T3CH-4-C4MPU5 – Student Challenge – Project Proposal

Our Vision: A Virtual TÜV

A Feasibility Study Based On Today's Technology

Project Proposal

TEAM GREEN

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1 Details of project partners involved

Company / Organisation	Contact	Role
Verband der TÜV e.V	Friedrichstraße 135 10117 Berlin berlin@vdtuev.de	Help for legalization and certification, connection with authorities
ZF Friedrichshafen	Löwentaler Straße 20 88046 Fridrichshafen	Partner in development of special parts for the cars
Daimler AG.	Geb. 120, 4. OG, Zone A D-70372 Stuttgart ir.dai@daimler.com	Main partner for project realization
Nvidia	2788 San Tomas Expressway Santa Clara, CA 95051 info@nvidia.com	Supplier for chips, hardware and software
Sony	Hedelfinger Str. 61, 70327 Stuttgart sony@haebmau.de	Supplier for high-resolution camera

2 Short Abstract

In Germany there are currently (01.01.21 [1]) around 48 million cars registered, of which each one has to undergo the TÜV check-up every two years. That makes 24 million cars checked by the TÜV per year, resulting in an enormous financial effort. Furthermore, the time spent by vehicle owners having to take their cars to the TÜV adds up to a vast amount. But most importantly, in between these check-ups the safety of the vehicles are not evaluated by an expert. Therefore detecting anomalies while driving falls into the responsibility of the owner, or in the case of autonomous cars currently won't be performed at all.

Our idea is to create a “virtual TÜV” that monitors the condition of the cars in real time, making the check-up every two years unnecessary.To achieve that we want to collect and process data from various sensors built into cars to create a software that is able to cover all aspects checked in the current TÜV in real time. Moreover we want to use the data form traffic cameras and the cameras built into the cars to detect damage on the vehicle body. This would not only get rid of the timespan the safety of the vehicles are not monitored and increase the overall safety of the vehicles, but may also lead to financial savings and increased sustainability, as life spans of various parts could be estimated more precisely. Additionally the time for private car owners having to take their cars to the TÜV would be saved, which could help the general acceptance of the virtual TÜV.

If and how exactly the TÜV can be reshaped into a virtual one we want to test in our feasibility study described below.

3 Motivation and project goals

It is very apparent that Virtual TÜV comes with quite a lot of advantages. Some primary examples would be spending less time than normal TÜV, a couple of security aspects such as carrying out checks at each start of the engine and eventually improving safety of the vehicle since more regular checks will lead to increased security. In other words, the idea of virtual TÜV is indeed sensible and practical, however there are various searching questions to be answered, to be more precise, is the Virtual TÜV feasible, realizable with today’s technology and if so, how expensive is this project going to get if we build something similar?

From our perspective there exist some possible pathways for answering these questions, therefore we provide two types of prototypes. The first one is to supply several sensors which will operate on the vehicle to check specific parts and give an immediate feedback so that the problem can be fixed in a short space of time. In the second prototype, a data-gathering platform will be developed in order to compare the usage data of one’s vehicle with others to be able to unveil inconsistencies, abnormalities and react to them as quickly as possible.

4 How the virtual TÜV will change the way to live

Doing our research we came across a question that would decide on the success of our project. Would society accept the new technology? Wouldn't especially elderly people mistrust our system? With good conscience we can answer all of those questions with no.

First of all we will be presented with more free time and no worries. We never have to bother with remembering the date of the TÜV again, we never have to make an appointment again, we never have to spend time bringing the car to the TÜV and picking it up later again, we never have to deal with unfriendly personal again. All this will lead to an increased customer experience.

Furthermore, machines eliminate human error. Every faulty part will be detected, machines aren't tired, they aren't bored, they haven't got a bad day. And even if humas would work with a flaw, cars must be checked every two years. We believe that's not enough. Especially with modern ways of travel where the usage of an individual car will increase. The sensors in the car are working all the time, your car will be safe at any given time. As sad as it is, you can bribe humans, but machines are resilient against that, they do what they are designed for, making sure your car is safe. Ensuring you and your surrounding are safe.

Also this new technology enables us to rethink our way of travel. Everyone is used to own his/her own car but this might not be the case is the future. The future of mobility lies in car sharing where no one owns a car but can access one at any given time at any given place. This bright future creates some new challenges, who is responsible for the car and makes sure the car has got TÜV? No one! Virtual TÜV is part of the key to the future of mobility.

