

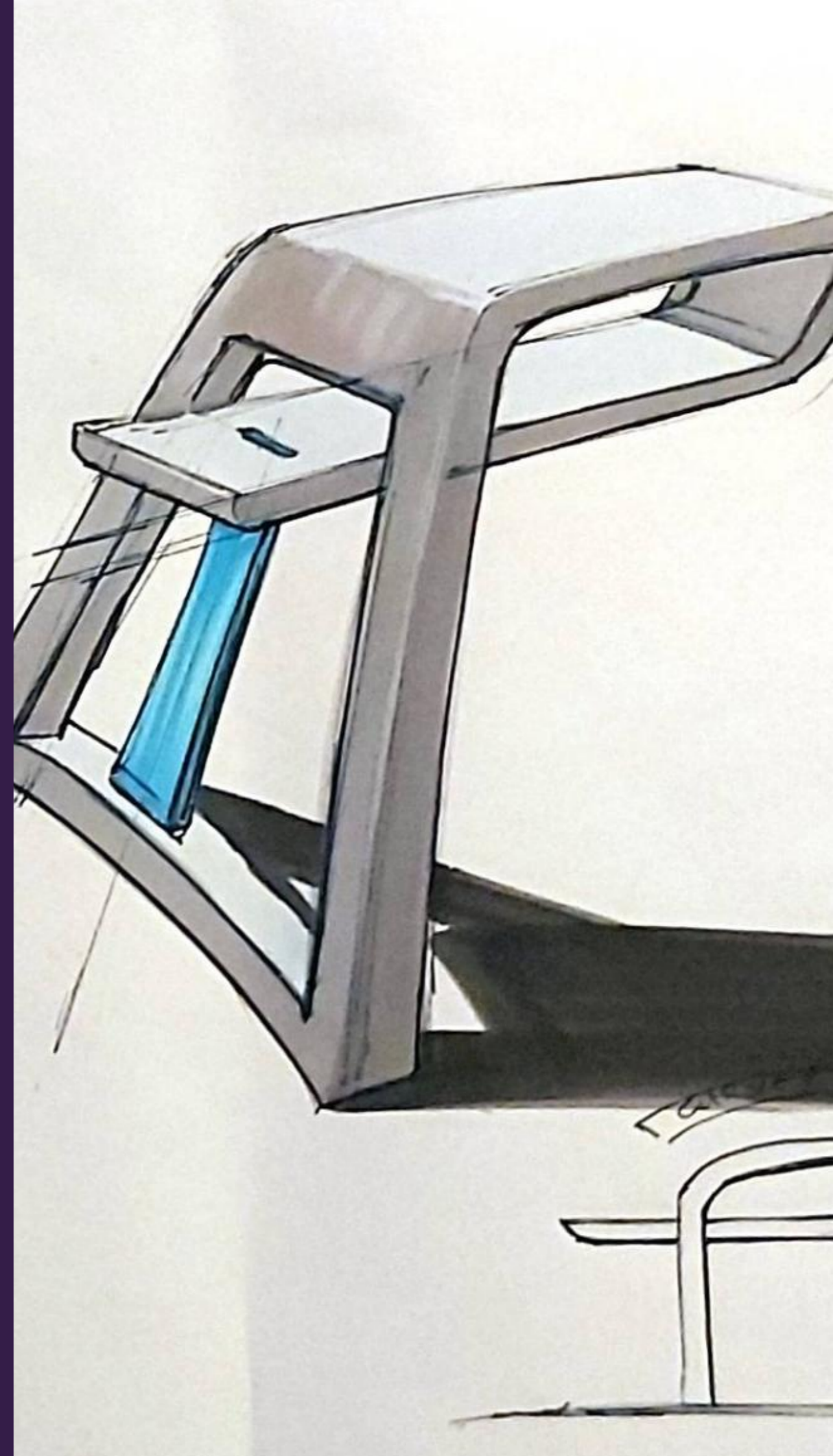


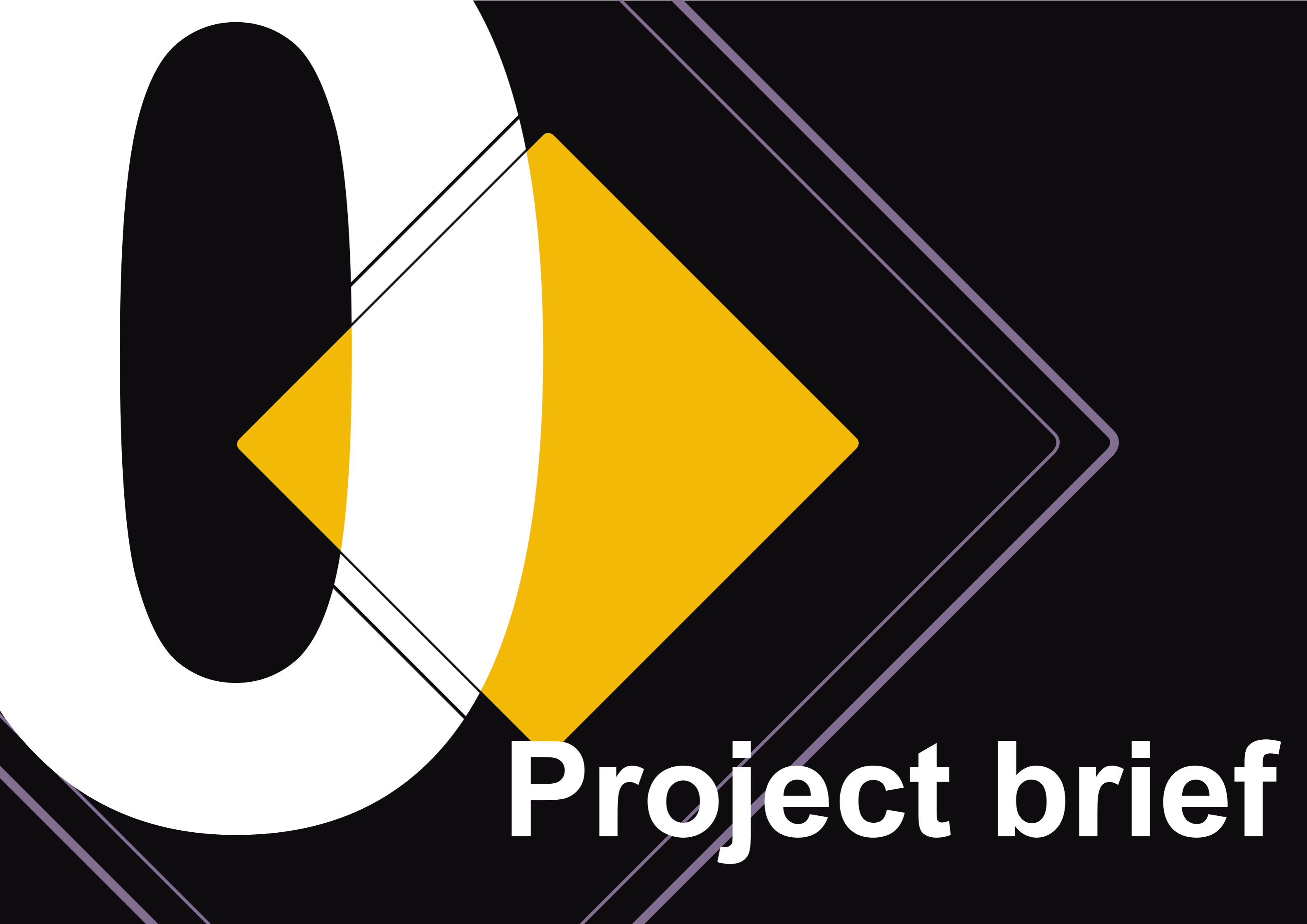
Appendix

Design of Control Transfer Rituals for Automated Vehicles
T.Q. Mallon - 4226399 - Delft - July-December 2020

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Project brief

IDE Master Graduation

Project team, Procedural checks and personal Project brief

This document contains the agreements made between student and supervisory team about the student's IDE Master Graduation Project. This document can also include the involvement of an external organisation, however, it does not cover any legal employment relationship that the student and the client (might) agree upon. Next to that, this document facilitates the required procedural checks. In this document:

- The student defines the team, what he/she is going to do/deliver and how that will come about.
- SSC E&SA (Shared Service Center, Education & Student Affairs) reports on the student's registration and study progress.
- IDE's Board of Examiners confirms if the student is allowed to start the Graduation Project.

! USE ADOBE ACROBAT READER TO OPEN, EDIT AND SAVE THIS DOCUMENT

Download again and reopen in case you tried other software, such as Preview (Mac) or a webbrowser.

STUDENT DATA & MASTER PROGRAMME

Save this form according the format "IDE Master Graduation Project Brief_familyname_firstname_studentnumber_dd-mm-yyyy". Complete all blue parts of the form and include the approved Project Brief in your Graduation Report as Appendix 1 !

family name <u>Mallon</u> <u>4264</u>	Your master programme (only select the options that apply to you):
initials <u>T.Q.</u> given name <u>Thomas</u>	IDE master(s): <input checked="" type="checkbox"/> IPD <input type="checkbox"/> Dfl <input type="checkbox"/> SPD
student number <u>4226399</u>	2 nd non-IDE master: _____
street & no. _____	individual programme: _____ (give date of approval)
zipcode & city _____	honours programme: <input type="checkbox"/> Honours Programme Master
country _____	specialisation / annotation: <input type="checkbox"/> Medisign
phone _____	<input type="checkbox"/> Tech. in Sustainable Design
email _____	<input type="checkbox"/> Entrepreneurship

SUPERVISORY TEAM **

Fill in the required data for the supervisory team members. Please check the instructions on the right !

** chair E.D. van Grondelle dept. / section: DA

** mentor W.F. Kets dept. / section: DA

2nd mentor _____

organisation: _____

city: _____ country: _____

Chair should request the IDE Board of Examiners for approval of a non-IDE mentor, including a motivation letter and c.v..

- ! Second mentor only applies in case the assignment is hosted by an external organisation.

comments (optional) Both chair and mentor are from the same department (Design Aesthetics). This choice was made based on the foreseen required competences to successfully finalize the project, as well as the personal learning ambitions in

- ! Ensure a heterogeneous team. In case you wish to include two team members from the same section, please explain why.

Procedural Checks - IDE Master Graduation

APPROVAL PROJECT BRIEF

To be filled in by the chair of the supervisory team.

chair E.D. van Grondelle date 23 - 07 - 2020 signature Elmer van Grondelle - IO

Digitally signed by Elmer van Grondelle - IO Date: 2020.07.23 14:29:52 +02'00'

CHECK STUDY PROGRESS

To be filled in by the SSC E&SA (Shared Service Center, Education & Student Affairs), after approval of the project brief by the Chair. The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total: 30 EC

Of which, taking the conditional requirements into account, can be part of the exam programme 30 EC

List of electives obtained before the third semester without approval of the BoE

YES all 1st year master courses passed

NO missing 1st year master courses are:

name _____ date _____ signature _____

FORMAL APPROVAL GRADUATION PROJECT

To be filled in by the Board of Examiners of IDE TU Delft. Please check the supervisory team and study the parts of the brief marked **. Next, please assess, (dis)approve and sign this Project Brief, by using the criteria below.

- Does the project fit within the (MSc)-programme of the student (taking into account, if described, the activities done next to the obligatory MSc specific courses)?
- Is the level of the project challenging enough for a MSc IDE graduating student?
- Is the project expected to be doable within 100 working days/20 weeks ?
- Does the composition of the supervisory team comply with the regulations and fit the assignment ?

Content: APPROVED NOT APPROVED

Procedure: APPROVED NOT APPROVED

- adapted version approved

comments

name Monique von Morgen date 28 - 07 - 2020 signature _____

Design of Control Transfer Rituals for automated vehicles project title

Please state the title of your graduation project (above) and the start date and end date (below). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

start date 26 - 07 - 2020 04 - 12 - 2020 end date

INTRODUCTION **

Please describe, the context of your project, and address the main stakeholders (interests) within this context in a concise yet complete manner. Who are involved, what do they value and how do they currently operate within the given context? What are the main opportunities and limitations you are currently aware of (cultural- and social norms, resources (time, money,...), technology, ...).

The European Union has started a program to regulate automated vehicles on public roads (Horizon 2020 research and innovation programme). An international consortium is building a way to safely and in real-time switch between a human driver and an automated system based on who is most fit to drive. This mediating system for drivers in semi-automated and highly automated, road-going vehicles [read: SAE level 0-4* vehicles i.e. cars, trucks, lorries, buses] has taken the name MEDIATOR, MEdiatingbetween Driver and Intelligent Automated Transport systems on Our Roads. The Institute SWOV (Stichting Wetenschappelijk Onderzoek Verkeersveiligheid, or Institute of Road Safety Research) has taken coordinating responsibilities. The faculty of IDE at TU Delft has taken the responsibilities for the design of the Human-Machine-Interface (HMI) that drivers will interact with.

This assignment is focussed on the switches between levels of automation (e.g. switch from SAE level 2 to SAE level 0), especially the interactions between the human driver and the automation which initiate and communicate these switches. At this moment, another graduation student, B. Grazian, works on the MEDIATOR project. Her project does not intervene but rather completes this assignment as she takes an interest in mode awareness and attention load during an automated process (e.g. during SAE level 3 driving).

Within this project, the most fit driver will be able to control the vehicle in the most safe, fuel efficient and comfortable fashion. However, all humans, both driver and passengers, in the vehicle need to accept the product, trust in the system and can tell what is going on. Other road-users are acknowledged, but are not within the scope of the project.

Furthermore, the producers of the final product, automotive oriented Original Equipment Manufacturers (OEMs), need their design space to create products that fit within their product line.

Currently, automation is frequently experienced on public roads with a wide variety of Advanced Driver-Assistance Systems (ADAS). Examples are Adaptive Cruise Control, Anti-lock Braking System (ABS), Collision Avoidance System (CAS), and parking assist. Other industries, such as the military, nautical, and aviation, have used automated drivers for over a century. However, semi-automated driving has not been commercially implemented until 2014, with Tesla's first, crude version of "Autopilot".

*SAE levels indicate level of automation in vehicles. Level 0 is no automation, where level 5 is full automation.

space available for images / figures on next page

introduction (continued): space for images

TO PLACE YOUR IMAGE IN THIS AREA:

- **SAVE THIS DOCUMENT TO YOUR COMPUTER AND OPEN IT IN ADOBE READER**
- **CLICK AREA TO PLACE IMAGE / FIGURE**

PLEASE NOTE:

- **IMAGE WILL SCALE TO FIT AUTOMATICALLY**
- **NATIVE IMAGE RATIO IS 16:10**
- **IF YOU EXPERIENCE PROBLEMS IN UPLOADING, CONVERT IMAGE TO PDF AND TRY AGAIN**

image / figure 1: _____

TO PLACE YOUR IMAGE IN THIS AREA:

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- **CLICK AREA TO PLACE IMAGE / FIGURE**

PLEASE NOTE:

- **IMAGE WILL SCALE TO FIT AUTOMATICALLY**
- **NATIVE IMAGE RATIO IS 16:10**
- **IF YOU EXPERIENCE PROBLEMS IN UPLOADING, CONVERT IMAGE TO PDF AND TRY AGAIN**

image / figure 2: _____

PROBLEM DEFINITION **

Limit and define the scope and solution space of your project to one that is manageable within one Master Graduation Project of 30 EC (= 20 full time weeks or 100 working days) and clearly indicate what issue(s) should be addressed in this project.

With the increase of automation in the automotive industry, it is time to take the human-machine interface (HMI) of these automated systems into account. This assignment will focus on the transfer of control between the automated system and the driver of a vehicle ranging between SAE level 0 through 4. These different degrees of automation change the actions required by the driver, and consequently their responsibilities. Because the wide range of problems and opportunities, this assignment will focus on the transfer of control between the automated system and the human driver. This does not include the assessment of driver or automation, nor the design of the decision making component. The problems that are touched to be touched upon within the scope of this project can be categorized as follows:

- How must the HMI inform a driver on an upcoming control transfer?
- How may the driver inform the automation of a desired control transfer?
- How to guide a driver through a control transfer?
- How to elicit appropriate driver attention throughout the control transfer?
- How will the implementation of such control transfer look and feel?

ASSIGNMENT **

State in 2 or 3 sentences what you are going to research, design, create and / or generate, that will solve (part of) the issue(s) pointed out in "problem definition". Then illustrate this assignment by indicating what kind of solution you expect and / or aim to deliver, for instance: a product, a product-service combination, a strategy illustrated through product or product-service combination ideas, In case of a Specialisation and/or Annotation, make sure the assignment reflects this/these.

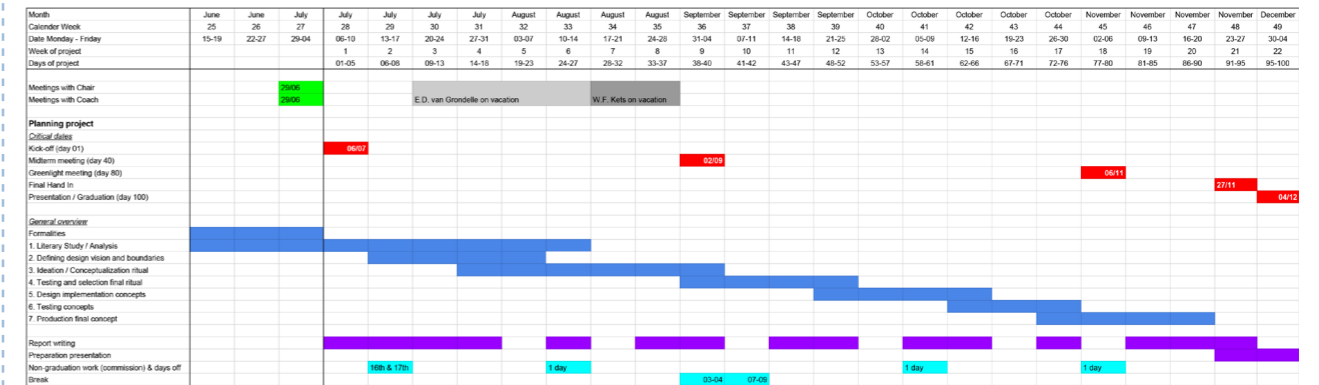
This assignment will aim to create an intuitive control transfer ritual that allows for safe, sustainable and comfortable travel by automated, road-going vehicles.

This will be done by assessment of the current behaviour in both automated and regular vehicles as well as user based testing of several concepts. The goal of the assignment is to iterate, with the use of the Basic Design Cycle, towards a concept in the form of a physical prototype of a product that will allow for the control transfer ritual. This prototype is desired to reach the stage of final concept. In the end, a control transfer ritual and accompanying concept will be presented.

PLANNING AND APPROACH **

Include a Gantt Chart (replace the example below - more examples can be found in Manual 2) that shows the different phases of your project, deliverables you have in mind, meetings, and how you plan to spend your time. Please note that all activities should fit within the given net time of 30 EC = 20 full time weeks or 100 working days, and your planning should include a kick-off meeting, mid-term meeting, green light meeting and graduation ceremony. Illustrate your Gantt Chart by, for instance, explaining your approach, and please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any, for instance because of holidays or parallel activities.

start date 26 - 7 - 2020 end date 4 - 12 - 2020



The project flow is roughly based on the Basic Design Cycle, which is both intuitive to use and fits the goal of the assignment well. Initial steps of the project are to analyse existing research, stakeholder needs and wants, and legislation (1) in order to create insight into the factors that influence the experience of a human driver in an automated vehicle with the goal to formulate a clear design vision (2). This design vision opens the path to define, and explore various components that interact with the human driver, which in turn define the requirements and restrictions that influence the control transfer ritual.

With the knowledge acquired in the initial analysis phase, a variety of control transfer rituals can be designed (3). These are explored, tested, and evaluated to aid in the definition of the final control transfer ritual. By iteration, one can finetune the ritual to the level that is required to start conceptualization.

During this extensive conceptualisation phase, I will both individually as with a group of either peers or stakeholders ideate in order to create a spectrum of possible implementations of the control transfer ritual (5). By iterative searching for an implementation, the ritual will be tested for criteria such as executability, complexity, producibility, and, to a certain extend, safety. This iterative process does include a new stakeholder test (6).

The results of all phases are implemented into a final prototype (7), which is used to communicate the desired control transfer ritual to all stakeholders

The planning shows a duration of 22 weeks, this compensation for 10 days in which I cannot work on the assignment. Total workdays: 100.

MOTIVATION AND PERSONAL AMBITIONS

Explain why you set up this project, what competences you want to prove and learn. For example: acquired competences from your MSc programme, the elective semester, extra-curricular activities (etc.) and point out the competences you have yet developed. Optionally, describe which personal learning ambitions you explicitly want to address in this project, on top of the learning objectives of the Graduation Project, such as: in depth knowledge a on specific subject, broadening your competences or experimenting with a specific tool and/or methodology, Stick to no more than five ambitions.

Motivation

During my high-school days, all I wanted was to become an inventor. Thus I chose my courses to fit the requirements for IDE (N&T, N&G). At time of graduation I had already passed the numerus fixus. During my bachelors I heard the term "Automotive Specialization", which constituted of completing multiple Automotive related courses, a minor in the automotive domain and graduating my masters in the same area of expertise. Years later I found that this specialization had been omitted. However, the drive is the same to me. As became more intrigued with the automotive industry with each course, it is to me a natural conclusion to graduate in this field. As I matured, so did my interest. At first, all I wanted was to design the next Lamborghini. Though it would be awesome, I also got interested in different aspects to the industry such as interior design.

