal, Surjeet Dalal, Vivek Jalglan, and Dac-Nhuong Le. "Driving pattern profiling and classification using Deep Learning". In: *Intelligent Automation & Soft Computing* 28.3 (2021), pp. 887–906. DOI: 10.32604/iasc.2021.016272.

[121] Azam Memon, Faisal Karim Shaikh, and Emad Felemban. "Experimental evaluation of vehicle-to-vehicle based data transfer". In: *2015 International Conference on Information and Communication Technology Research (ICTRC)* (2015). DOI: 10.1109/ictrc.2015.7156475.

[122] Massimo Merenda, Vincenzo Mazzullo, Marco Princi, Antonio Martino, Riccardo Carotenuto, and Demetrio Iero. "Evaluation of OBDII data contribution in tiny machine learning based driving behaviour monitoring". In: *2022 7th International Conference on Smart and Sustainable Technologies (SpliTech)* (2022). DOI: 10.23919/splitech55088.2022.9854360.

[123] NHTSA. In: *Exploratory Study of Early Adopters, Safety-Related Driving with Advanced Technologies* (Jan. 2006). URL: https://www.nhtsa.gov/sites/nhtsa.gov/files/doths_809972.pdf.

[124] Hizir Gökhan Özlem Çavuş and Imdat As Delara Razzaghmanesh. "An evolutionary approach for topology finding in flexible and modular housing". In: *CAADRIA proceedings* (2021). DOI: 10.52842/conf.caadria.2021.1.231.

[125] G. Priyadharshini and J. S. Femilda Josephin. "A comprehensive review of various data collection approaches, features, and algorithms used for the classification of driving style". In: *IOP Conference Series: Materials Science and Engineering* 993.1 (2020), p. 012098. DOI: 10.1088/1757-899x/993/1/012098.

[126] G. Priyadharshini and M. Ferni Ukrit. "An empirical evaluation of importance-based feature selection methods for the driver identification task using OBD Data". In: *International Journal of System Assurance Engineering and Management* (2022). DOI: 10.1007/s13198-022-01695-1.

[127] Clarence Ramai, Veeresh Ramnarine, Shankar Ramharack, Sanjay Bahadoorsingh, and Chandrabhan Sharma. "Framework for building low-cost OBD-II data-logging systems for battery electric vehicles". In: *Vehicles* 4.4 (2022), pp. 1209–1222. DOI: 10.3390/vehicles4040064.

[128] Navin Ramesh Reddy. *Driving Behaviour Classification : An Eco-driving Approach*. Nov. 2019. URL: http://essay.utwente.nl/80158/.

[129] Konrad Reif. *Fundamentals of automotive and engine technology standard drives, hybrid drives, brakes, safety systems*. Springer Fachmedien Wiesbaden, Imprint: Springer Vieweg, 2014.

[130] Dimitrios Rimpas and Andreas Papadakis. "Driving events identification and operational parameters correlation based on the analysis of OBD-II timeseries". In: *Proceedings of the 8th International Conference on Vehicle Technology and Intelligent Transport Systems* (2022). DOI: 10.5220/0011036400003191.

[131] Young Ryan Frank. *Utilization of a Neural Network to Improve Fuel Maps of an Air-Cooled Internal Combustion Engine*. Aug. 2010. URL: https://etd.ohiolink.edu/apexprod/rws_etd/send_file/send?accession=ohiou1282143527%5C&disposition=inline.

[132] Elisabeth Uhlemann. "Autonomous Vehicles Have Entered the Off-Road Market [Connected and Automated Vehicles]". In: *IEEE Vehicular Technology Magazine* 16.2 (2021), pp. 15–19. DOI: 10.1109/MVT.2021.3065792.

[133] Shan Ullah and Deok-Hwan Kim. "Lightweight driver behavior identification model with sparse learning on IN-vehicle can-bus sensor data". In: *Sensors* 20.18 (2020), p. 5030. DOI: 10.3390/s20185030.

[134] Tin Vaiti, Leo Tišljarić, Tomislav Erdelić, and Tonči Carić. "Traffic emissions clustering using OBD-II dataset based on machine learning algorithms". In: *Transportation Research Procedia* 64 (2022), pp. 364–371. DOI: 10.1016/j.trpro.2022.09.040.

[135] Cheng Zhang, Mitesh Patel, Senaka Buthpitiya, Kent Lyons, Beverly Harrison, and Gregory D. Abowd. "Driver classification based on driving behaviors". In: *Proceedings of the 21st International Conference on Intelligent User Interfaces* (2016). DOI: 10.1145/2856767.2856806.