5 State of the art/technology

5.1 Technical examinations of the current TÜV

During a TÜV inspection in Germany, various technical and non-technical aspects of a vehicle are examined which can be both, safety-related and non-safety-related. In general, the inspection can be divided into four different categories.
Firstly, the vehicle body is checked. The windshield and wing mirrors are examined for damage of any kind. The function of the headlights as well as all the other lights at the rear of the vehicle are tested. In addition the settings of the headlights have to pass a test. The vehicle body is controlled for weaknesses caused by rust and other anomalies. The majority of these steps are handled by a visual inspection of the tester during the inspection.
Secondly, the chassis is checked. Here the steering system is examined for vibration while driving. The position of the steering wheel while driving in a straight line and the

movement of the steering wheel without direct impact to the wheels is tested. Most of this is done during a short test drive. The different elements of the brakes are monitored (breaking fluid, brake pads, brake drum) and the braking pedal is checked for anomalies while being used. Furthermore all elements of the suspension (joints, dampers, axles, wishbones and springs) are inspected for damages visually. In this step, the tread depth of the tires is also checked and any damage of the wheels respectively of the tires is documented.
The third category includes the verification of exhaust emission values of vehicles with internal combustion engines. This check is not necessary for vehicles with an electric drivetrain and therefore does not need to be performed.
Additionally, not fitting into the three categories mentioned above, the car is checked for mandatory safety equipment like the first aid kit, warning triangle and reflective vests.

5.2 Used technology for the feasibility study

5.2.1 Windshield and Lights

The first parts which should be checked are the windshield as well as the lights of the vehicle. For example damages could be cracks, color changes, malfunctions plus wrong settings for a bad light distribution. Image analysis is used to detect damage of any kind. To generate the data for the examination two approaches are imaginable.

The first option is to use the cameras for driving assistance functions of other vehicles participating in road traffic. These do not necessarily have to be participants in the study, but in these cases high data protection hurdles have to be overcome. In the case that only data from vehicles that are part of the study is used, there is a problem regarding sufficient data generation. It should be mentioned here, for example, that the vehicles taking part in the study do not necessarily drive behind or against each other, so that any damage is not noticeable or is only noticeable at a very late stage. Another problem of this decentralized data acquisition is the evaluation and transmission of the image data: Evaluation directly in the vehicle is time-consuming and additional structures must be created in the vehicles to carry out image processing. On the other hand, the transmission of the captured images to a central server causes high data volumes and requires high data rates emanating from the vehicle at the same time.
The second option to create data for the image analysis is to use the infrastructure of already existing traffic cameras. This approach will be pursued further in the feasibility study. While the vehicles in the study are driving normally on the road, they are filmed by the already increasing number of traffic cameras in cities and on highways. The images from these cameras are originally used to control and monitor the flow of traffic. There are several advantages in using this repurposed data. First, sufficient data collection is ensured. On the other hand, vehicle owners of other vehicles outside the study do not have to ask for permission to access the cameras of their vehicles. Centralized analysis of the image files is also more efficient than a decentralized image analysis. Finally, the smaller amount of data to be transferred between a vehicle and the server should be mentioned here.

Picture 1: Centralized Image analysis. [2]

A brief summary of the intended solution for the study of the windshields or lighting of a vehicle: High resolution traffic cameras capture images of the study vehicles and transmit them to a central server where automatic image analysis is performed. The image analysis by means of AI technology is adapted and improved continuously during the project.

In order to follow this approach during the study, further work packages have to be processed. Here, for example, the buildup of the server structure or the replacement of the existing cameras with high resolution cameras have to be mentioned. Currently used traffic cameras often have a too low resolution to show the smallest cracks in the windshield or discolorations of the headlights. Another point that needs to be worked on is ensuring data transfer between the municipal traffic cameras and the server structure set up for evaluation.

5.2.2 Vehicle Body Check - Rust and other Damages

Another important safety-relevant aspect of a vehicle, whose practicability will be investigated in the virtual TÜV feasibility study, is checking the body for rust and other damage that weakens the structure. As with the windshield check, there are several approaches that have been evaluated and narrowed down in the course of the project so far.