I chose the IPD master course, because I enjoy solving puzzles and making prototypes. Though the product is often my main focus, the people using it cannot be ignored. In this specific graduation opportunity, I see possibilities to act on both people and product. As the project requires a solution for switching control in vehicles, the device has to be both intuitive (people) and widely applicable (brand/industry), which can be combined in a prototype (product).

Strengths & Competences

As I do not wish to be a jack-of-all-traits (master of none), I would like to focus on expertises I am already comfortable or that I feel the need to refresh.

- Solving puzzles. I start looking for sensible/logical solutions when I am confronted with a problem.
- Sense of space/geometry. This in regard to understanding how a product will function and look like.
- Sketching / drawing. Though I am no master painter, I do draw above average.
- 3D modelling / 3D printing. I have my own 3D printer.

Personal Ambitions

- Learn to communicate better to different parties. This can be seen as improved presentation skills, both to stakeholders as experiment participants.
- Sketching, I would like to improve my drawing skills to allow for better communication towards stakeholders. This is beneficial to both my own understanding of the product as the understanding of whomever I try to communicate the product to.
- (Rapid) Prototyping will allow me to get more comfortable with 3D modelling software and 3D printing. This also allows for learning a more industry relevant 3D modelling software than Solidworks.
- Programming in C++. In order to create a working prototype, I predict that some level of programming in Arduino is needed. I would like to sharpen this skill before graduating, because I have not had the opportunity to do so during the IPD master and enjoyed it during the bachelor.
- Sticking to a planning. Oddly enough, I tend to work best under pressure. However, this also brings forth that I postpone my responsibilities uncomfortably close to a deadline. This time around I would like to have a more evenly divided workload during the project.

FINAL COMMENTS

In case your project brief needs final comments, please add any information you think is relevant.

The background features a black field with a large white vertical rectangle on the left. A yellow diamond is positioned in the center, partially overlapping the white rectangle. Several thin purple lines are scattered across the black background, some forming a diamond shape that encloses the yellow diamond. The text 'Testdrives' is written in a bold, white, sans-serif font at the bottom right.

Testdrives

Context

This research is done as an orientation into the domain of, and user interactions with, the Human Machine Interface (HMI) in automated vehicles to fill implicit and explicit knowledge gaps (Goals). The answers to these knowledge gaps will aid in the design of Control Transfer Rituals (CTR) between SAE levels 0 through 4 of vehicular automation. Currently, however, only level 2 automation is legally available for on-road use. Though some questions regard the actual CTRs connotated to level 2 automation, I believe there to be viable information in user experience with automated vehicles so far. This information can lead to, for example, insights in human behaviour and user acceptance. Furthermore, my own experience with level 2 automated vehicles is currently limited and mostly theoretical. Though absolutely not the main goal, this experiment will allow me to get acquainted with automated vehicles.

Goals

Main Goal (MG)

Map current Control Transfer Rituals in current-generation, commercial vehicles equipped with SAE level 2 capabilities.

Subgoals (SG)

SG.1: Determine user experience of switching to SAE level 2

SG.2: Determine user experience of driving at SAE level 2

SG.3: Determine and evaluate the interactions used to switch to SAE level 2

SG.4: Determine and evaluate the design of the HMI in SAE level 2 vehicles

SG.5: Get acquainted with SAE level 2 driving myself

Research questions (RQ)

RQ.1: What CTRs exist in SAE level 0-2 vehicles?

RQ.2: How is switching between SAE levels 0-2 experienced?

RQ.3: How is driving under SAE 2 circumstances experienced?

RQ.4: What level of trust do drivers have in SAE level 2? (i.e. are they aware of the balance in functionalities of the automation and their own responsibilities?)

RQ.5: How does a driver, in theory, react to an obstacle in his lane. Driving at SAE level?

Method

Applied method

Initial user observation with a vehicle equipped with SAE level 2 capabilities

- van Boeijen, A.G.C. et al., R.S.A. (eds.) (2013) Delft Design Guide. Amsterdam: BIS Publishers. p.45

Follow-up user interview with questionnaire with drivers of a vehicle equipped with SAE level 2 capabilities

- van Boeijen, A.G.C. et al., R.S.A. (eds.) (2013) Delft Design Guide. Amsterdam: BIS Publishers. p.47
- van Boeijen, A.G.C. et al., R.S.A. (eds.) (2013) Delft Design Guide. Amsterdam: BIS Publishers. p.49

Participants

Drivers in possession of a vehicle with SAE level 2 capabilities

Equipment

- Camera with wide-angle lens
- Tripod
- Mat
- Dictaphone
- Pen
- Paper
- Road-legal vehicle with SAE level 2 capabilities
- Questionnaire with open questions and 7-point Likert-scale closed questions (appendix A)
- Participant gift
- Play-back device for (motion)pictures (i.e. laptop)

Equipment setup

The camera is put on a tripod on the rear seat of the vehicle, able to record the dashboard. Underneath the tripod is a mat, to protect the car interior. The dictaphone is placed in the front of the cabin to ensure that the conversation is recorded.

Course of action

After a short introduction to the experiment and consent of the participant is given, I will build the test setup in the car. Next, we will enter the car; the participant will enter the driver seat, whilst I enter the passenger seat.

The driver will make a lap in a real-world scenario, on public roads. The use of SAE level 1 and 2 capabilities will be tested on the highway only. Drive to and from the highway will be performed under SAE level 0 conditions and is minimized in time consumption (i.e. we drive the quickest route to the highway). The driver is owner of the vehicle, thus assumed acquainted with its features and handling. During the drive, the driver will be recorded (both audio and video) and any interesting behaviour on both driver side and HMI side will be noted, as well as my own experience as

passenger.

On the highway, if road conditions allow, the participant is first asked to engage SAE level 1 capability of Adaptive Cruise Control* for 300 [s], then Lane Assist** for 300 [s], then we turn around on next exit and engage SAE level 2, for 600 [s].

Back at the start, the participant is asked questions in accordance with the questionnaire to answer RQ.2 – RQ.5.

Finally, the participant is thanked and offered a gift for his efforts.

At later date, the (motion)pictures are analysed to answer RQ 1 and add to RQ.2 – RQ.5 where needed.

*Adaptive Cruise Control allows a driver to partially hand over speed, acceleration, and braking to the machine.

**Lane Assist Systems, such as Lane Departure Warning Systems and Lane Centring, are designed to keep a car within its current lane. Approach differs per system; some correct the steering of the car to keep it within (the centre of) its current lane, these systems are limited to relatively straight roads, others sound an alarm to alert the driver if the vehicle is departing the lane unwillingly.

User Stimuli

- Road conditions
- ADAS engagement requests by me
- HMI output of vehicle

Pilot

A small pilot was executed to confirm the use of the equipment setup and the questions of the questionnaire. A small loop of 5 minutes over a road with speedbumps confirmed rigidity of the camera/tripod setup. The car (Lancia Ypsilon) had no SAE level 1 or level 2 capabilities.



Appendix A – Questionnaire – Experience SAE level 2

Date: ... / ... / 2020

Location:

Participant nr.

1. General information

a. How often do you drive? _____ times a week/month/year

b. Have you ever driven in SAE level 2 before? Yes/No. If Yes; _____ times

c. What make and model car? _____

d. How long do you own this car? _____ Months/Years

2. Driving SAE level 2 experience

Not Neutral Very

a. Did you enjoy driving at level 2? Why?

b. Was it easy? Why?

c. Do you think it was relaxing?

d. Do you think it is safe? Why?

e. Did you prefer level 2 over level 0 driving? Why?

f. Did you prefer level 2 over level 1 driving? Why?

g. Do you think it is the future? Why?

h. Would you recommend these features to a friend?

3. Switching to/from SAE level 2 experience

a. Did you enjoy switching to level 2? Why?

Not Neutral Very

b. Do you think it was fast enough? Why?

c. Did you enjoy switching back to level 0? Why?

d. Do you think it was fast enough? Why?

e. Do you think it was intuitive? Why?

f. Do you think switching between state was safe?

g. What do you think can be improved? And how?

h. Further notes on switching between modes

4. Trust (next questions are under the condition of driving at SAE level 2)

a. Did you trust the system in SAE level 2? Why?

Not Neutral Very

b. Did you trust the system to respond to your switch?

c. What would make you switch to SAE level 2 autonomous driving?

d. How much control would you like to give the car? (put an X on the dashed line)

None Little Moderate Much All

-----|-----|-----|-----|-----|

Why?

e. What would make you switch to this level of autonomous driving?

f. When, if at all, would you like to drive yourself?

Short cases

g. You receive a text, do you read it?

NO YES

h. You get a call, do you pick up?

NO YES

i. Would you put the phone to your ear?

NO YES

j. You see a news alert, do you read the article?

NO YES

k. Would you watch a movie?

NO YES

l. Would you dare to sleep?

NO YES

m. Would you use this mode in a traffic jam?

NO YES

n. Who is responsible if you hit a stationary object?

Driver Manufacturer

o. Who is responsible if you hit a moving object?

Driver Manufacturer

5. Case study

a. Scenario 1:

You are driving in the right lane of a four lane highway, going 100 [km/h]. You have SAE level 2 engaged, no traffic near you. You notice an accident 320 [m] ahead of you in your lane. Braking takes 2 [s] (or 55 [m]) to stop. You have **10 [s]** to brake before you hit the broken car.

Question:

What do you expect the system to do? Would you intervene, and if so, how?

b. Scenario 2:

The accident happens 100 [m] ahead of you, you have **1.5 [s]** (average minimal time) to react.

Question:

What do you expect the system to do? Would you intervene, and if so, how?

c. Scenario 3:

The accident happens 60 [m] ahead of you, you have **no time** to react.

Question:

What do you expect the system to do? Do you expect to try to intervene, and if so, how?

Notes

Date: 17/7/2020

Location: Zeist

Participant nr. 1

3. Switching to/from SAE level 2 experience

	Not		Neutral		Very
a. Did you enjoy switching to level 2? Why?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>

It's very easy.

b. Do you think it was fast enough? Why?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>
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one click.

c. Did you enjoy switching back to level 0? Why?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>
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one click.

d. Do you think it was fast enough? Why?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>
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idem.

e. Do you think it was intuitive? Why?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>
--	-----------------------	-----------------------	-----------------------	-----------------------	-----------------------	----------------------------------

yes

f. Do you think switching between state was safe?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>
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g. What do you think can be improved? And how?

lane change, more accurate.

h. Further notes on switching between modes

Date: 17/7/2020

Location: Zeist

Participant nr. 1

5. Case study

a. Scenario 1:

You are driving in the right lane of a four lane highway, going 100 [km/h]. You have SAE level 2 engaged, no traffic near you. You notice an accident 320 [m] ahead of you in your lane. Braking takes 2 [s] (or 55 [m]) to stop. You have 10 [s] to brake before you hit the broken car.

Question:

What do you expect the system to do? Would you intervene, and if so, how?

The car is braking faster

b. Scenario 2:

The accident happens 100 [m] ahead of you, you have 1.5 [s] (average minimal time) to react.

Question:

What do you expect the system to do? Would you intervene, and if so, how?

Car is faster

c. Scenario 3:

The accident happens 60 [m] ahead of you, you have no time to react.

Question:

What do you expect the system to do? Do you expect to try to intervene, and if so, how?

Brake and alert.

Notes

Thank you for your participation!

Appendix A – Questionnaire – Experience SAE level 2

Date: 12/7/2020

Location: ZEIST

Participant nr. 1

1. General information

- a. How often do you drive? 10 times a week/month/year
- b. Have you ever driven in SAE level 2 before? Yes/No. If Yes; often times
- c. What make and model car? Tesla model S
- d. How long do you own this car? 2 Months/Years

2. Driving SAE level 2 experience

- a. Did you enjoy driving at level 2? Why? Not Neutral Very
- b. Was it easy? Why?
Very comfortable.
- c. Do you think it was relaxing?
It much more convenient.
- d. Do you think it is safe? Why?
Very safe, however depends on external factors
- e. Did you prefer level 2 over level 0 driving? Why?
Comfort
- f. Did you prefer level 2 over level 1 driving? Why?
Comfort
- g. Do you think it is the future? Why?
Absolutely.
- h. Would you recommend these features to a friend?

Date: 12/7/2020

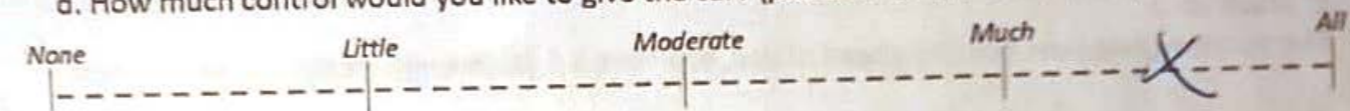
Location: ZEIST

Participant nr. 1

4. Trust (next questions are under the condition of driving at SAE level 2)

- a. Did you trust the system in SAE level 2? Why? Not Neutral Very
- yes, it's very trustworthy
- b. Did you trust the system to respond to your switch?

- c. What would make you switch to SAE level 2 autonomous driving?
no much.
- d. How much control would you like to give the car? (put an X on the dashed line)



Why?

Preventing accidents.

- e. What would make you switch to this level of autonomous driving?

On highways.

- f. When, if at all, would you like to drive yourself?

Between home / within city limits

- Short cases
- g. You receive a text, do you read it? NO YES
 NO YES
- h. You get a call, do you pick up? NO YES
 NO YES
- i. Would you put the phone to your ear? NO YES
 NO YES
- j. You see a news alert, do you read the article? NO YES
 NO YES
- k. Would you watch a movie? NO YES
 NO YES
- l. Would you dare to sleep? NO YES
 NO YES
- m. Would you use this mode in a traffic jam? NO YES
 NO YES
- n. Who is responsible if you hit a stationary object? Driver Manufacturer
 Driver Manufacturer
- o. Who is responsible if you hit a moving object? Driver Manufacturer
 Driver Manufacturer

Date: ... / ... / 2020

Location:

Participant nr.

2

4. Trust (next questions are under the condition of driving at SAE level 2)

a. Did you trust the system in SAE level 2? Why? Not Neutral Very

Expect it comes with experience, uncertain in sharper corners.

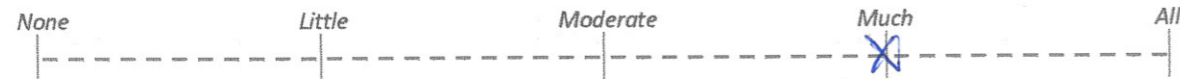
b. Did you trust the system to respond to your switch?

Absolutely push button -> Action

c. What would make you switch to SAE level 2 autonomous driving?

No hurry on the Highway -> go with the flow

d. How much control would you like to give the car? (put an X on the dashed line)



Why?

Comfort. If you made the decision of driving autonomously, it just comfortable to give a lot of control to the vehicle

f. When, if at all, would you like to drive yourself?

When you feel like driving instead of travelling from A to B

Short cases

g. You receive a text, do you read it? NO YES

h. You get a call, do you pick up? NO YES

i. Would you put the phone to your ear? NO YES

j. You see a news alert, do you read the article? NO YES

k. Would you watch a movie? NO YES

l. Would you dare to sleep? NO YES

m. Would you use this mode in a traffic jam? NO YES

n. Who is responsible if you hit a stationary object? Driver Manufacturer

o. Who is responsible if you hit a moving object? Driver Manufacturer

*car should

Appendix A – Questionnaire – Experience SAE level 2

Date: 20/07/2020

Location: Oosterschou

Participant nr.

2

1. General information

a. How often do you drive? 10 times a week/month/year

b. Have you ever driven in SAE level 2 before? Yes/No. If Yes; 50-75 times

c. What make and model car? Tesla Model 3 2019

d. How long do you own this car? 15 Months/Years

2. Driving SAE level 2 experience

a. Did you enjoy driving at level 2? Why? Not Neutral Very

All reacts unpleasant to other traffic. Big at high speed diff.

b. Was it easy? Why?

As Very intuitive

c. Do you think it was relaxing?

you have to pay attention

d. Do you think it is safe? Why?

A little unpredictable, have to stay vigilant. I am aware of limitations but don't know the limits

e. Did you prefer level 2 over level 0 driving? Why?

SAE level 2 is fairly dull, I prefer to drive myself. I respond faster.

f. Did you prefer level 2 over level 1 driving? Why?

if you give control to the car, why not all

g. Do you think it is the future? Why?

for highway purposes -> create a chain of cars -> less traffic

h. Would you recommend these features to a friend?

within city limits
Need a lot of proof that the automation can do everything

5. Case study

a. Scenario 1:

You are driving in the right lane of a four lane highway, going 100 [km/h]. You have SAE level 2 engaged, no traffic near you. You notice an accident 320 [m] ahead of you in your lane. Braking takes 2 [s] (or 55 [m]) to stop. You have 10 [s] to brake before you hit the broken car.

Question:

What do you expect the system to do? Would you intervene, and if so, how?

Expect the system to brake gently and apply warning lights
* ~~and~~ ~~st~~ by braking and thus assume control over the vehicle → Braking + Steering

b. Scenario 2:

The accident happens 100 [m] ahead of you, you have 1.5 [s] (average minimal time) to react.

Question:

What do you expect the system to do? Would you intervene, and if so, how?

yes Brake myself. steer to the side
Expect the system to emergency brake,

c. Scenario 3:

The accident happens 60 [m] ahead of you, you have no time to react.

Question:

What do you expect the system to do? Do you expect to try to intervene, and if so, how?

yes → push Brake (And maybe steer)
No idea what the system will do → is it realistic that you won't collide?

Notes

Thank you for your participation!

3. Switching to/from SAE level 2 experience

Not Neutral Very

a. Did you enjoy switching to level 2? Why?

Very short action, ergonomic

b. Do you think it was fast enough? Why?

(though one need to push consciously)

c. Did you enjoy switching back to level 0? Why?

Very light to do, less harm if one does it unconsciously

d. Do you think it was fast enough? Why?

faster is impossible

e. Do you think it was intuitive? Why?

Sometimes I make the wrong switch

f. Do you think switching between state was safe?

it is in the right order.

g. What do you think can be improved? And how?

- Combination of Regenerative braking and disabling ACC brakes unintuitively fast.
-

h. Further notes on switching between modes

- I would like the option of LCA without ACC → = not "smooth" enough. Why do unsure as to what the vehicle reacts to
- I like to drive myself.
- The car reacts to obstacles which are in practice not a problem

Appendix A – Questionnaire – Experience SAE level 2

Date: 23/07 2020 Location: Zeist Participant nr. 3

1. General information

- a. How often do you drive? 60 times a week/month/year
- b. Have you ever driven in SAE level 2 before? Yes/No. If Yes; 10 times
- c. What make and model car? Tesla model 3 2019
- d. How long do you own this car? 8 Months/Years

2. Driving SAE level 2 experience

- a. Did you enjoy driving at level 2? Why? Not Neutral Very
omdat het ontspannend rijd.
- b. Was it easy? Why?
als het bekend is hoe het werkt dan is het eenvoudig.
- c. Do you think it was relaxing?
omdat de auto het rijden overneemt.
- d. Do you think it is safe? Why?
gevoel van veiligheid door vertrouwen in fabrikant en omdat ik niet ergens dat het onveilige situaties met via meebreyt.
- e. Did you prefer level 2 over level 0 driving? Why?
omdat het spanning weg neemt.
- f. Did you prefer level 2 over level 1 driving? Why?
omdat het rijden in level 2 alleen mogelijk is op snelweg. So wegens zou ik niet snel doen in level 2.
- g. Do you think it is the future? Why?
ontwikkeldig stop je niet
- h. Would you recommend these features to a friend?
Omdat het heel prettig is en ontspannend

Date: ... / ... / 2020 Location: Participant nr.

4. Trust (next questions are under the condition of driving at SAE level 2)

- a. Did you trust the system in SAE level 2? Why? Not Neutral Very

vertrouwen in fabrikant en regelgeving.

- b. Did you trust the system to respond to your switch?

omdat het zo is, wel nadat in begin vertrouwen moet groeien

- c. What would make you switch to SAE level 2 autonomous driving?

als ik op de snelweg zit.

- d. How much control would you like to give the car? (put an X on the dashed line)



Why? omdat ik zelf graag nog controle heb.

- e. What would make you switch to this level of autonomous driving?

de auto snelheid, afstand, ^{sturen} ingrijpen bij gevaarlijke situaties.

- f. When, if at all, would you like to drive yourself?

bij inhalen, in stadverkeer, en bij in en uitrijgen op snelweg.

Short cases

- g. You receive a text, do you read it? NO YES
- h. You get a call, do you pick up? NO YES
- i. Would you put the phone to your ear? NO YES
- j. You see a news alert, do you read the article? NO YES
- k. Would you watch a movie? NO YES
- l. Would you dare to sleep? NO YES
- m. Would you use this mode in a traffic jam? NO YES
- n. Who is responsible if you hit a stationary object? Driver Manufacturer
- o. Who is responsible if you hit a moving object? Driver Manufacturer

Date: ... / ... / 2020

Location:

Participant nr.

3

3. Switching to/from SAE level 2 experience

Not Neutral Very

a. Did you enjoy switching to level 2? Why?

eenvoudig (ah je het weet).

b. Do you think it was fast enough? Why?

omdat het naar mijn gevoel snel genoeg is.

c. Did you enjoy switching back to level 0? Why?

om 2 redenen, uitritten is eenvoudig en de auto doet het zelf ook bij urgente situaties.

d. Do you think it was fast enough? Why?

omdat het naar mijn gevoel snel genoeg is.

e. Do you think it was intuitive? Why?

omdat de auto reageert zoals ik zou verwachten.*¹

f. Do you think switching between states was safe?

omdat het heel intuïtief is.

g. What do you think can be improved? And how?

- que gebruikzaam; sneller bij intake op ingestelde snelheid
- auto pilot inhalen aanblijft en niet uitschakelt
- betere instructie vanaf; of herbevestiging van de gebruiker; eerste keer

h. Further notes on switching between modes

*¹ als ik inhaal met lagere snelheid dan de course control staat ingesteld dan reageert de auto niet snel genoeg om in de ingestelde (snellere) snelheid te komen, vandaar score 6.

Date: ... / ... / 2020

Location:

Participant nr.

3

5. Case study

a. Scenario 1:

You are driving in the right lane of a four lane highway, going 100 [km/h]. You have SAE level 2 engaged, no traffic near you. You notice an accident 320 [m] ahead of you in your lane. Braking takes 2 [s] (or 55 [m]) to stop. You have 10 [s] to brake before you hit the broken car.

Question:

What do you expect the system to do? Would you intervene, and if so, how?

ik verwacht, b. mer de intelligentie van de afstand, dat de auto stopt, maar zal denk ik snel zelf remmen als ik voel dat de auto niet afremt.

b. Scenario 2:

The accident happens 100 [m] ahead of you, you have 1.5 [s] (average minimal time) to react.

Question:

What do you expect the system to do? Would you intervene, and if so, how?

ik verwacht dat de auto remt en niet zal uitwijken, (ik veronderstel dat de auto dat niet kan). Ik denk dat ik ga remmen, uit intuïtie, en ook zal uitwijken.

c. Scenario 3:

The accident happens 60 [m] ahead of you, you have no time to react.

Question:

What do you expect the system to do? Do you expect to try to intervene, and if so, how?

de auto zal een nood rem actie uitvoeren verwacht ik; ik zal proberen om te intervenieren, of het nu heb weet ik niet.

Notes

Thank you for your participation!

see added form

Appendix A – Questionnaire – Experience SAE level 2

Date: ... / ... / 2020

Location: Defi Zest

Participant nr. 4

1. General Information

- a. How often do you drive? pre-corona: every day 3 times a week/month/year
- b. Have you ever driven in SAE level 2 before? Yes/No If Yes; 3 times
- c. What make and model car? Polestar 2
- d. How long do you own this car? 1 Months/Years

2. Driving SAE level 2 experience

- a. Did you enjoy driving at level 2? Why? Not Neutral Very

a'cc adaptive cc is ok, but has flaws. Pilot ass. doesn't add much

- b. Was it easy? Why?

to switch on/off: no, not intuitive

- c. Do you think it was relaxing?

yes and no -> it makes you wander off -> which is dangerous, so the balance is negative *

- d. Do you think it is safe? Why?

a'cc: not in curves & on highways when driving fast -> borries (zie notes)

- e. Did you prefer level 2 over level 0 driving? Why?

a'cc is ok, PA not. see form

- f. Did you prefer level 2 over level 1 driving? Why?

- g. Do you think it is the future? Why?

yes, but it needs enhancements!

- h. Would you recommend these features to a friend?

with extra advice

*for especially for pilot assist.

Date: ... / ... / 2020

Location:

Participant nr.

3. Switching to/from SAE level 2 experience

- a. Did you enjoy switching to level 2? Why? Not Neutral Very

not very intuitive. esp. Polestar PA on/off...

- b. Do you think it was fast enough? Why?

immediate reaction

- c. Did you enjoy switching back to level 0? Why?

too complicated! there is no easy accessible

- d. Do you think it was fast enough? Why?

when you know what to do reaction is immediate

- e. Do you think it was intuitive? Why?

no, see above

- f. Do you think switching between state was safe?

not very, as you have to divert your eyes

- g. What do you think can be improved? And how?

that's your job is to the physical switch!

easy answer & intuitive way of

switching on/off PA/Acc

- h. Further notes on switching between modes

see form.

Date: ... / ... / 2020

Location:

Participant nr.

4. Trust (next questions are under the condition of driving at SAE level 2)

a. Did you trust the system in SAE level 2? Why? Not Neutral Very

see form

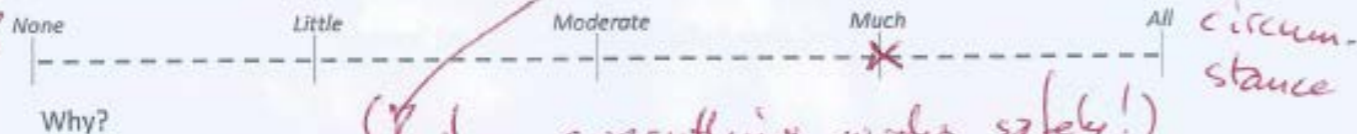
b. Did you trust the system to respond to your switch?

when doing what one "must do" it works

c. What would make you switch to SAE level 2 autonomous driving?

absolute insight in behaviours under every possible

d. How much control would you like to give the car? (put an X on the dashed line)



Why?

(when everything works safely!)

Current functions do have added value, only it's Neanderthal phase

e. What would make you switch to this level of autonomous driving?

f. When, if at all, would you like to drive yourself?

Mountains

Short cases

g. You receive a text, do you read it? NO YES

h. You get a call, do you pick up? NO YES

i. Would you put the phone to your ear? NO YES

j. You see a news alert, do you read the article? NO YES

k. Would you watch a movie? NO YES

l. Would you dare to sleep? NO YES

m. Would you use this mode in a traffic jam? NO YES

n. Who is responsible if you hit a stationary object? Driver Manufacturer

o. Who is responsible if you hit a moving object? Driver Manufacturer

↳ see form about curves & Acc!

Date: ... / ... / 2020

Location:

Participant nr.

5. Case study

a. Scenario 1:

You are driving in the right lane of a four lane highway, going 100 [km/h]. You have SAE level 2 engaged, no traffic near you. You notice an accident 320 [m] ahead of you in your lane. Braking takes 2 [s] (or 55 [m]) to stop. You have 10 [s] to brake before you hit the broken car.

Question:

What do you expect the system to do? Would you intervene, and if so, how?

Give a verbal (!) warning of situation plus the action it will take

b. Scenario 2:

The accident happens 100 [m] ahead of you, you have 1.5 [s] (average minimal time) to react.

Question:

What do you expect the system to do? Would you intervene, and if so, how?

I think this is so close that I wouldn't wait for the system. Reflexes take over, so system override or but

c. Scenario 3:

The accident happens 60 [m] ahead of you, you have no time to react.

Question:

What do you expect the system to do? Do you expect to try to intervene, and if so, how?

No time to react → system assistance is mandatory!

Notes

Split observations in adapt. cc and pilot assist. Very different functions, with different experiences

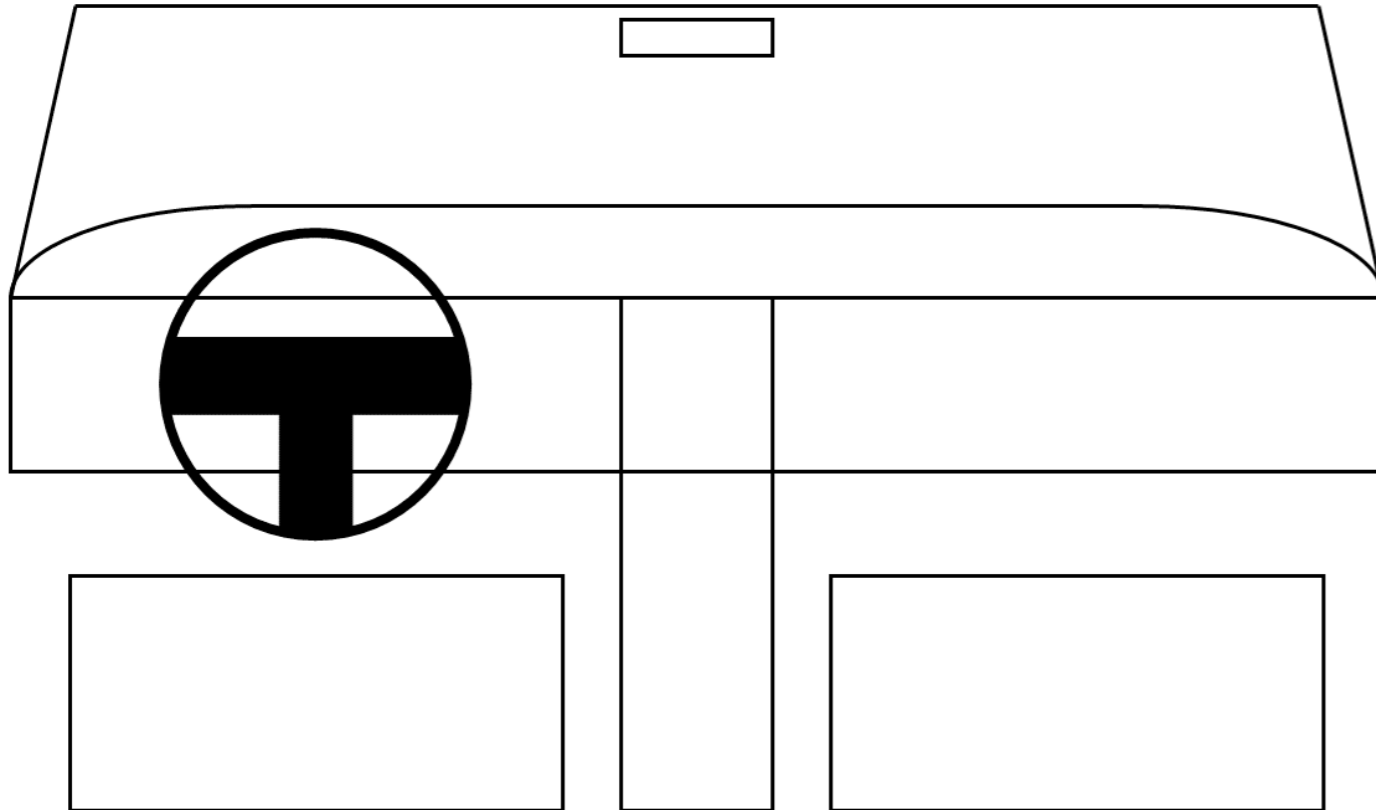
Thank you for your participation!

The image features a dark background with several overlapping geometric shapes. A large white shape on the left side has a semi-circular cutout at the top. A bright yellow diamond is positioned in the center. A purple diamond is located on the right side. The text 'Schematic' and 'HMI' is written in white, bold, sans-serif font, centered over the yellow diamond.

Schematic






HMI

Schematic Automotive HMI's



Legenda

Location specific

-  = Input
-  = Visual feedback
-  = Haptic feedback
-  = Moving component
-  = Touchscreen







Maximum SAE Level

-  0
-  1
-  2
-  3
-  4
-  5

Hypothetical maximum SAE level

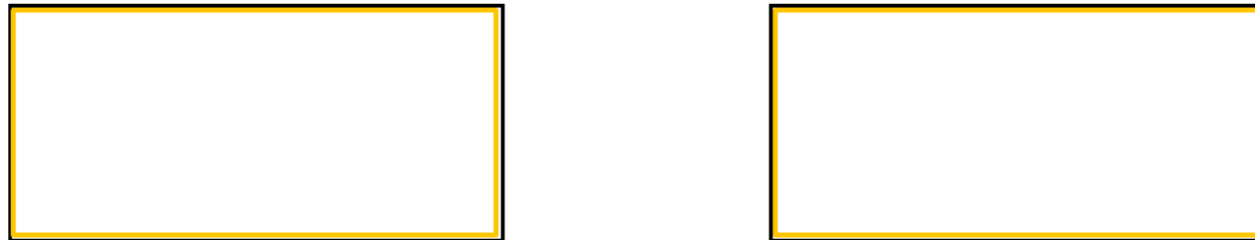
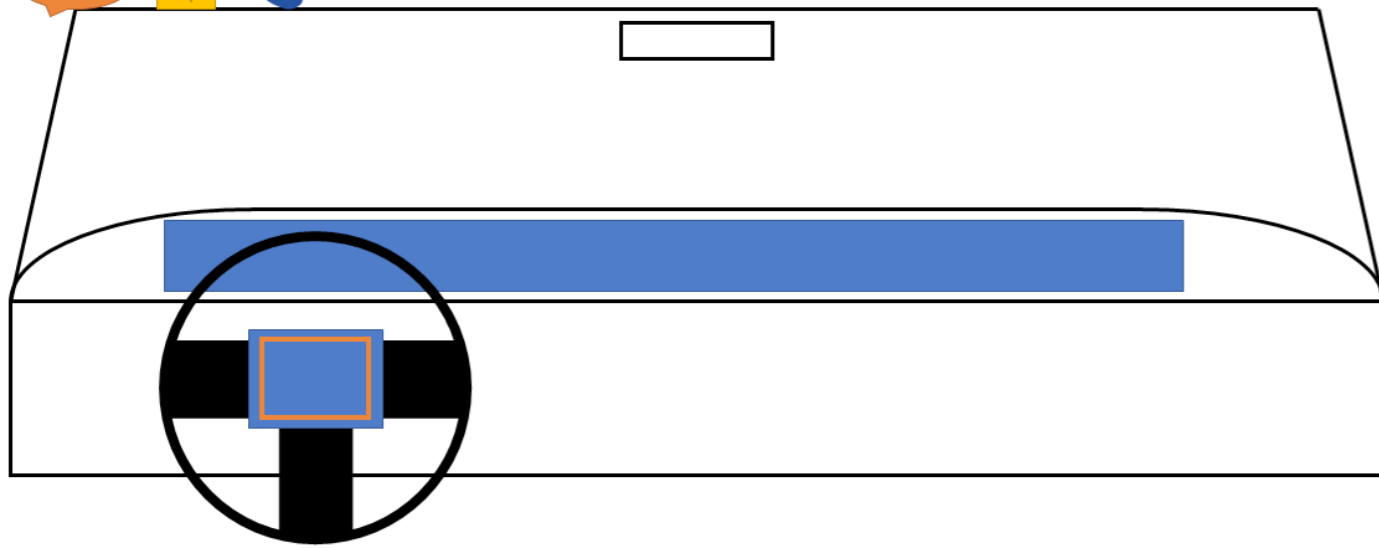
-  0
-  1
-  2
-  3
-  4
-  5

Ambient

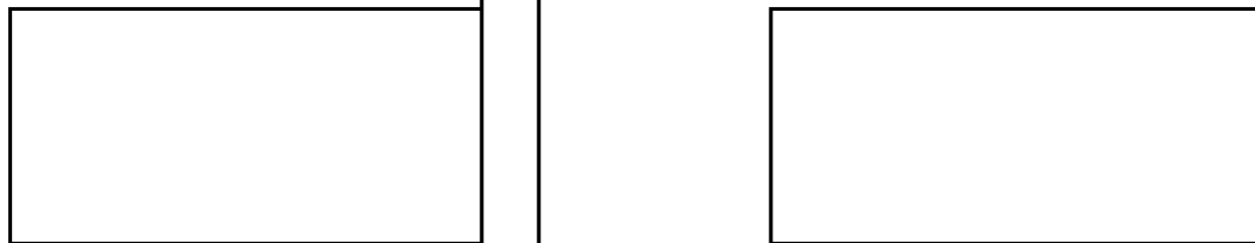
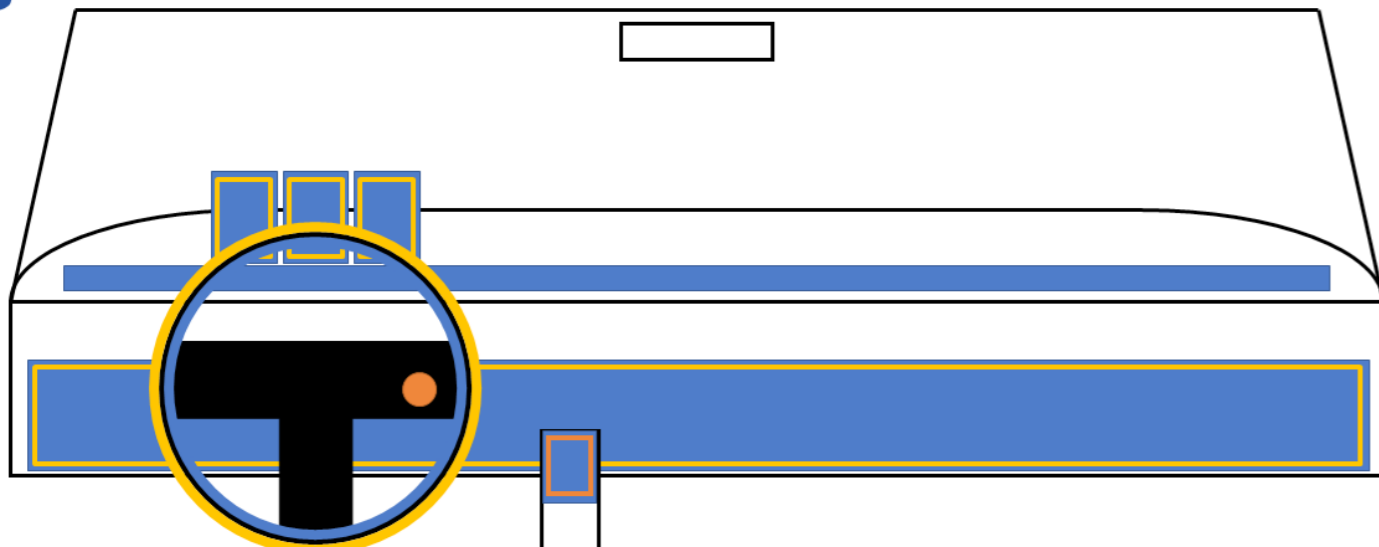
-  = Speech input
-  = Speech feedback
-  = Melodic feedback
-  = Gesture control
-  = AI based system
-  = Phone connectivity

Concept vehicles

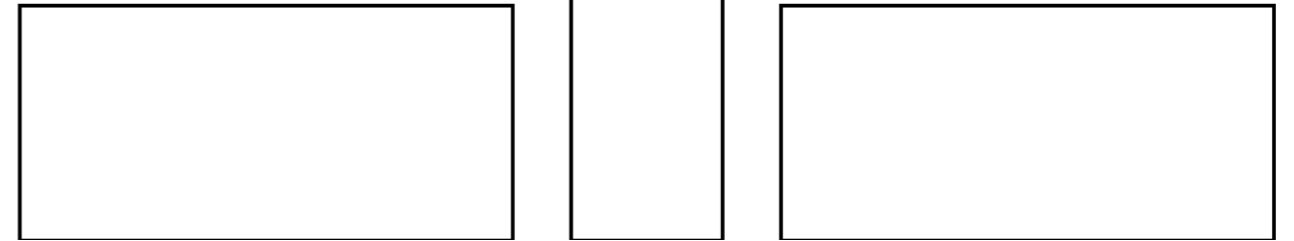
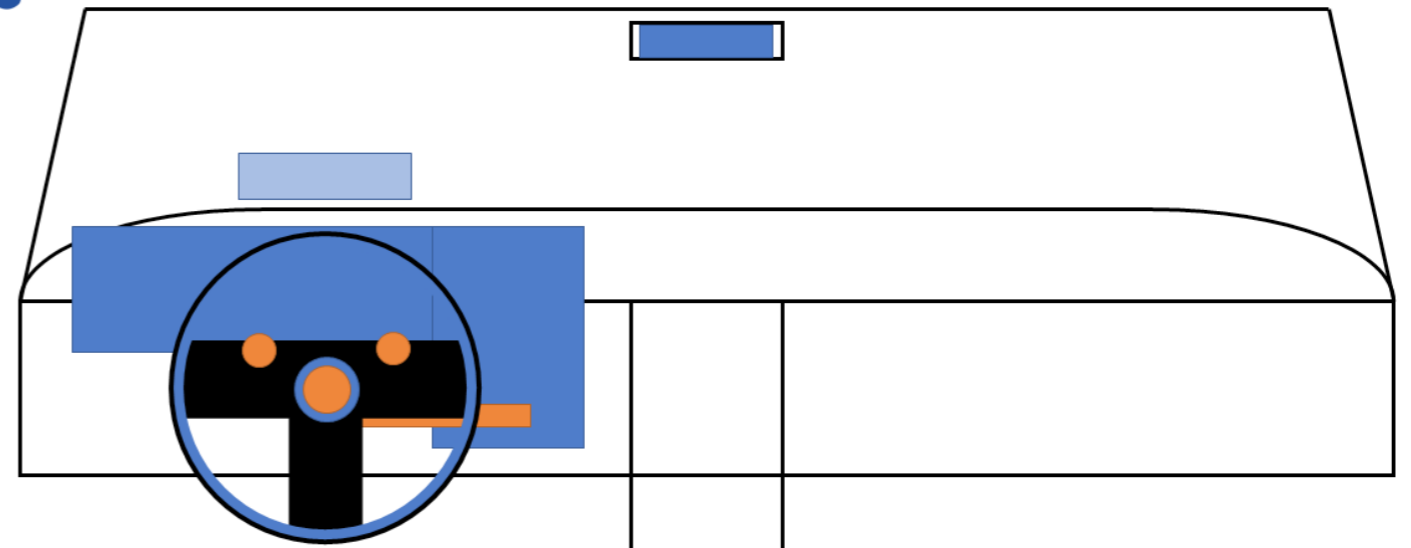
3 4 Byton M-Byte