The first option is to establish three dimensional scans of the vehicles. The actual shape of the vehicle is compared with the original shape of the vehicle at the time of delivery. With this knowledge, a conclusion can be drawn about deformations of the vehicle that are relevant to safety. With this approach, there are numerous problems to be solved before it can be deployed in the field. The most critical problem is certainly that damages

and weaknesses in the load bearing structure of the car body due to rust cannot be detected, or can only be detected at a very late stage. Another disadvantage is that the entire infrastructure for performing these 3D scans has to be rebuilt at high cost. This includes not only the technology itself, but also the necessary construction work at intersections in urban areas.
The second approach goes strongly with the approach to check the windshield and lights. In this case, the images from the installed high resolution traffic cameras are used not only to detect damage to the windshield, but also to detect deformations due to conspicuous light reflections. The biggest disadvantage by using this approach is the impossibility to detect weaknesses caused by rust as well as the difficulty to detect damages at the lower area of the vehicle due to the fact that mostly traffic cameras are mounted at higher areas to have a superior overview on the traffic flow.
To overcome the difficulties while detecting rust by using pictures and three dimensional scans, another concept is to locate changes of the structure by detecting changes of the structure-borne sound. The idea is to develop a threshold value of the structure-borne sound change of safety relevant parts of the vehicle body. Additional sensors at critical locations e.g. Crash-Impact-Sound-Sensing-Sensors (CISS-sensors) can be used for this purpose. These sensors can then integrate the function of detecting a crash of the vehicle as well as weaknesses caused by rust.

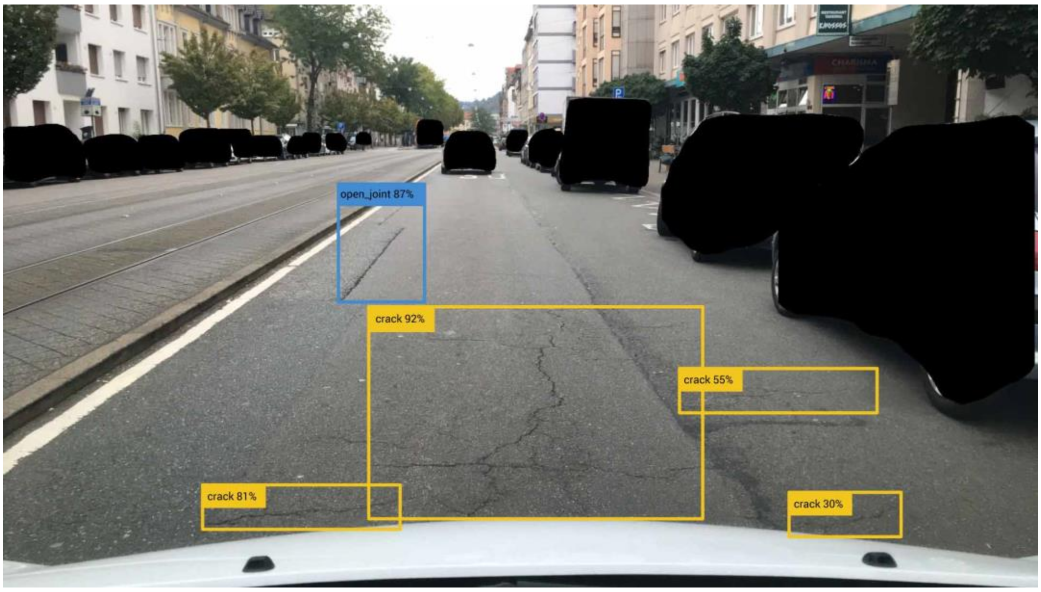
In the following, we summarize briefly the intended solution to check the vehicle body. A combination of using images from the traffic cameras and additional sensors that sense sound changes will be used. The evaluation of the sensor data is carried out directly in the vehicle and compared with target values. Finally, only key values and the results of the evaluation that are useful for other vehicles to compare with each other are transmitted. Evaluating the data at the point where it was generated has the advantage that the amount of data transferred is significantly reduced. This approach offers the additional advantage that both, the images from the traffic cameras and the data from the sensors, can be used for multiple applications. This not only reduces the amount of data that is generated, but also the monetary cost of implementing the features of the virtual TÜV. To decrease the amount of transferred data only key parameters and the results of

In order to be able to pursue the intended solution further, the applicability of CISS-sensors for this area of application must be investigated in the further course of the project. A further work package for the implementation of this technical solution is to determine limit values of structure-borne sound and assign them to individual damages. The replacement of the existing traffic cameras as well as the adaption of the image analysis software can be included in the previously mentioned work packages, which are a part of the windshield and light check.