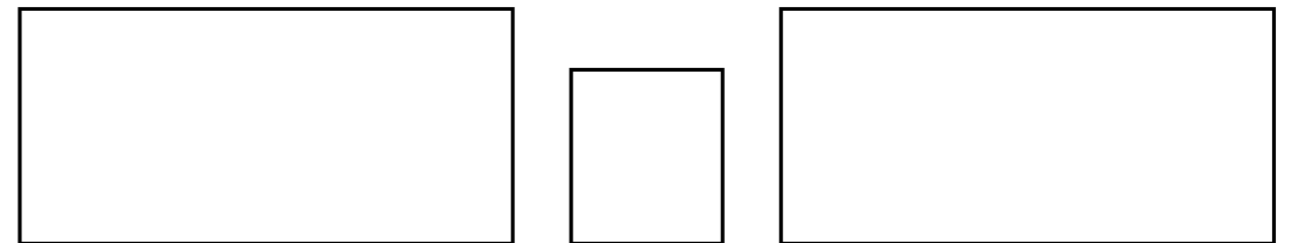
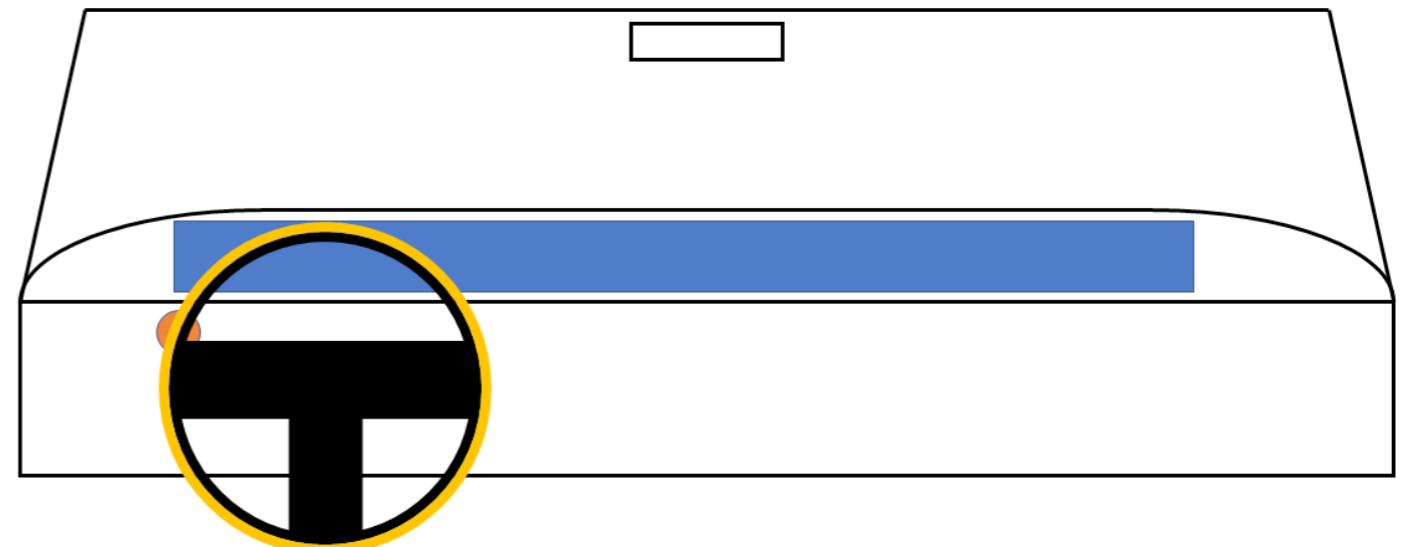
4 Peugeot E-legend



4 Renault Symbioz

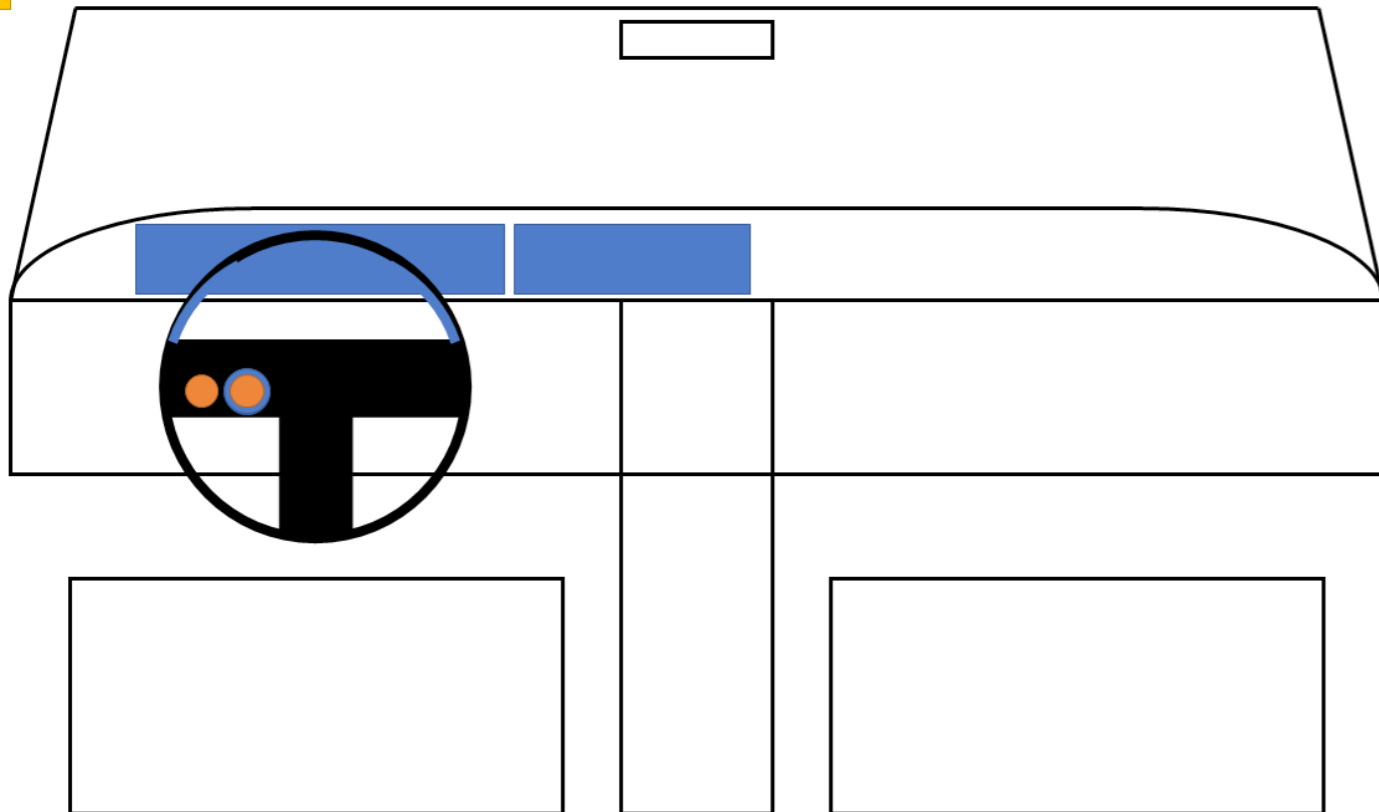


4 5 Audi AI:ME

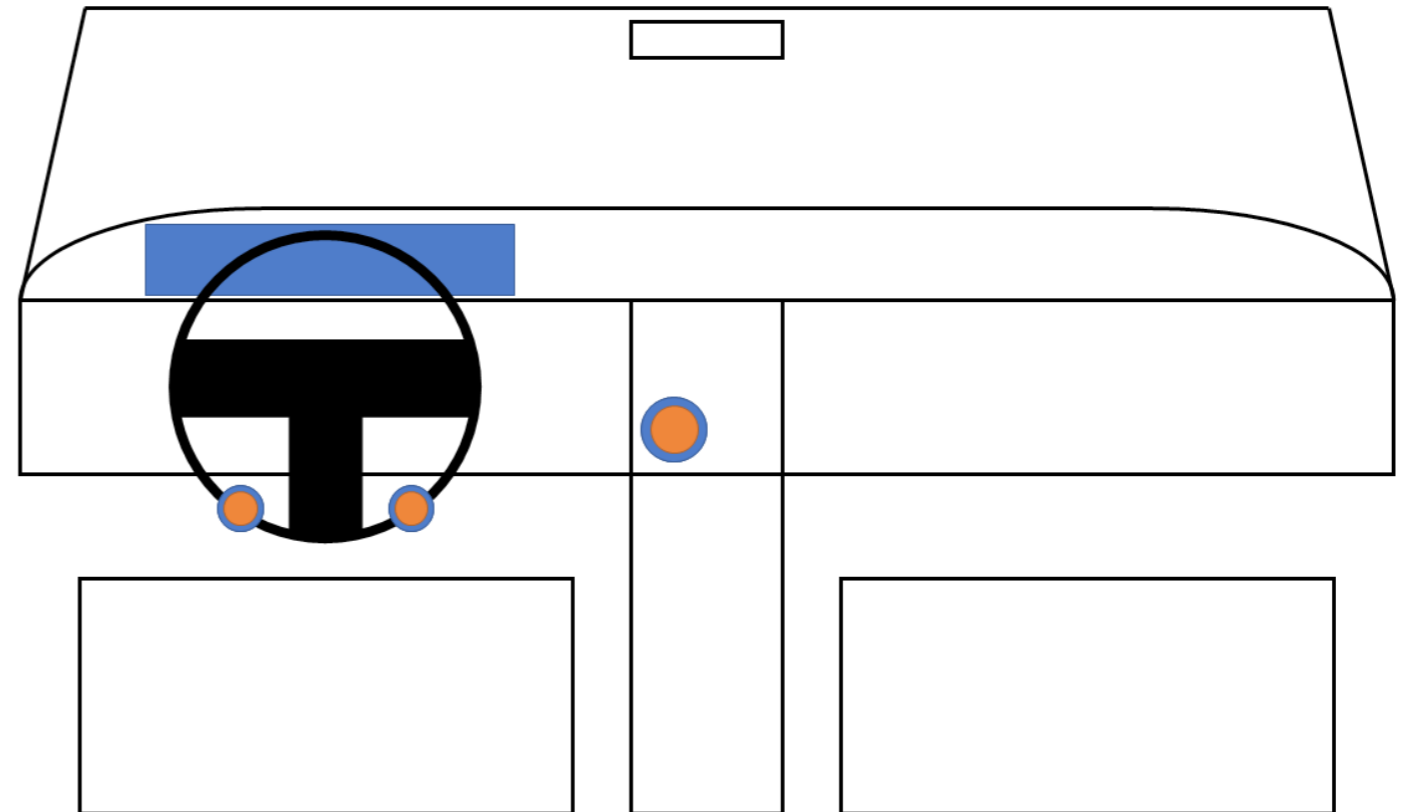




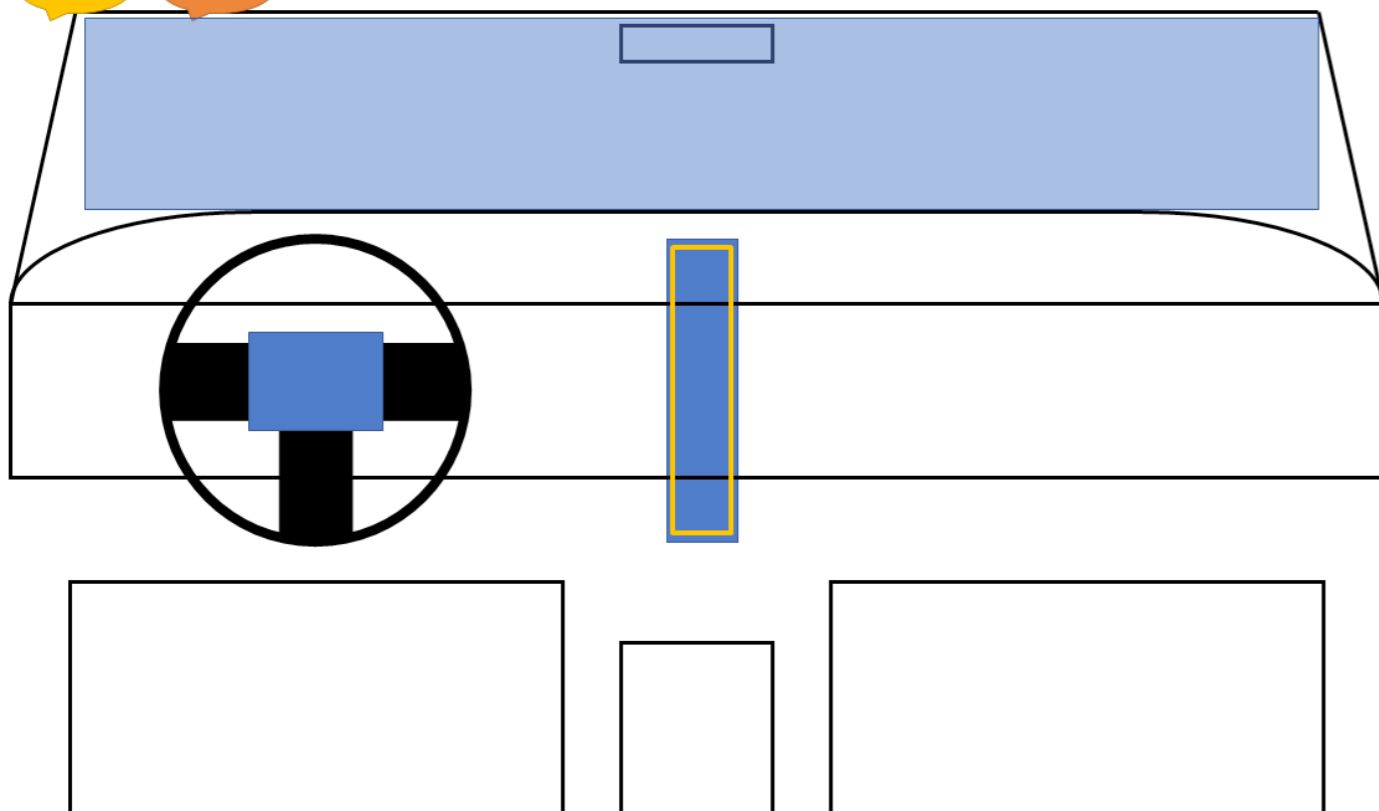
3 Mercedes 2020



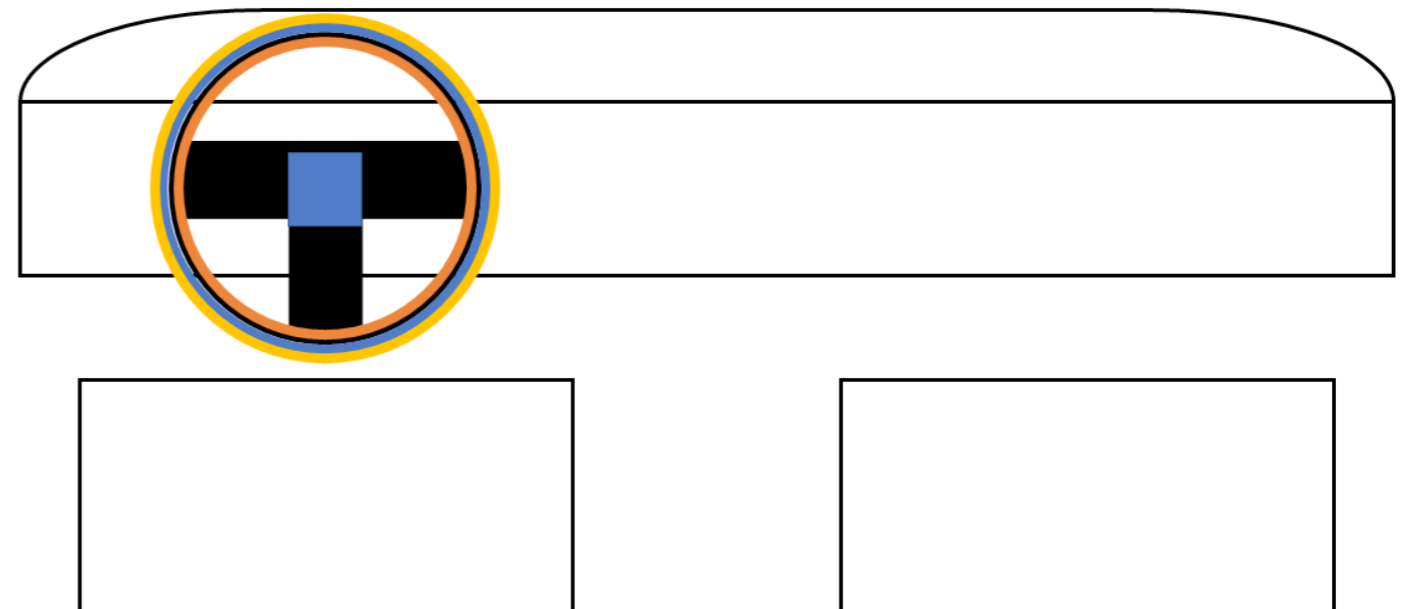
3 Tango HMI

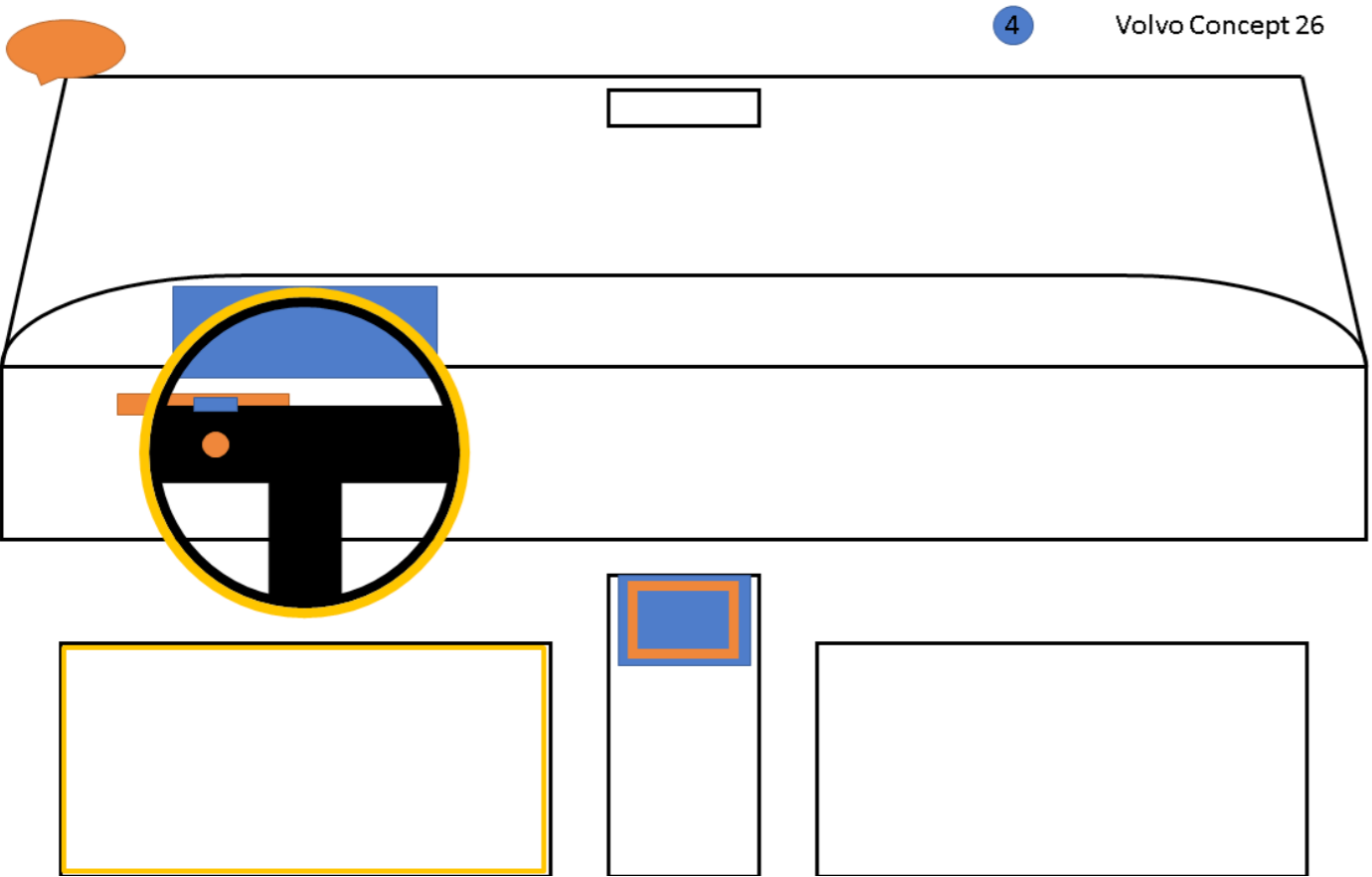


4 5 Citroën 19_19 concept

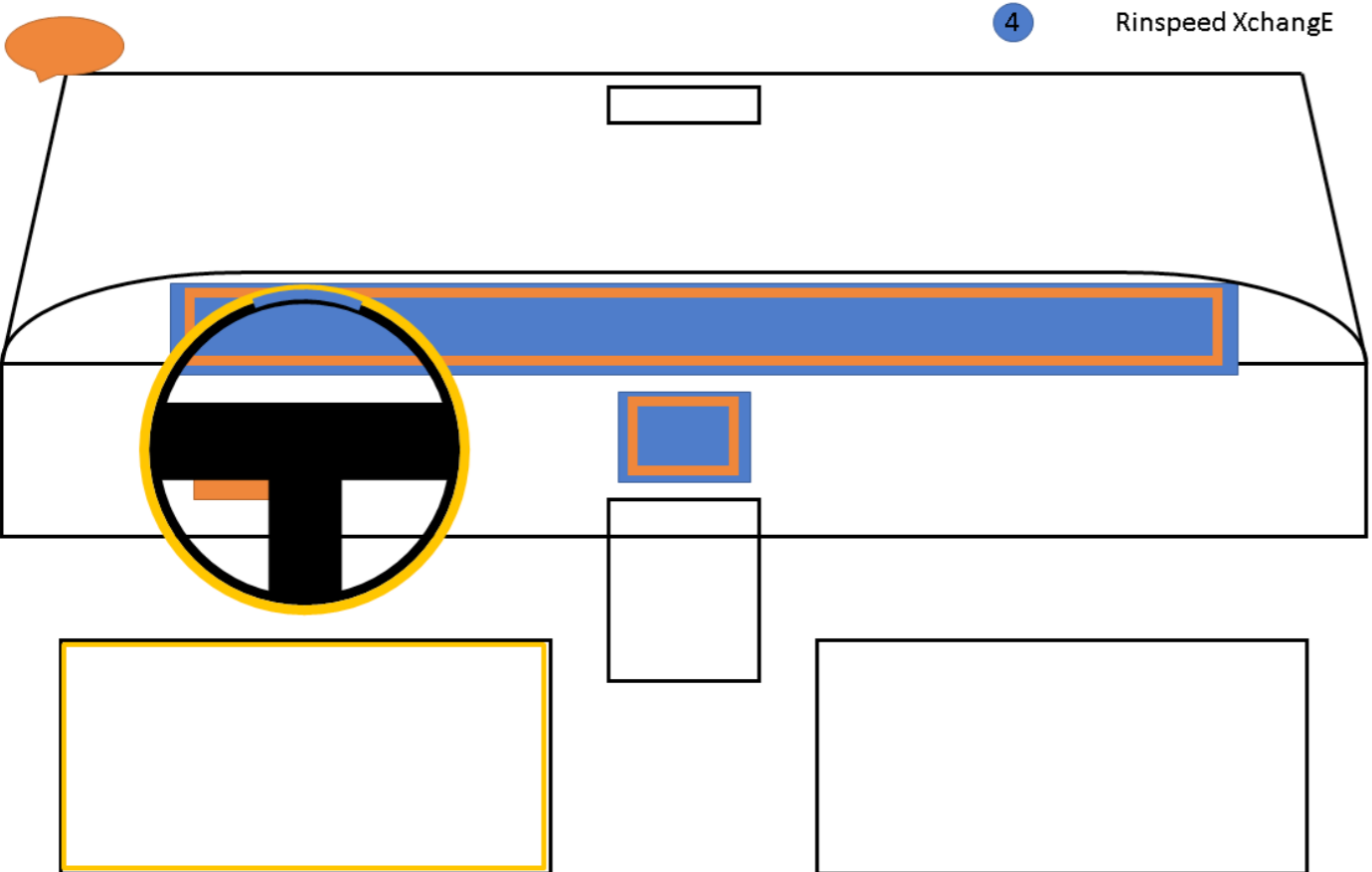


4 5 Honda ADC

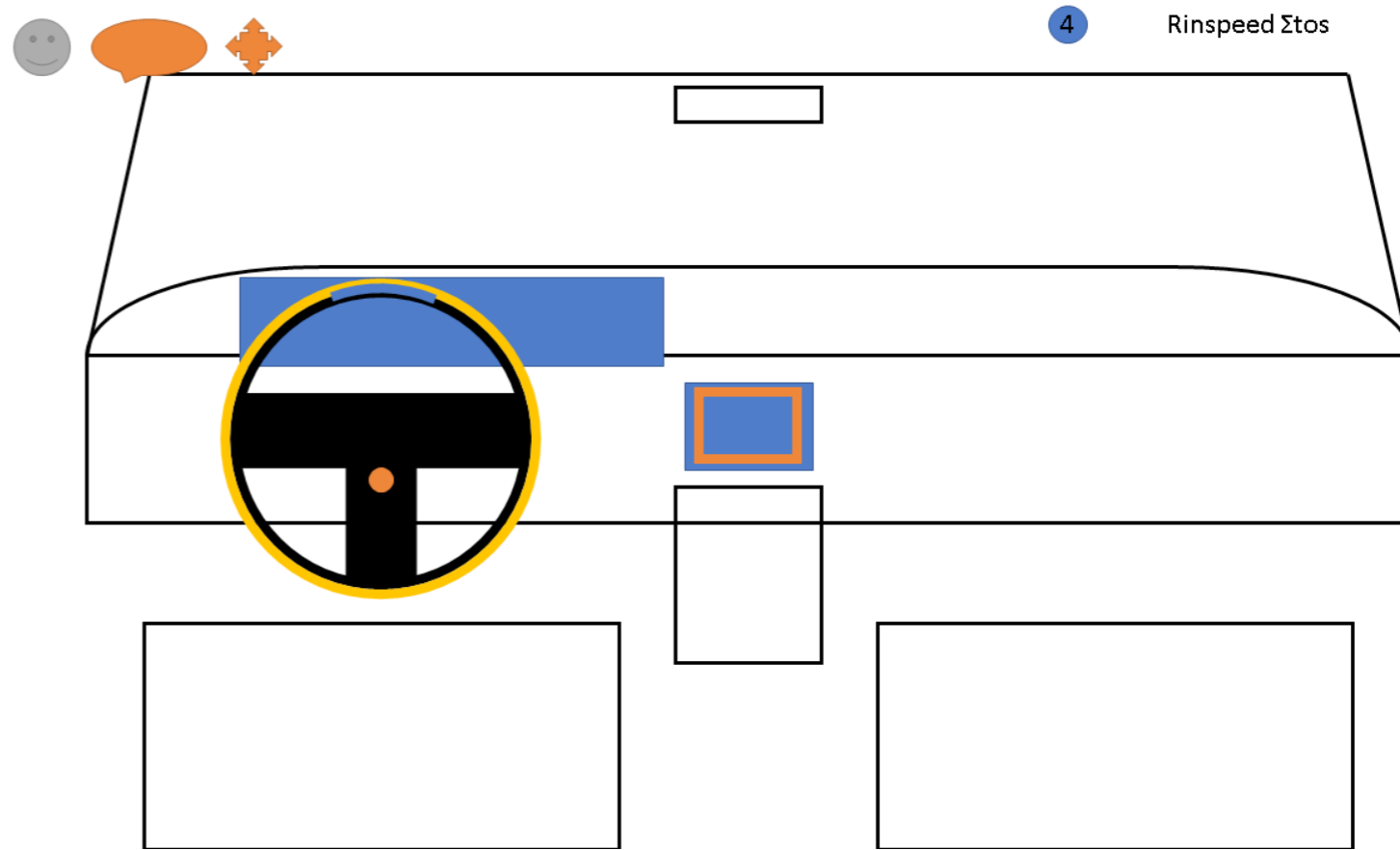




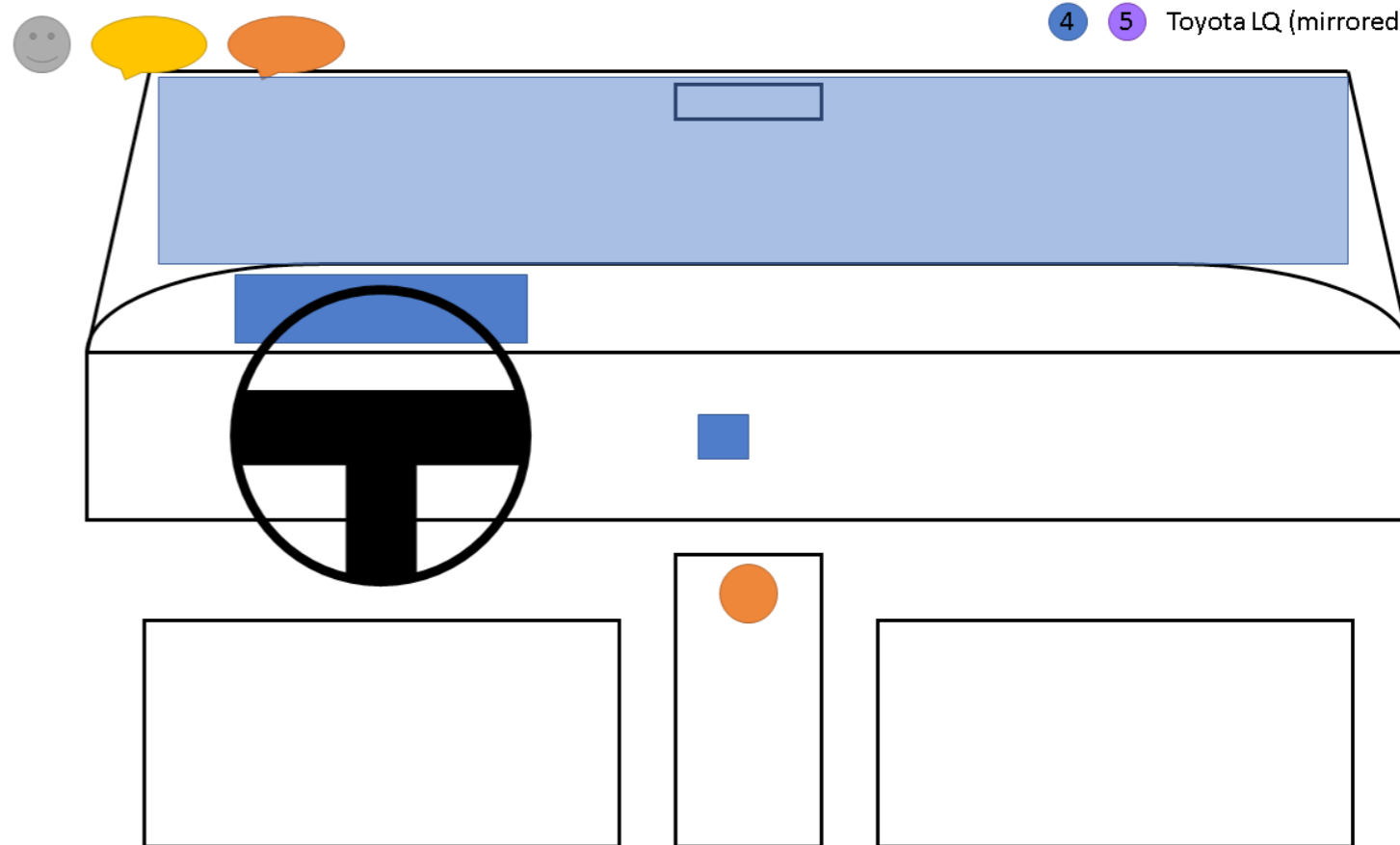
4 Volvo Concept 26



4 Rinspeed XchangE



4 Rinspeed Σtos



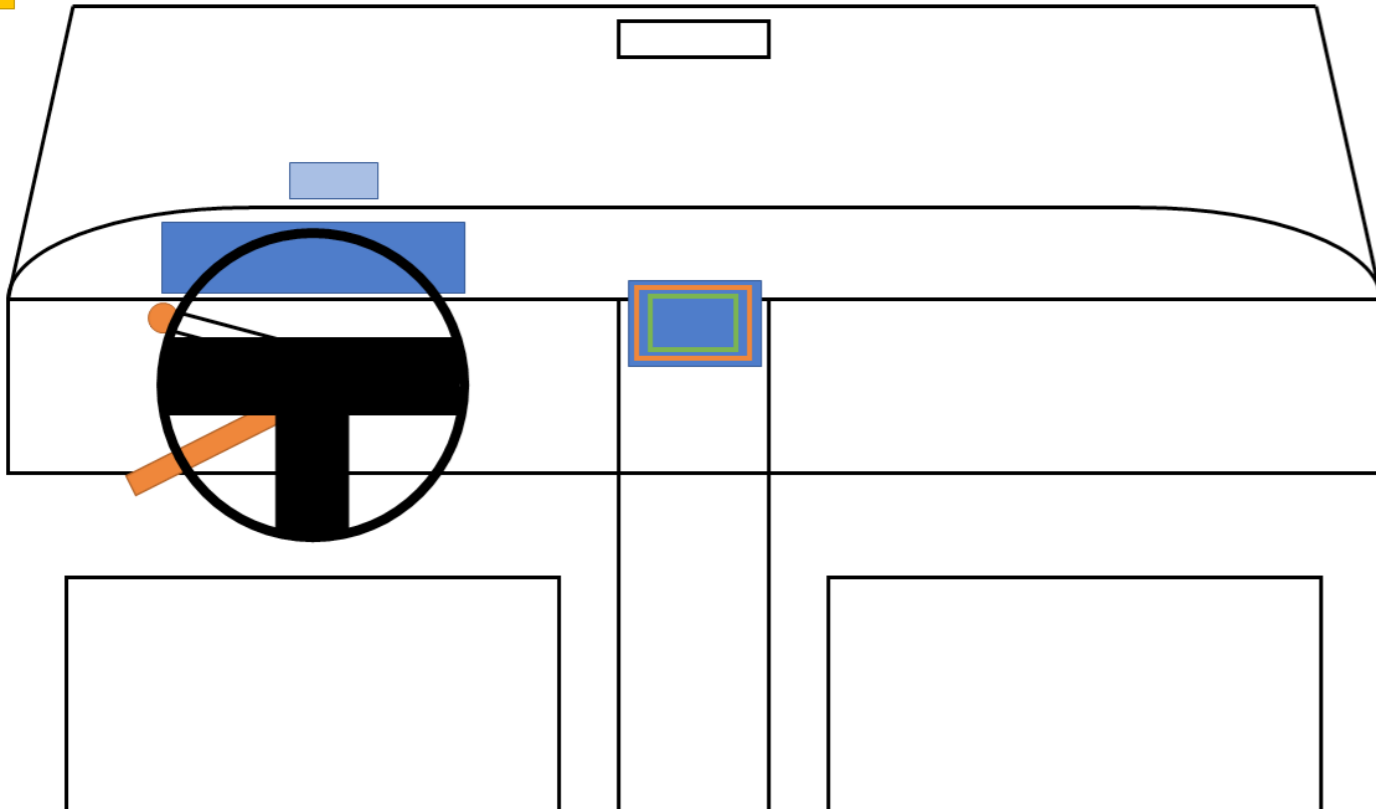
4 5 Toyota LQ (mirrored)

Currently existing HMIs



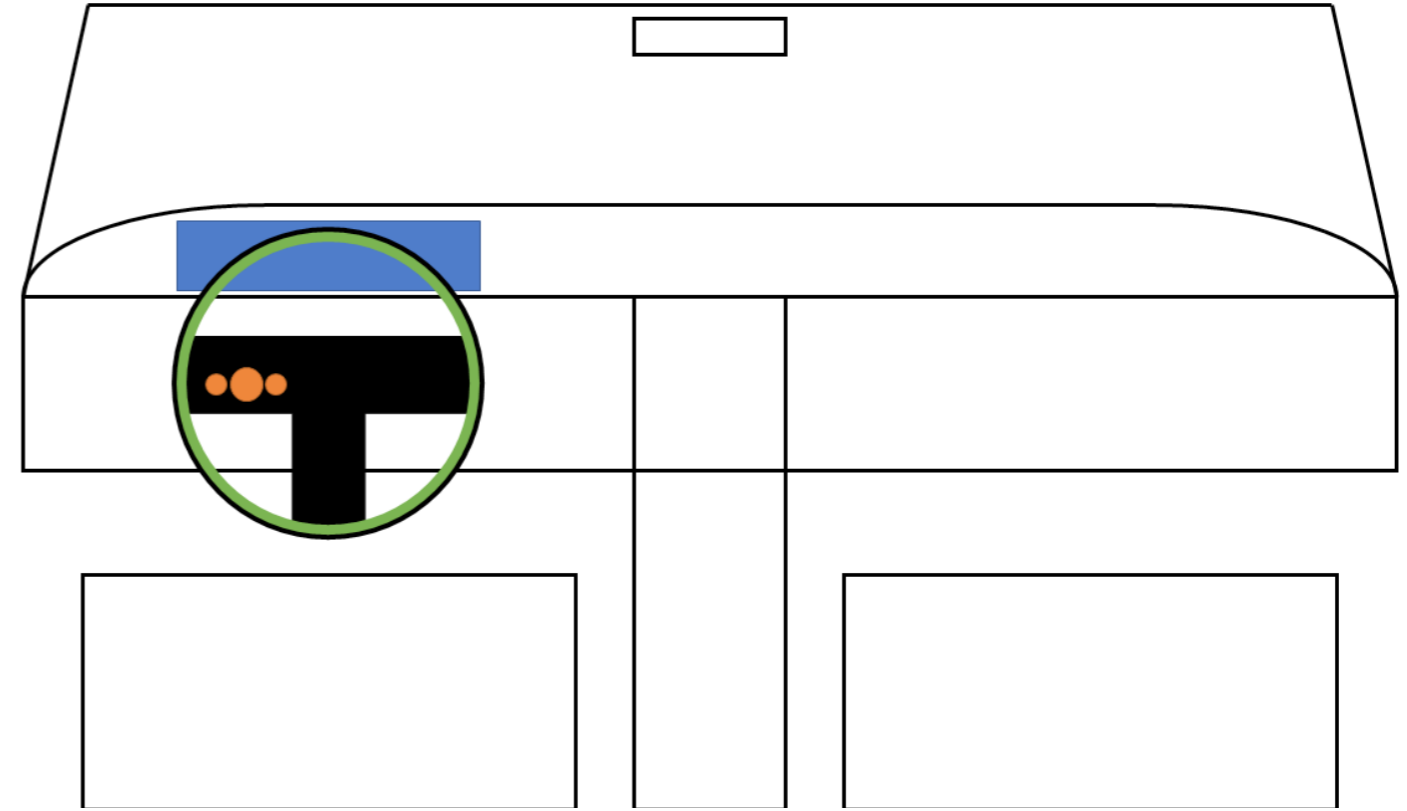
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Audi A8 2020