5.2.3 Chassis Check - Steering and Suspension

The goal of the feasibility study is to test different technologies for selected test criteria. Preference is given to safety-critical aspects of a vehicle. Testing the steering system and the suspension is another central component of this feasibility study.

The basic idea behind the steering review is to analyze data already collected in production vehicles today. The aim is to compare the steering angle at the steering wheel with the rack displacement in order to check the steering column for correctness. To check the other components of a conventional rack-and-pinion steering system, the values of the vehicle acceleration as a function of the rack displacement (and thus the steering angle) and as a function of the road conditions are to be compared with expected target values. Road conditions must be estimated using collected data on precipitation (rain sensor), temperature (temperature sensor), position (GPS), visual anomalies of the street (Camera behind the windshield) and traction (ESP sensors). All these data are available without additional sensors in today's vehicles. One difficulty with this approach is that a high number of boundary conditions must be considered for a robust determination of road conditions.



Picture 2: Determination of the road conditions using the camera for assisted driving. [3]

Steering arms, bushings, joints and bearings of the wheel suspension are tested for functionality on the basis of structure-borne sound. The idea behind this is that, due to damage, the characteristic vibrations of the individual components change. The problem is that an anomaly in a single component can fundamentally change the vibrations of the entire chassis. Furthermore, the identification of a critical damage due to the superposition of the vibrations can only be implemented by a very precise and extensive recording of the vibrations as well as complex algorithms.

Due to a lack of choice in alternative solutions, the previously listed solution strategies will be implemented and tested in the study.

Estimation algorithms for the road conditions on the basis of the provided data have to be developed and continuously adapted. In addition, algorithms must be developed to determine damage to the chassis components. These calculations also require vibration data. For this reason, suitable positions for sensors on the components must be determined. The final task package consists of adapting the test vehicles accordingly.

5.2.4 Chassis Check - Brakes

The last technical systems of the vehicles to be examined remotely within the framework of the feasibility study in accordance with TÜV requirements are the components of the braking system. A subsequent nationwide implementation of the virtual TÜV can only be sensibly implemented if the brake system, with its central importance for the safety of a vehicle, can also be reliably tested. The following components of a brake system must be checked: Brake fluid, brake lines, brake discs and brake pads.

If the brake fluid is considered, it is important, firstly, that it is available in a sufficient amount and, secondly, not too much water is in it. The amount of brake fluid can be determined using simple level sensors, such as those already installed in many vehicles. The hydrophilic brake fluid absorbs water through porous hoses or cuffs during its life. A high water content leads to compressible water vapor bubbles and thus reduces the functionality of the brakes. Boiling point testers are used in workshops to determine this water content. For mobile use in a vehicle, such a boiling point tester must be designed and developed along the lines of existing testers.
The tightness of the entire system can be checked by using pressure sensors. If a predefined threshold is exceeded, the system sounds an alarm and communicates the need for action.
Brake discs and brake pads must be checked for wear. Abrasion indicators in brake pads are already used in the majority of vehicles. The aim is to integrate the same sensors in the brake discs.
The last point of the strategy to check a brake system is a functionality test of the entire brake system. This is to compare the braking force on the pedal together with the pressure inside the brake pipes with the negative acceleration of the vehicle. Here, the road conditions must be taken into account too.

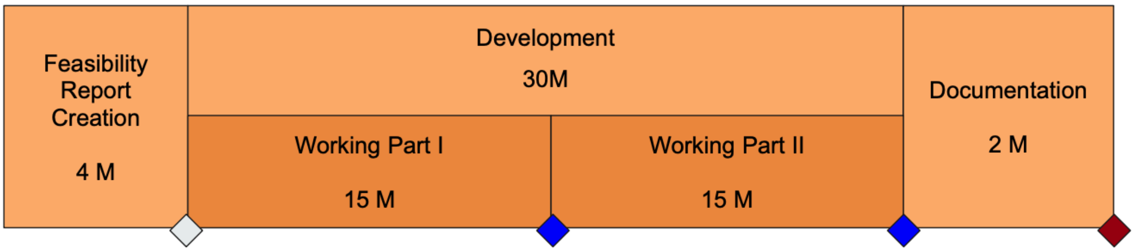
For the implementation of this test strategy, two work packages in particular must be successfully completed. On the one hand, the mentioned integrable boiling point tester has to be developed. Secondly, a reliable algorithm is needed that can determine the road conditions as accurately as possible. The development of such an estimation was already mentioned in the previous section.