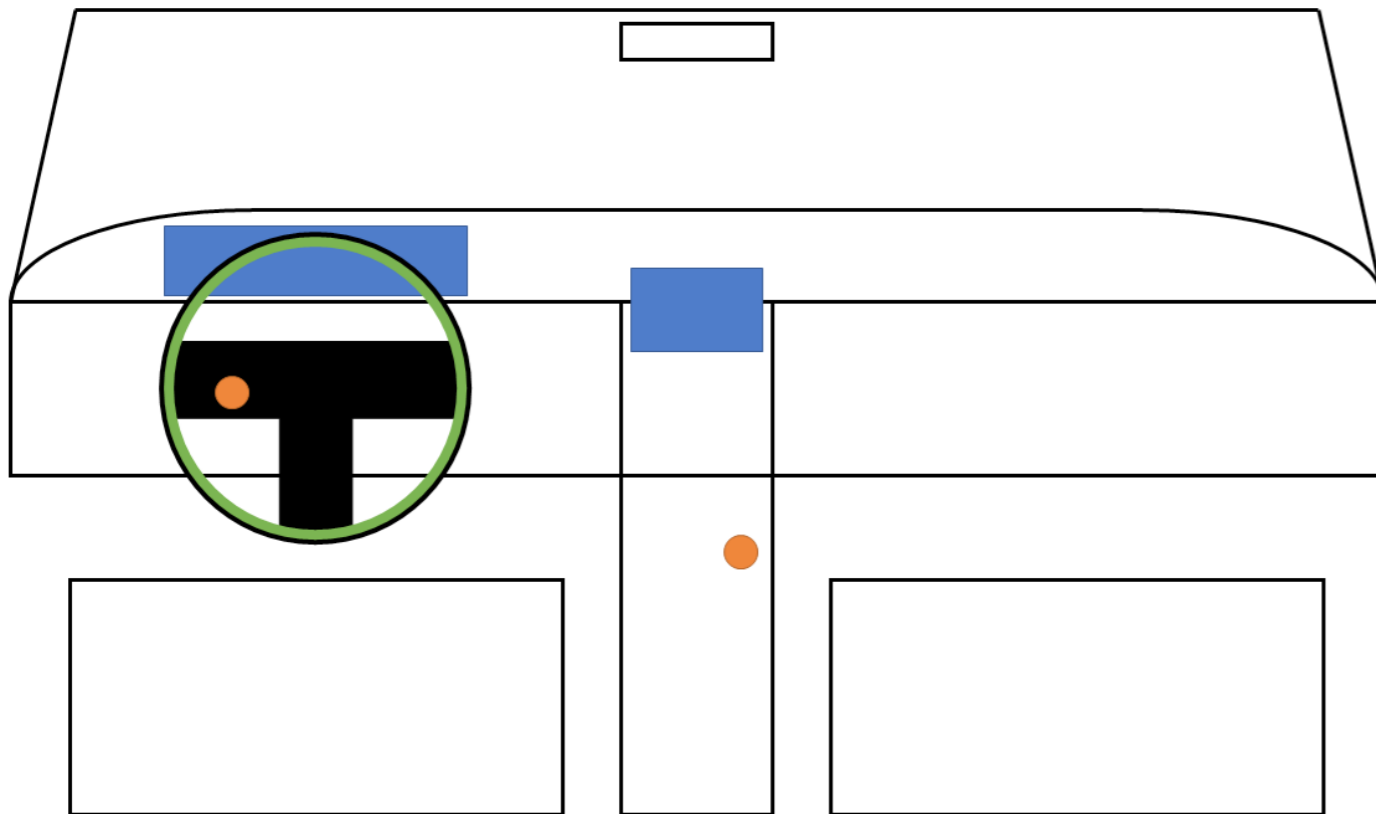
2

Volvo XC60



2

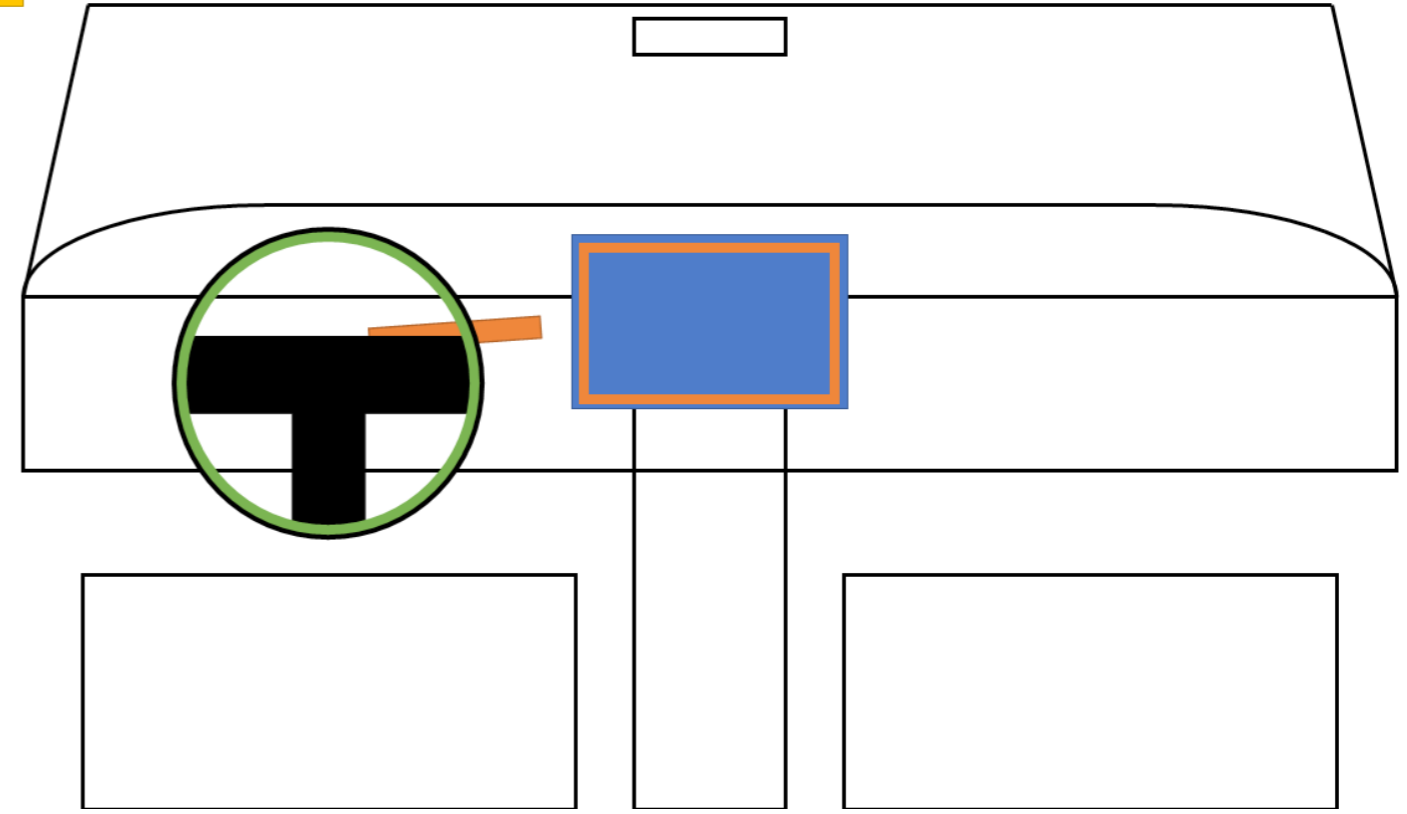
Aston Martin DBX



2

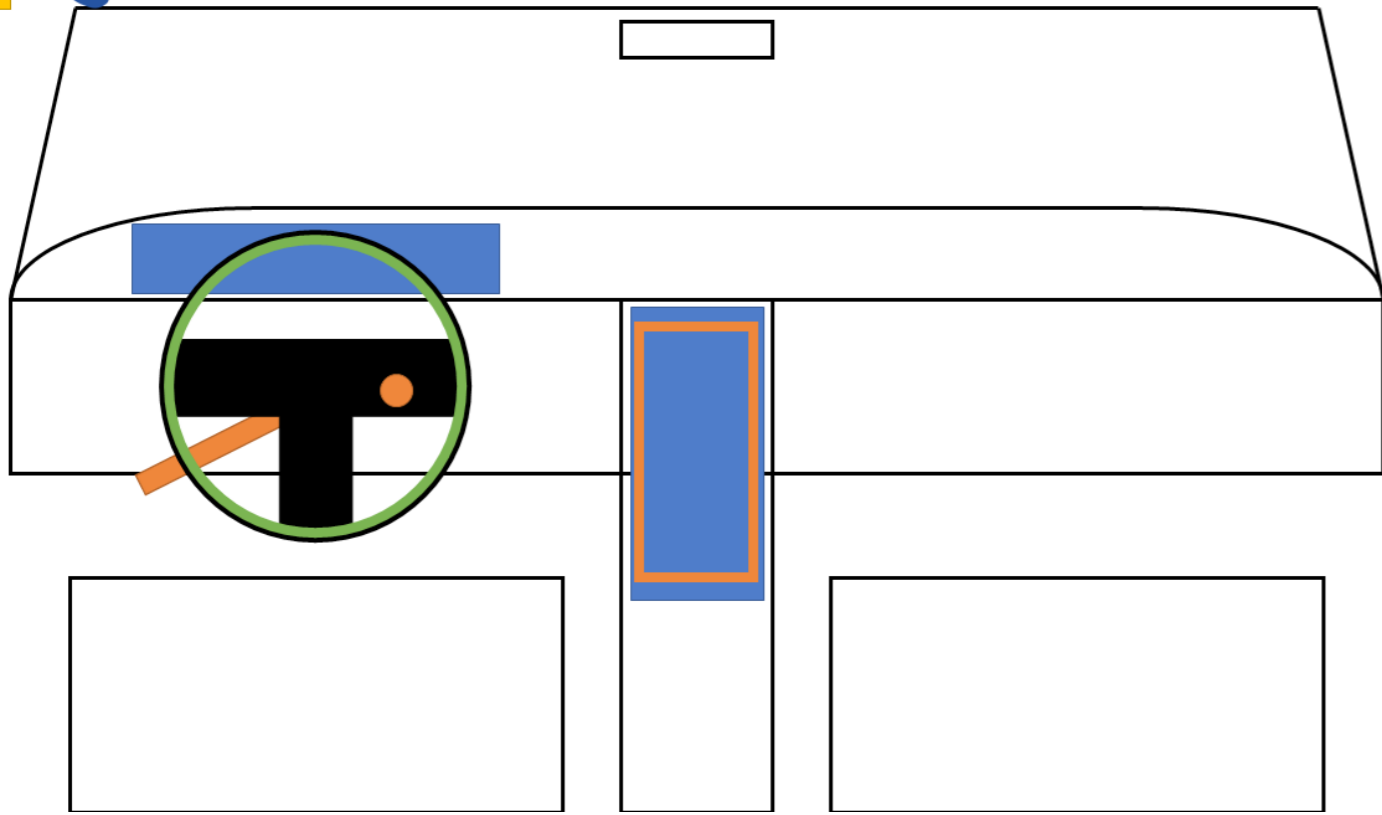
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Tesla Model 3

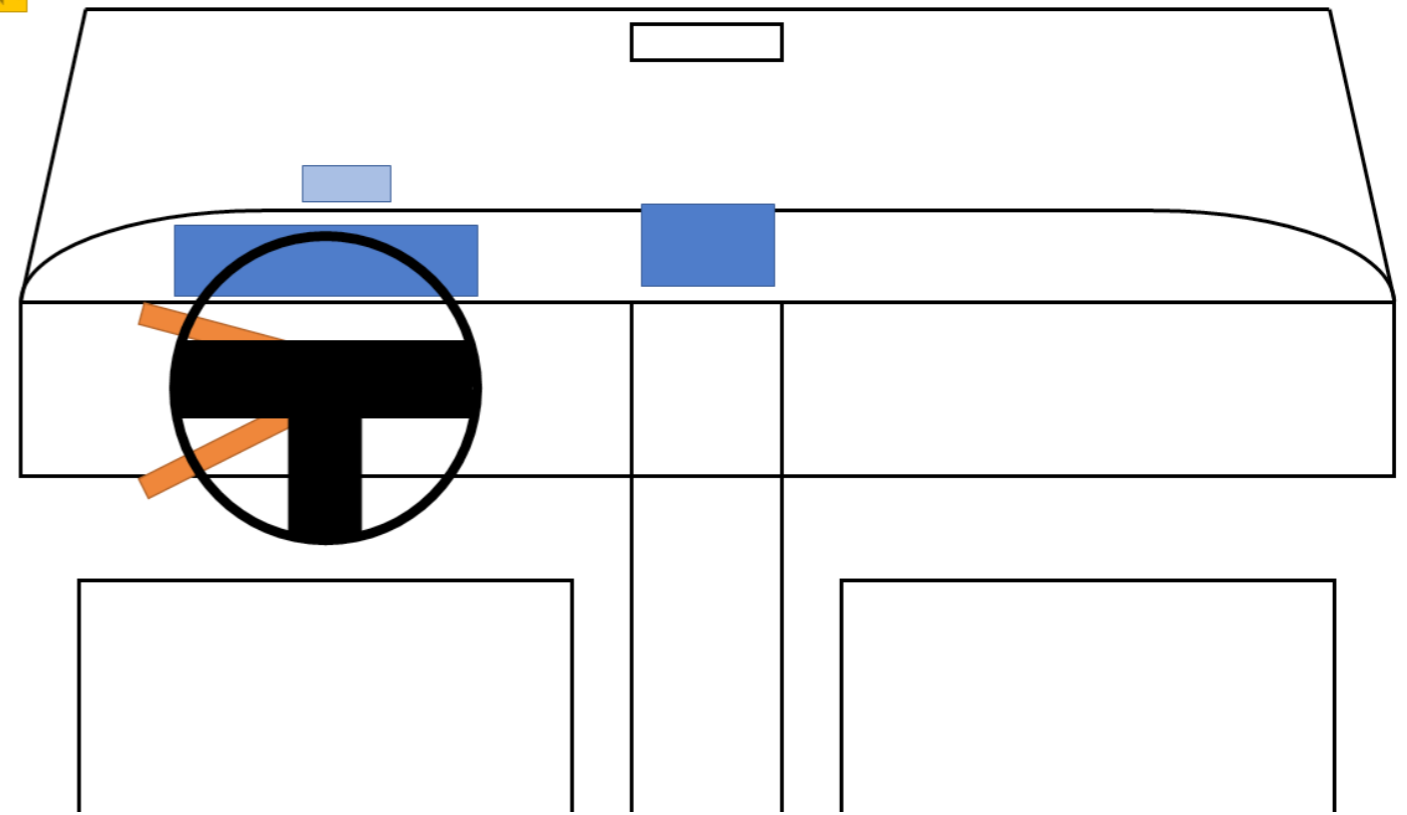


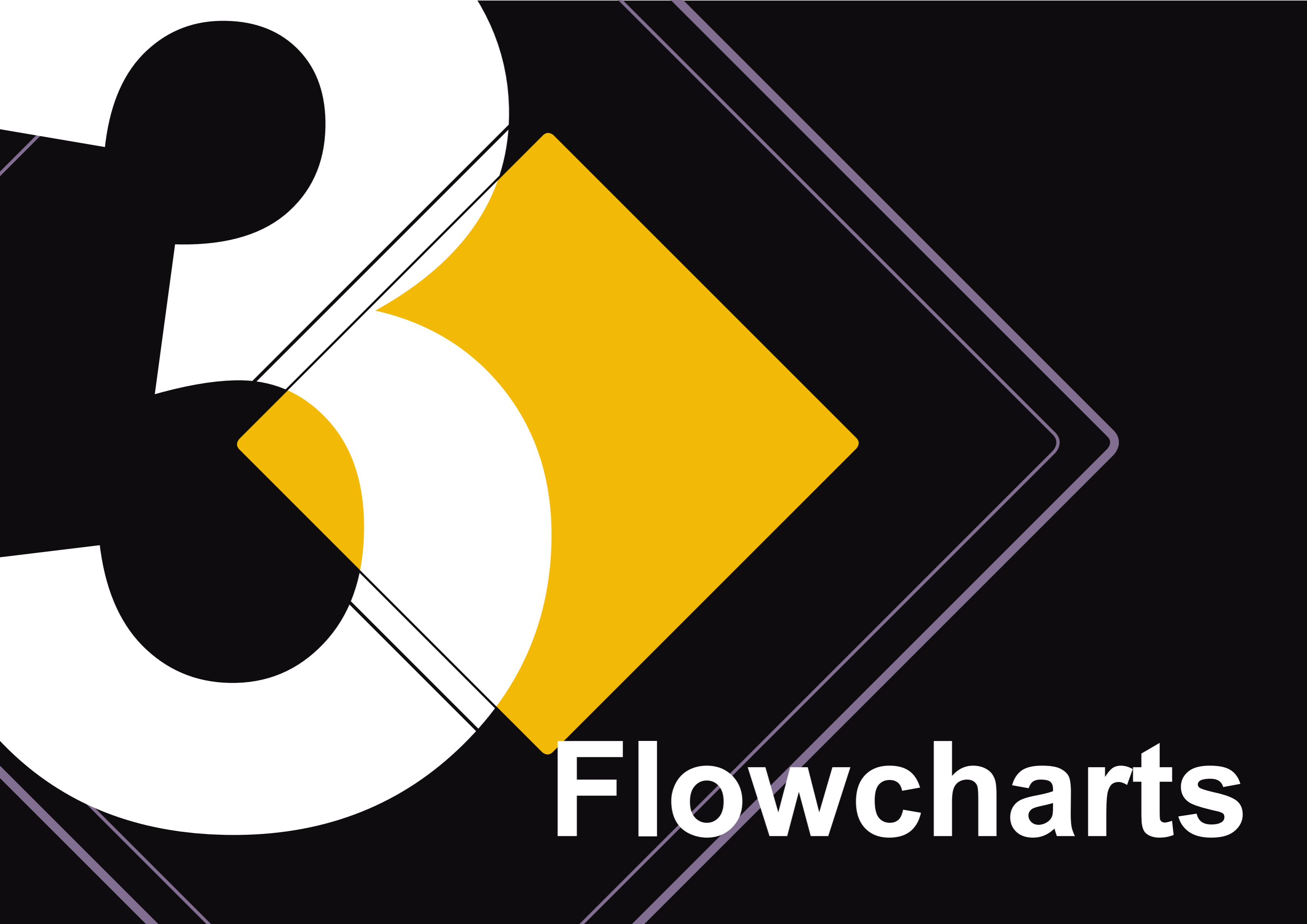


2 3 Tesla Model S 2019



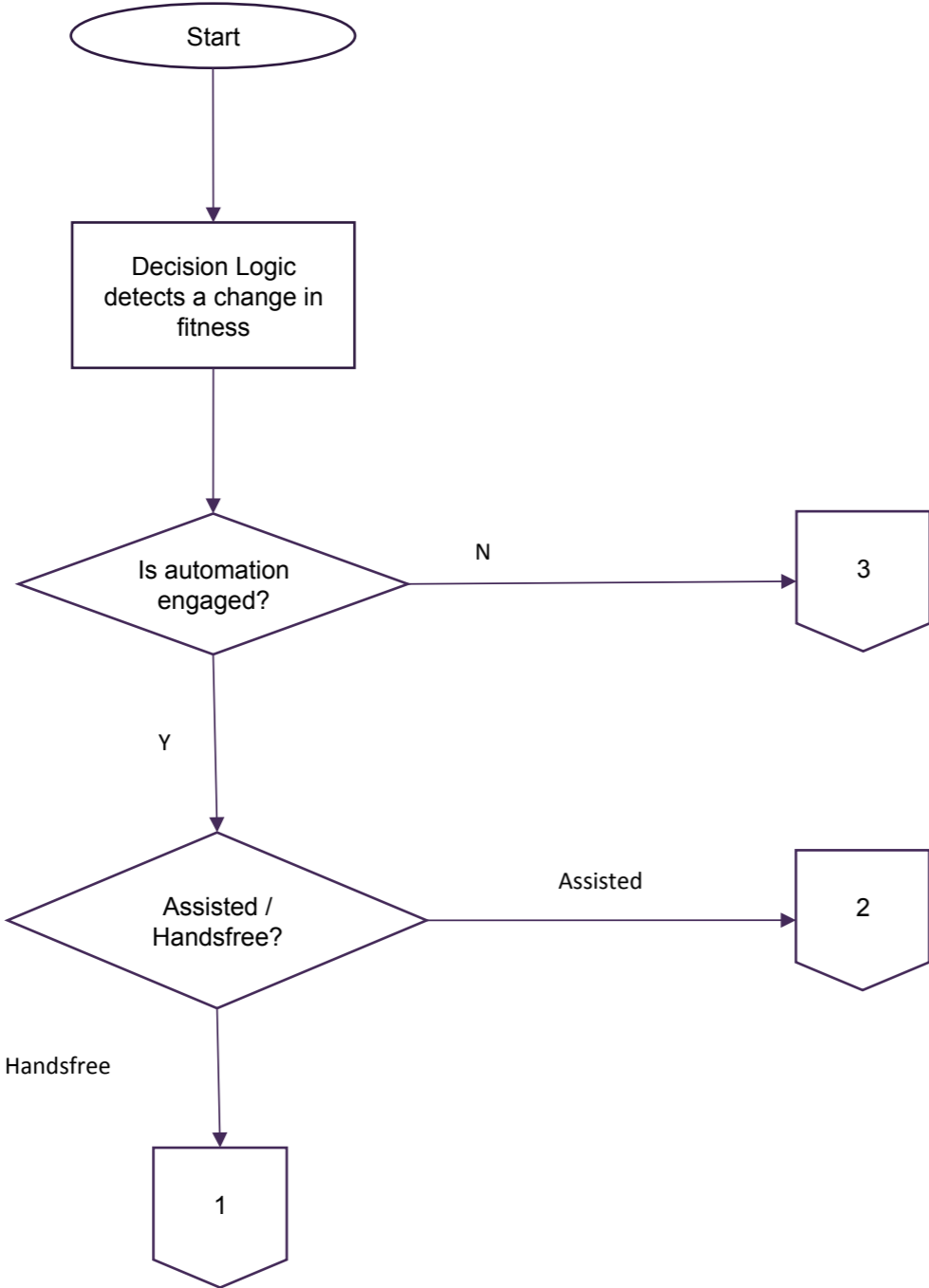
2 3 Audi A4 2017



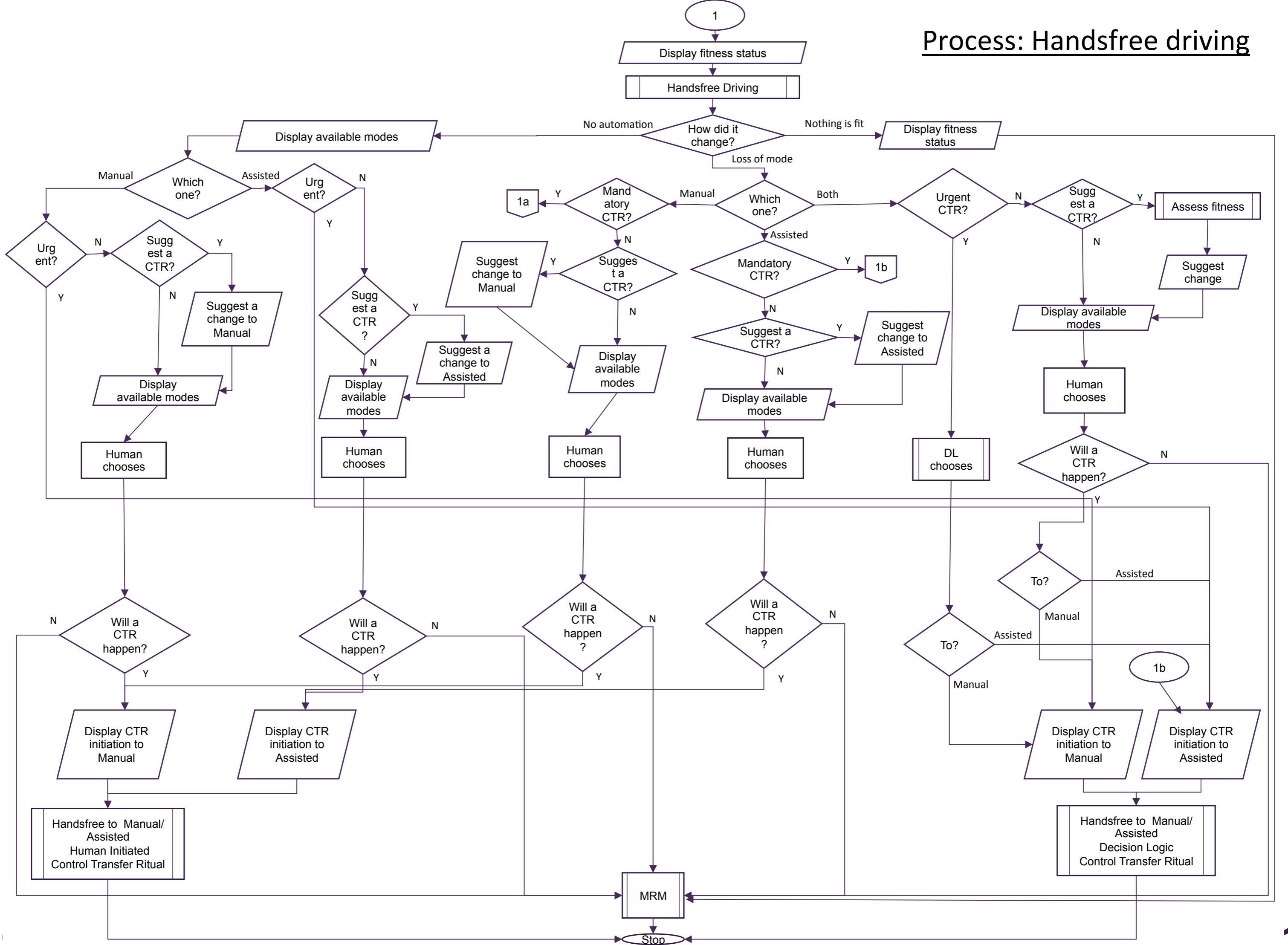


Flowcharts

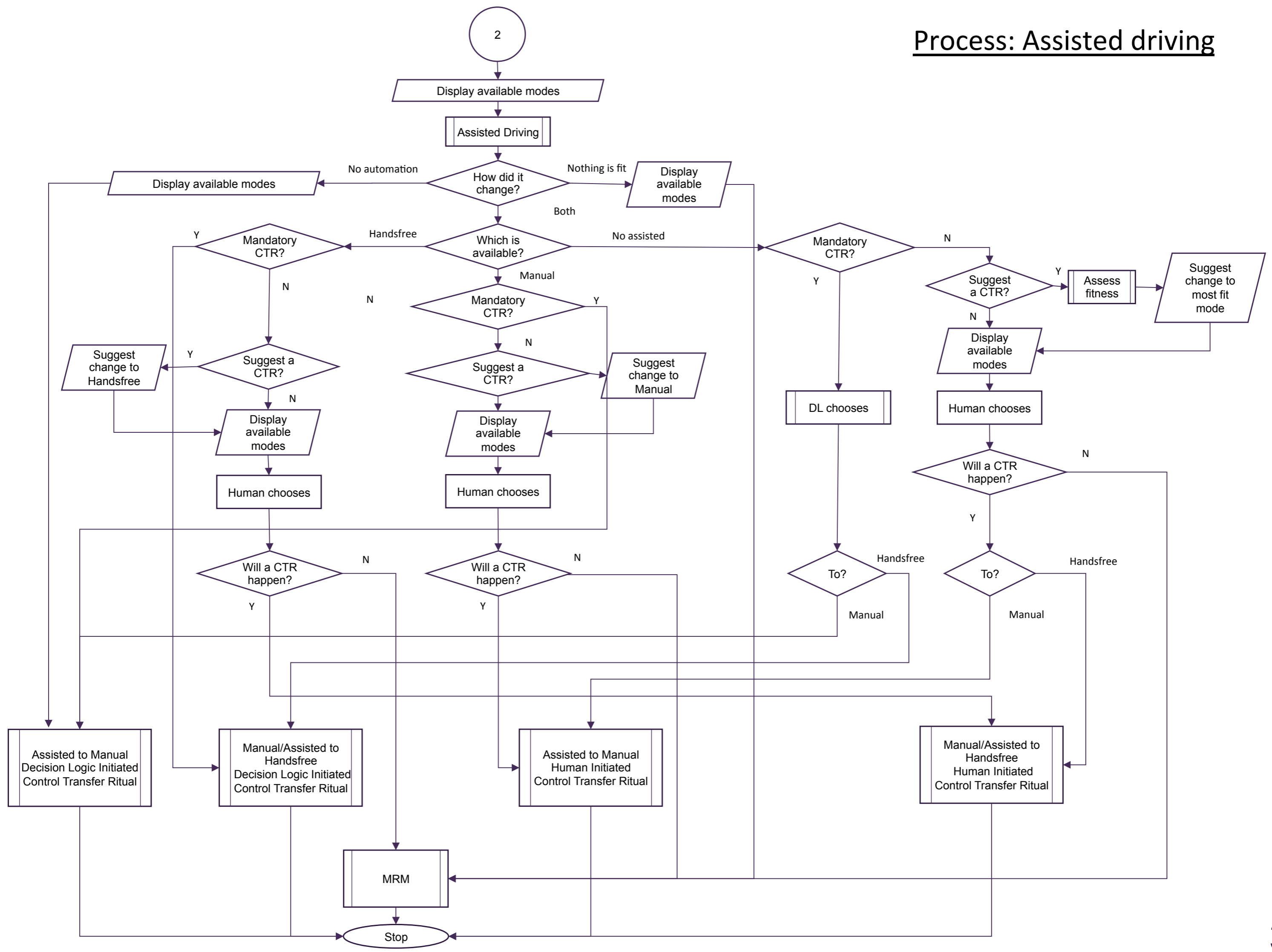
Overall Process: Initiation CTR



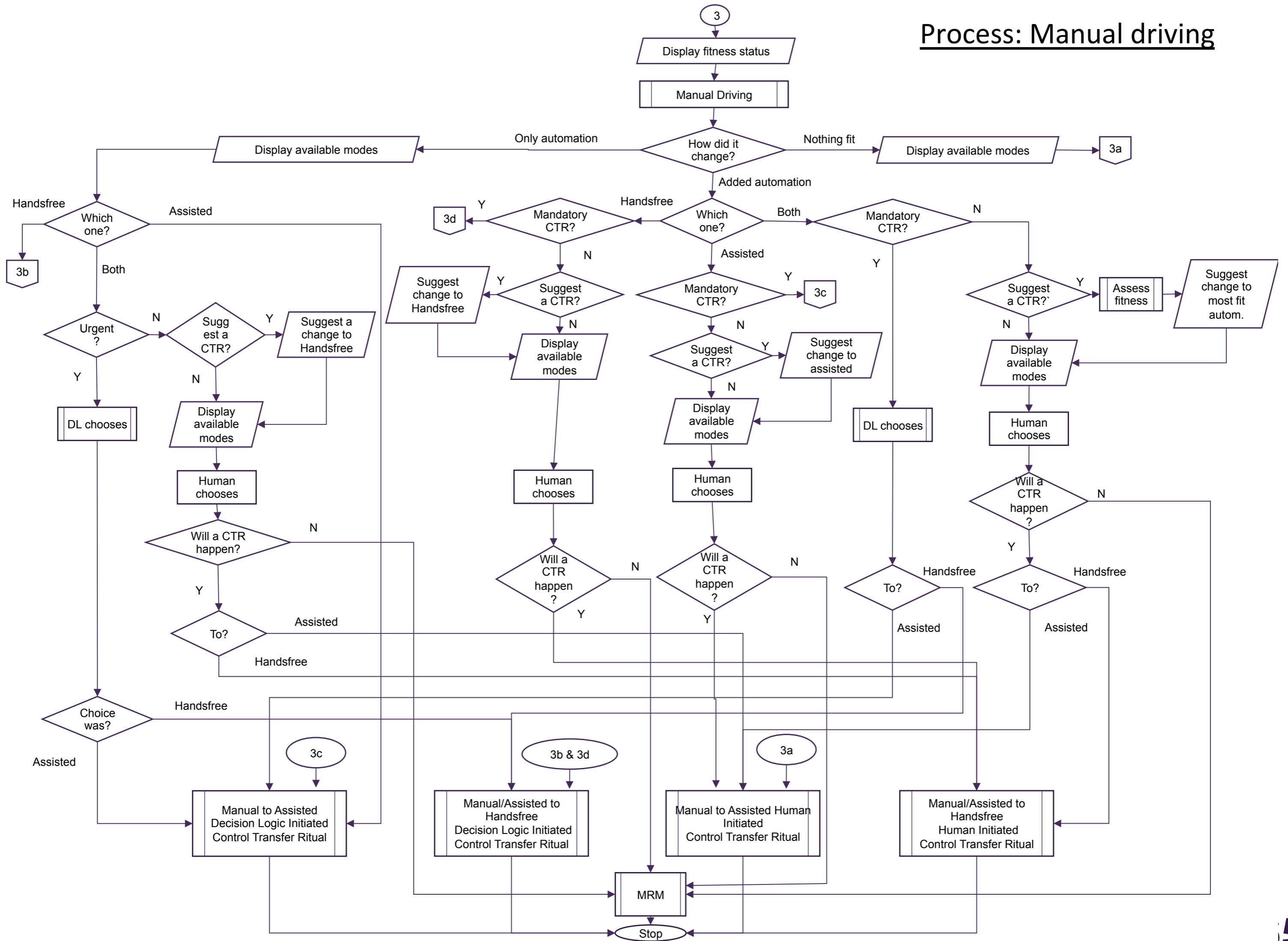
Process: Handsfree driving

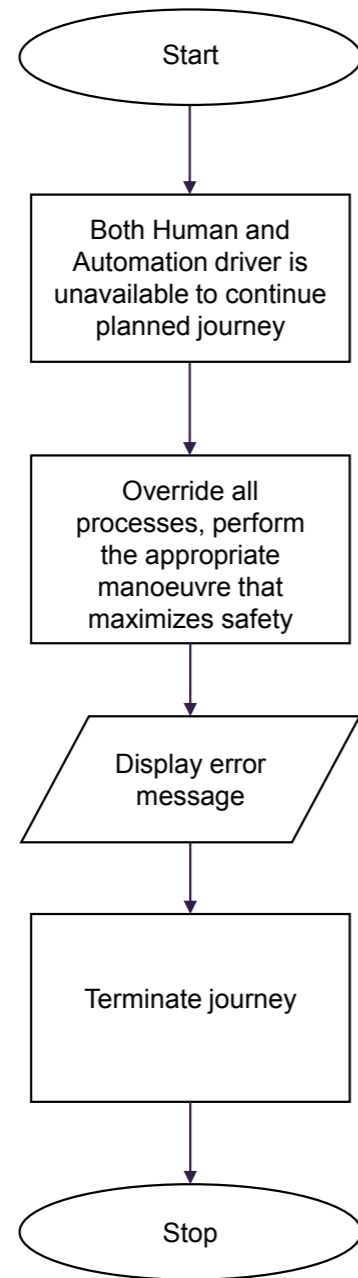


Process: Assisted driving

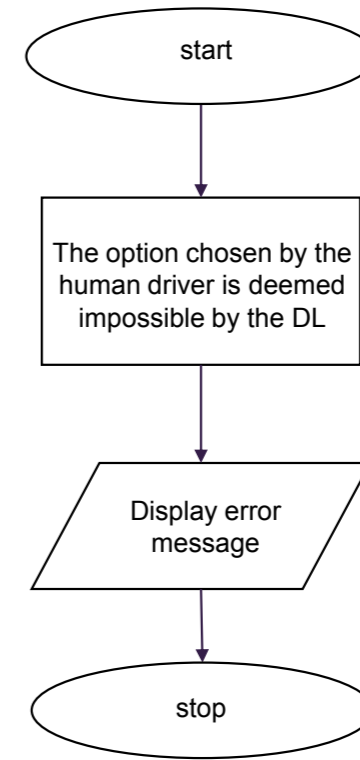


Process: Manual driving

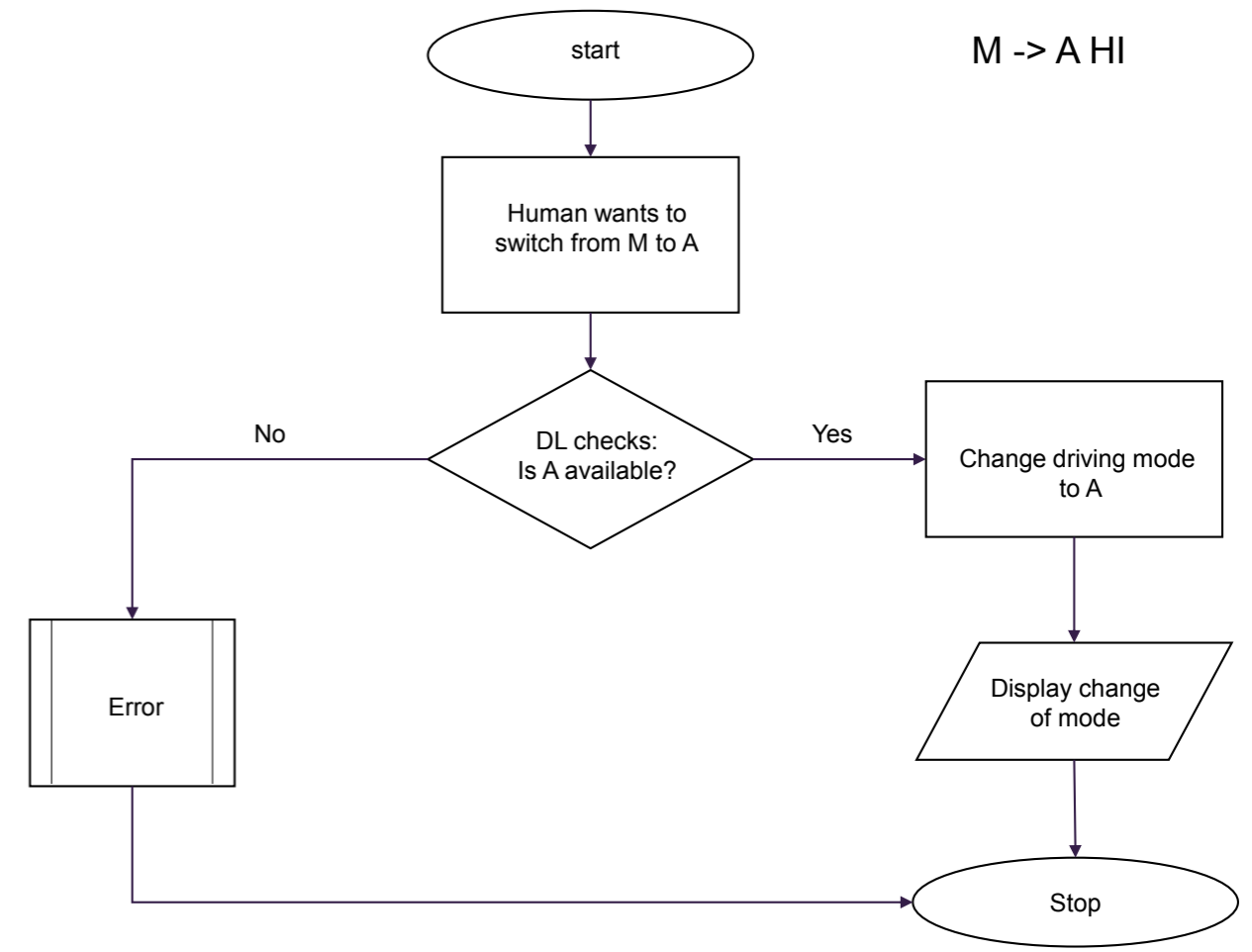
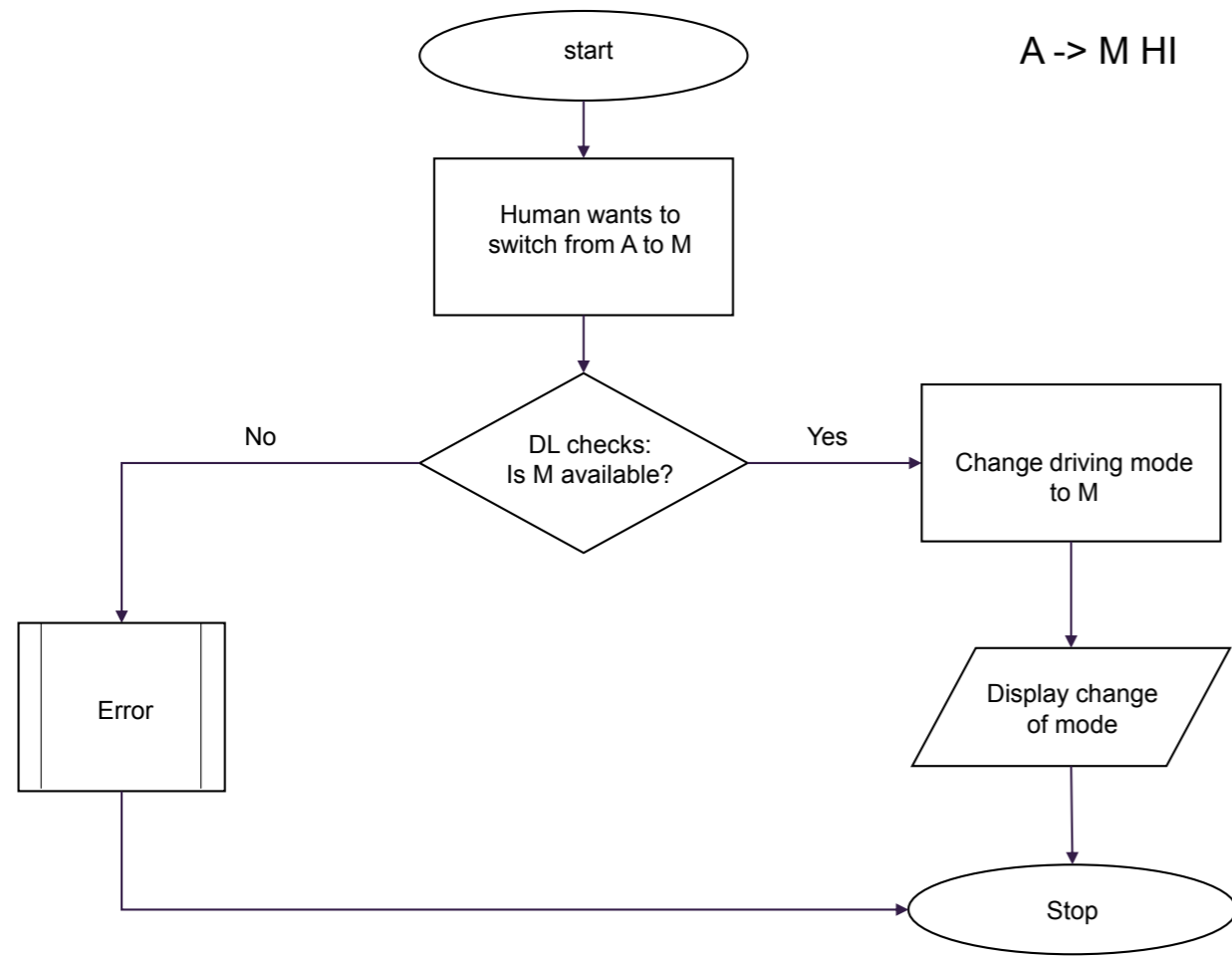