6 Work plan description

The goal of this project will be achieved by developing new prototypical implementations to get a better understanding for the possible complex automation of TÜV components. To do so, the project is split up into two independent sub-projects named static- and dynamic work. The names are chosen in such a way, how data is stored and treated.

6.1 Static Project Part

To work towards an intelligent TÜV, we want to investigate the difficulty of developing initial implementations for work currently performed during standard TÜV examinations. To frame a concrete, realistic and reachable goal, we only consider work activities in the context of the car-related TÜV. As described earlier in this proposal (see chapter 5), our initial research put forth some concrete ideas on how to replace presently performed examination scenarios with intelligent sensor- and application solutions. A potential high level working plan can be seen below:



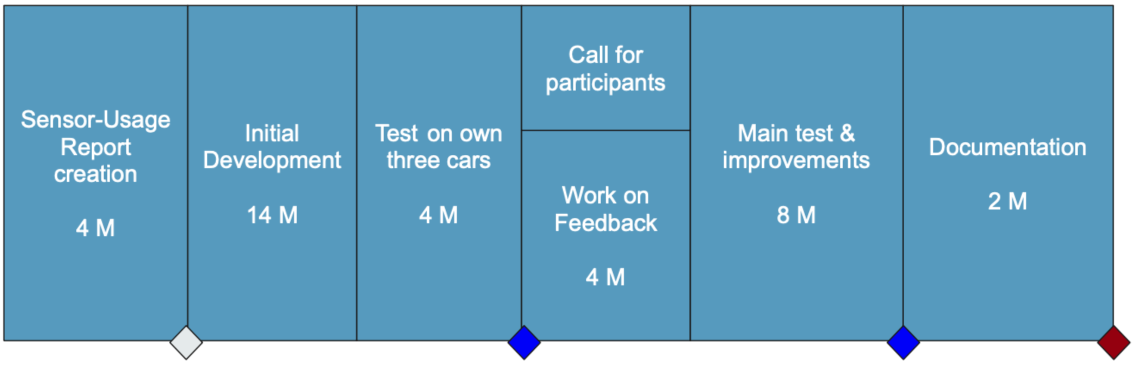
Picture 3: high level static work plan

The submission deadline for creating the feasibility report is highlighted in grey. The blue markers indicate the final presentation of the prototype developed and the submission of the documentation. The red marker indicates the final results presentation as well as a combined project-review documentation. The working packages and milestones are explicitly stated in more detail below.

- WP1: Feasibility Report Creation
  - WP1.1: Collate own ideas with TÜV partner
  - WP1.2: Update approaches based on Feedback
  - WP1.3: Consult Tech-partners to rate the implementation complexity
  - WP1.4: Rank results wrt. their realization difficulty
  - WP1.5: Summarize findings and partner’s feedback as a report
- WP2: Create a prototype II according to WP1’s report
  - WP2.1: Create prototype’s architecture
  - WP2.2: Implement human-computer-interface
  - WP2.3: Include logging functionalities
  - WP2.4: Provide test setup
  - WP2.5: Final rating of maturity and readiness
  - WP2.6: Documentation and presentation
- WP3: Create prototype I according to WP1’s report
  - WP3.1: Create prototype’s architecture
  - WP3.2: Implement human-computer-interface
  - WP3.3: Include logging functionalities
  - WP3.4: Provide test setup
  - WP3.5: Final rating of maturity and readiness
  - WP3.6: Documentation and presentation
- WP4: Summarize results

6.2 Dynamic Project Part

Beside from the development of technical aspects using stationary setups, the second project part deals with the detection of anomalies in car driving behavior. The goal is to develop a novel Machine Learning engine for car usage data to detect abnormal behaviours measured by already built-in onboard sensors. Therefore a massive amount of data has to be collected within this small experiment to find out which data measurements are useful for this purpose and what limitations emerge.



Picture 4: High level dynamic working plan

Similar to the marker legend depicted in section 5.1, the grey diamond indicates the submission of a sensor usage report depending on the partner vehicle involved. In a first working phase a ready-to-use prototype is developed to start the testing on. During this test, a massive amount of data is collected and various situations are tested and the software gets updated based on the collected feedback. Once the prototype platform performs well enough, new cars are added and data streams are filtered based on the initial results. Finally an extensive review process documentation is created and all findings and possible extensions are noted.
More concrete working steps are listed below.

- WP1: Creation of a Sensor-Usage Report
  - WP1.1: Decide on specific car type to use based on partners, included sensors and accessibility
  - WP1.2: List all available sensors API descriptions
- WP2: Create a prototype
  - WP2.1: Set up a simple data streaming storage
  - WP2.2: Install a local data gathering system (DGS) on the car to access the sensors
  - WP2.3: Setup a data connection between the DGS and the storage
  - WP2.4: Develop an external ML based data classifier / comparing system
  - WP2.5: Artificially create anomalies in recorded data
  - WP2.6: Test benchmark and accuracy of rating system
- WP3: Search for participants willing to share theirs data
- WP4: Summarize findings in a extensive documentation

7 Time and milestone planning

This section lists all milestones and dates, which are important to successfully complete all project goals.

7.1 Milestones

Below are the most important milestones to be achieved in time.

Milestone description (D=dynamic, S=static)	Maturity
(D) MS1: Sensor Usage report finished, decision about the required car type	Month 04
(S) MS1: Feasibility report finished, with a rating of solution complexities	Month 04
(D) MS2: Ready-to-use prototype	Month 18
(S) MS2: Ready-to-use sensor I	Month 19
(D) MS3: Tests on own cars passed	Month 22
(D):MS3: Successfully deployed software to other cars	Month 28
(S):MS3: Ready-to-use sensor II	Month 34

7.2 Deliverables

The most important deliverables are listed below. They are very similar to the milestones mentioned in the previous chapter. They describe at which point in the project individual results and decisions must be communicated to the project partners.

Description	Maturity
D01: Sensor usage report	Month 04
D02: Vehicle decision	Month 04
D03: Feasibility report	Month 04
D04: Summary of solution complexities	Month 04
D05: Supply of technical demonstrator	Month 18
D06: Ready-to-use sensor I	Month 19
D07: Complete test results	Month 22
D08: Distributable software for other cars	Month 28
D09: Ready-to-use sensor II	Month 34

8 Outlook

Assuming the feasibility study has a positive outcome and the virtual TÜV can be achieved, there are some aspects done in the TÜV today we did not cover in our feasibility study yet. To check for the safety equipment like the warning triangle and the first aid kit we want to implement contact sensors that detect if the equipment has been opened. Moreover the software to check for damages on the windshield and vehicle body should be extended to check for damage on the tires and even detect the profile depth of the tires. Additionally, more sensors have to be added to monitor the suspension. Furthermore a unit collecting the data from all sensors in the car and the cameras, which already processed the data as far as possible to minimise the data that needs to be transferred and stored, has to be created.
All the sensors would have to be included in newly manufactured cars and retrofitted as far as possible in old ones.
But most importantly one would have to create the infrastructure to make a fully automatic TÜV possible. All cars included, which ideally would be all cars driving on official roads, have to be able to transfer the collected data from the sensors and cameras monitoring the other cars in real time. After the feasibility study we would be able to precisely calculate the amount of data every car would transfer and the amount of storage capacity and computation power to collect the data and process it instantly.
After achieving that there would still be a long testing phase in which the virtual and the "normal" TÜV have to coexist. On the one hand, this phase is needed to prove that the

virtual TÜV can detect all damages the normal one can, but due to the constant monitoring of the cars compared to TÜV check-up every two years can do so even more accurately. Only then the virtual TÜV can be legally approved. On the other hand, as mentioned before, not all cars are already equipped with the soft- and hardware necessary for the virtual TÜV. So the replacement of the "normal" TÜV is going to be a soft transition over a long time.
After achieving all that in Germany, an European wide expansion of the TÜV could be achieved. This would lead to highly consistent safety standards on european roads, as well as financial savings and an increase in sustainability.

9 Cost plan

2022			
	Cost type	**Person months**	**Costs**
Personal	5 Scientific personal	12	200.000 €
	1 Consultant and 1 Technician from Daimler	11	73.334 €
	2 Technician from ZF	11	73.334 €
	1 Consultant from TUV Verband	12	40.000 €
	1 Consultant from Nvidia	12	40.000 €
Total Personal Costs			**426.668 €**
Material costs			
	- 3 Cars (for ex. Mercedes EQC) - Sensors and Cameras - Additional Material costs		189.000 € 2.000 € 1.000 €
Total Material Costs			**192.000 €**
Investition costs			
	- Hardware and Software		2.500 €
Total Investition costs			**2.500 €**
Subtotal			**621.168 €**

2023			
	Cost Type	**Person months**	**Costs**
Personal	5 Scientific personal	12	200.000 €
	1 Consultant and 1 Technician from Daimler	12	80.000 €
	2 Technician from ZF	12	80.000 €
	2 Technician from Nvidia	12	80.000 €
Total Personal Costs			**440.000 €**
Material Costs			
			1.000 €
Total Material Costs			**1.000 €**
Subtotal			**441.000 €**

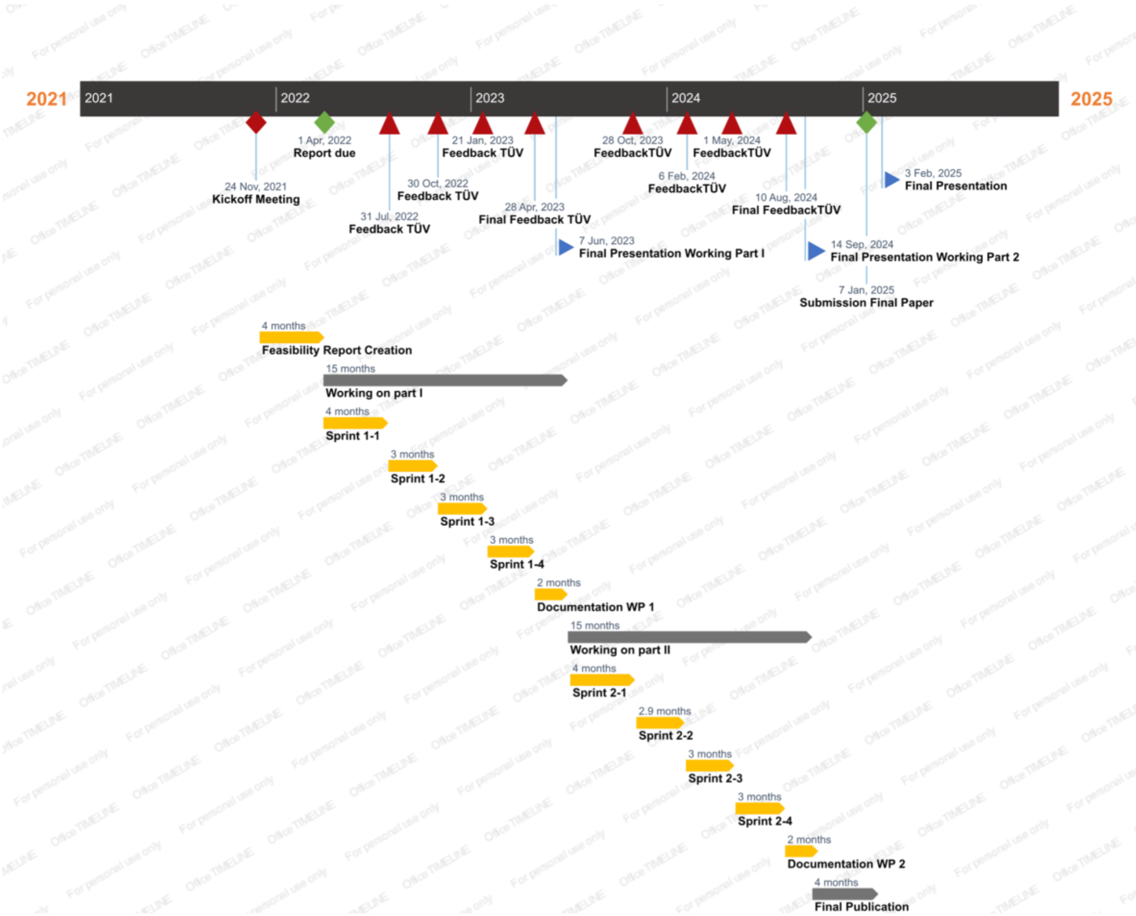
2024			
	Cost Type	**Person months**	**Costs**
Personal	5 Scientific personal	12	200.000 €
	1 Consultant from Daimler	12	40.000 €
	2 Technician from ZF	12	80.000 €
	2 Technician from Nvidia	12	80.000 €
	1 Consultant from TUV Verband	4	13.333 €
Total Personal Costs			**413.333 €**
Material Costs			
			1.000 €
Total Material Costs			**1.000 €**
Subtotal			**414.333 €**

Project altogether (2022-2024)	
Total	**1.476.501 €**

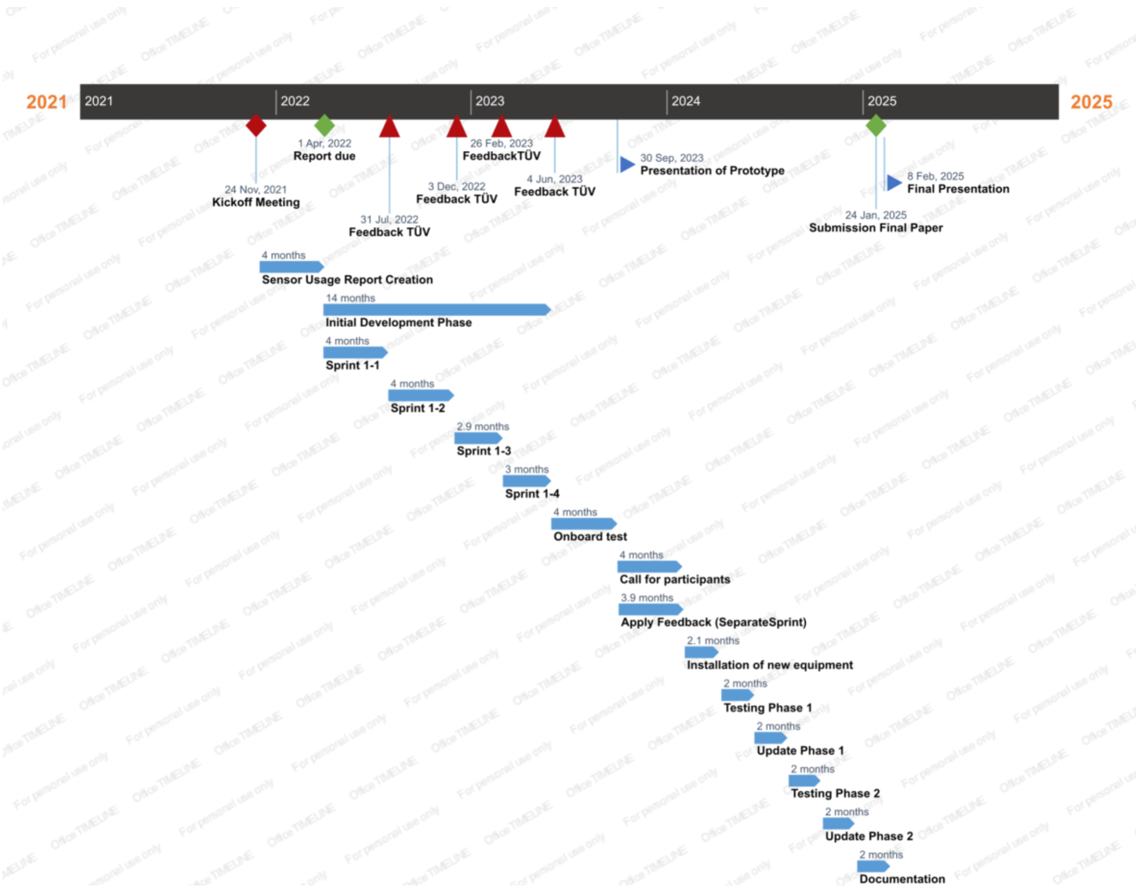
10 Work plan

As explained earlier, the project is split up into two independent parts, which are stated below individually.

10.1 Static Work Plan



10.2 Dynamic Work Plan



12 Literature and Sources

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