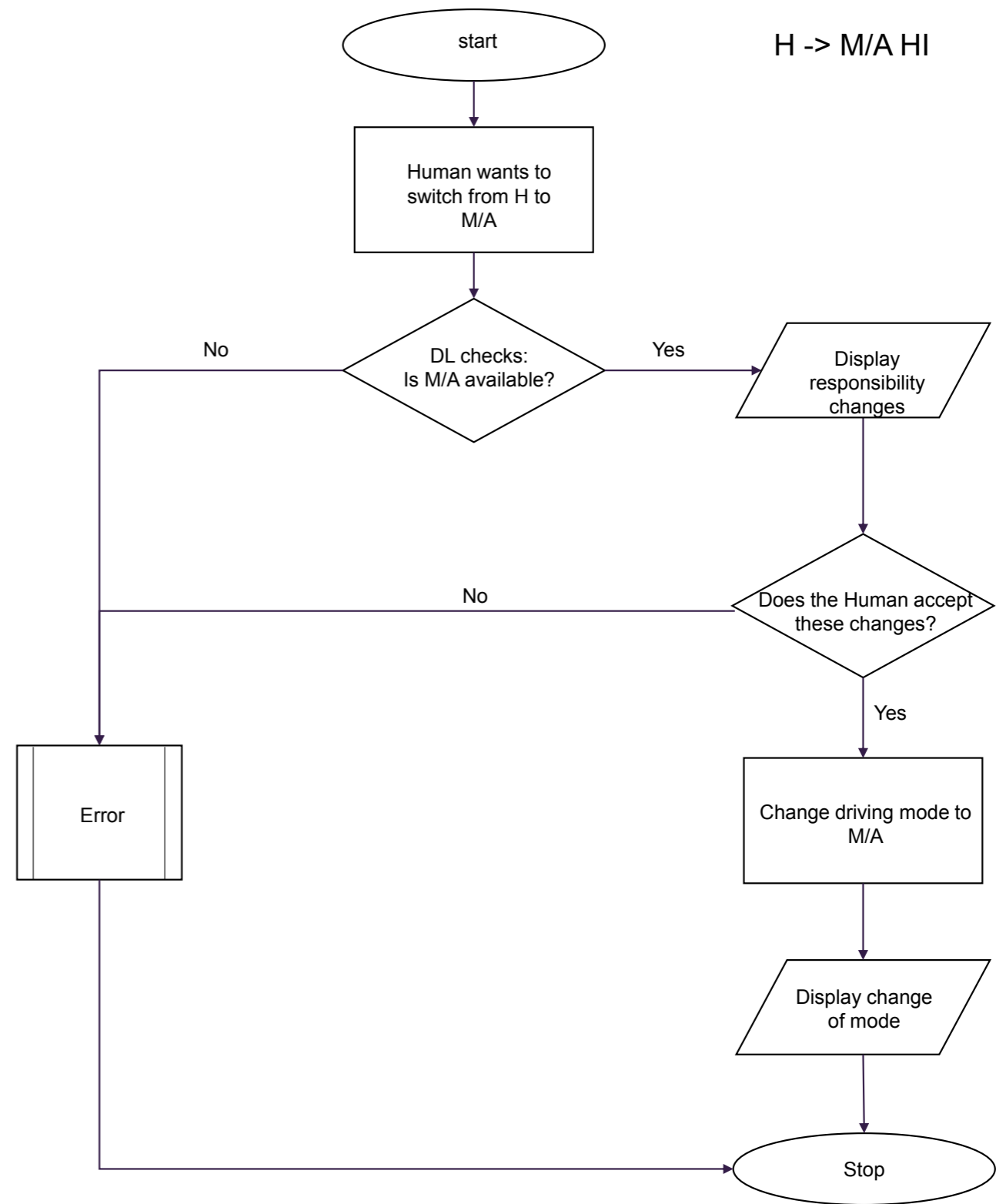
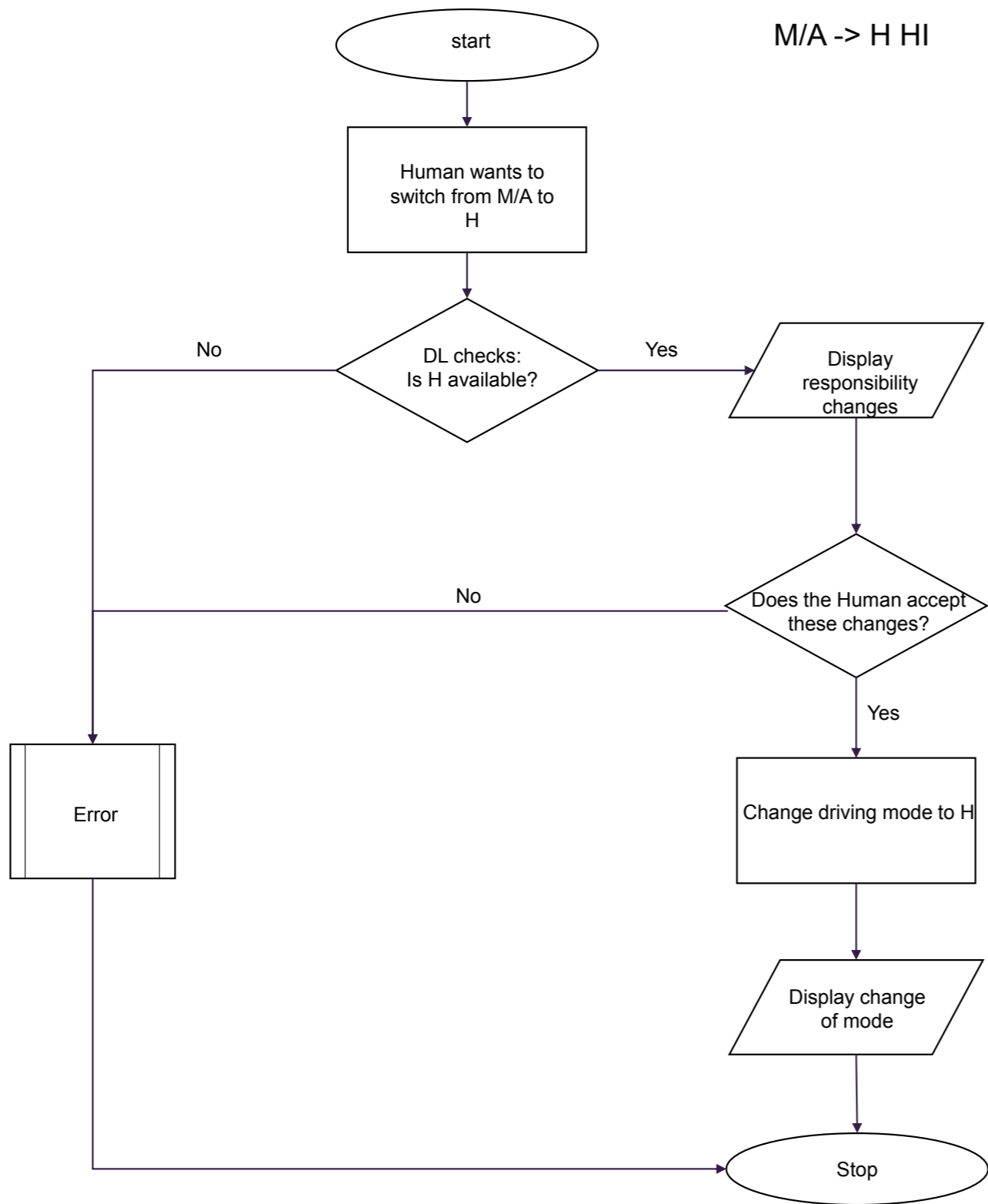


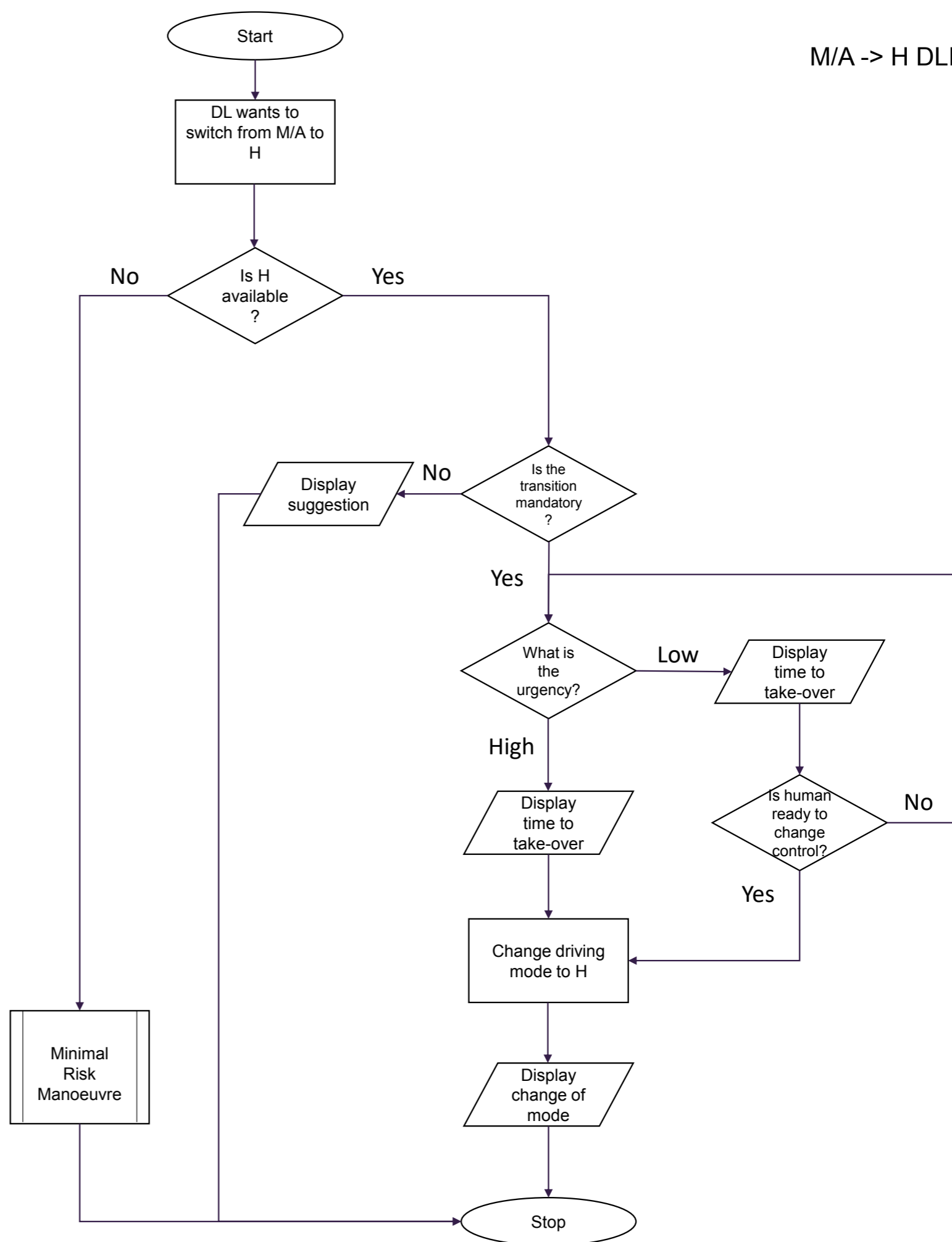
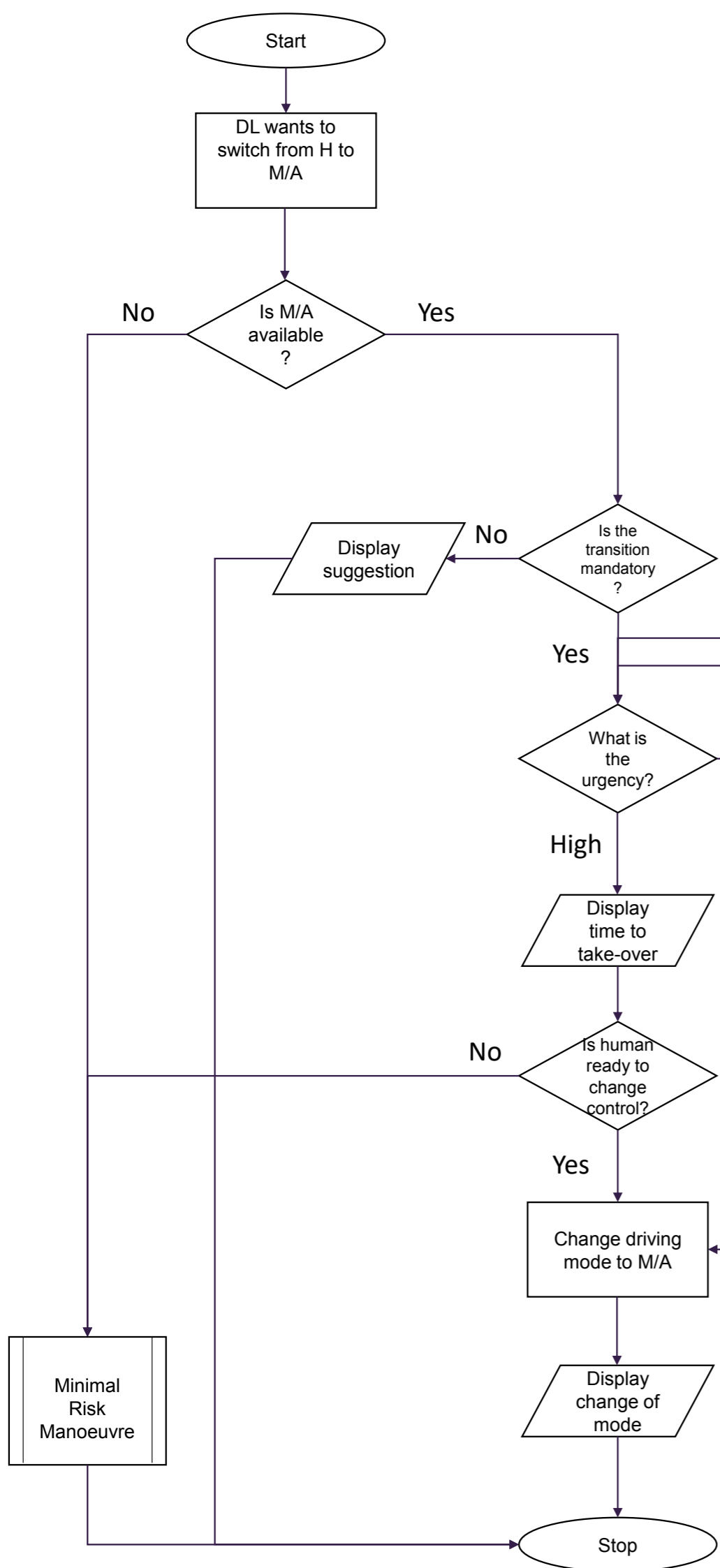
MRM

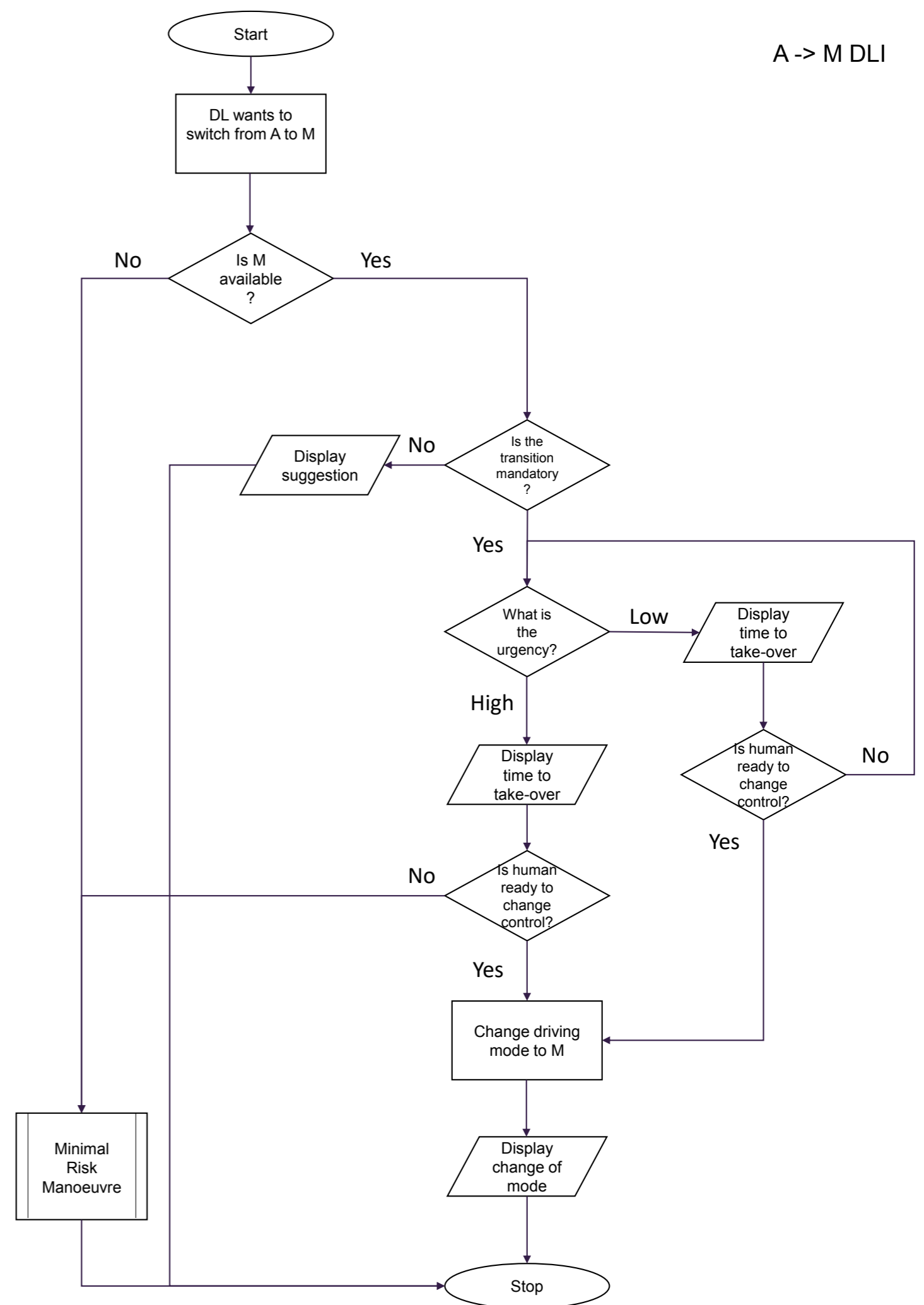
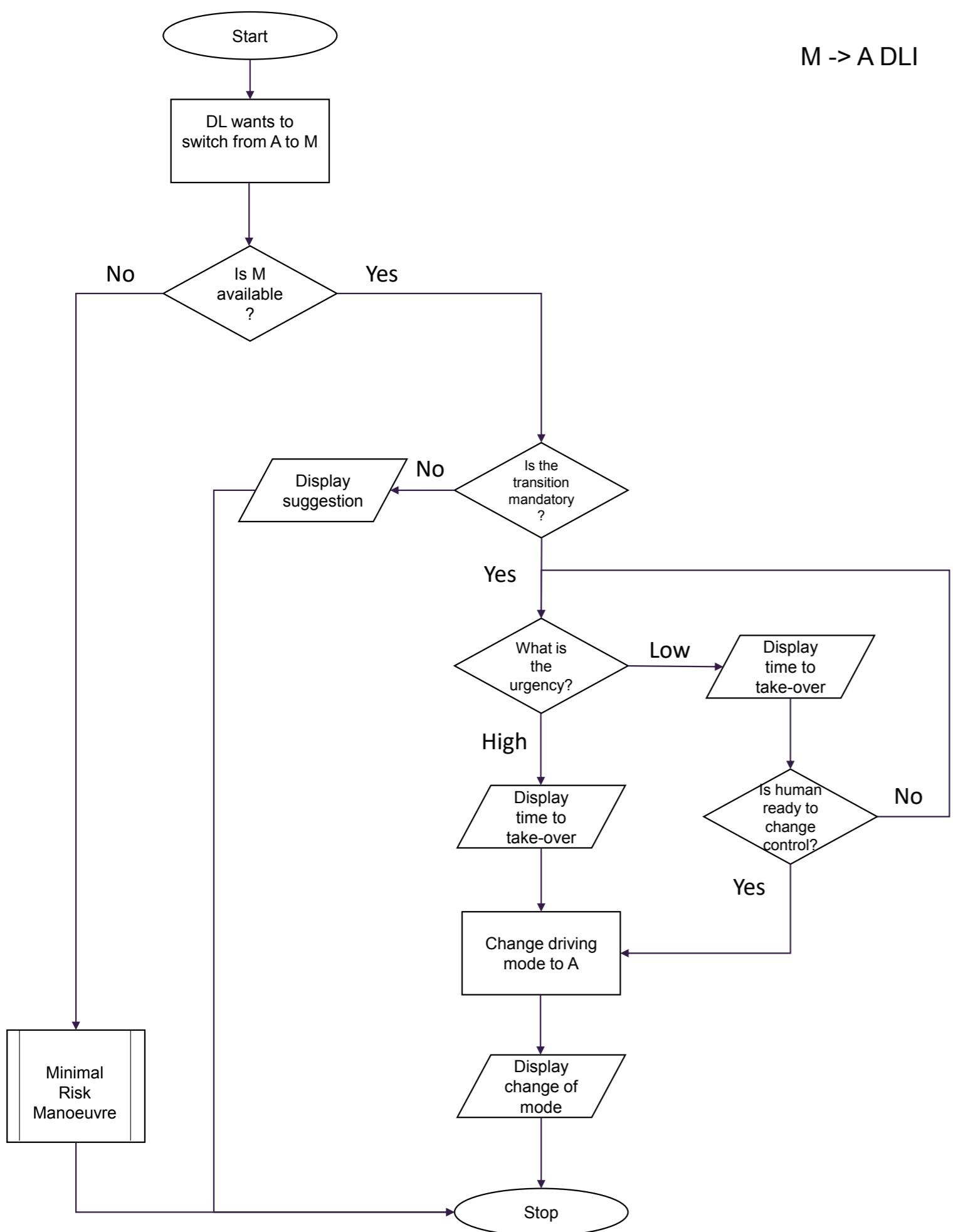


Error





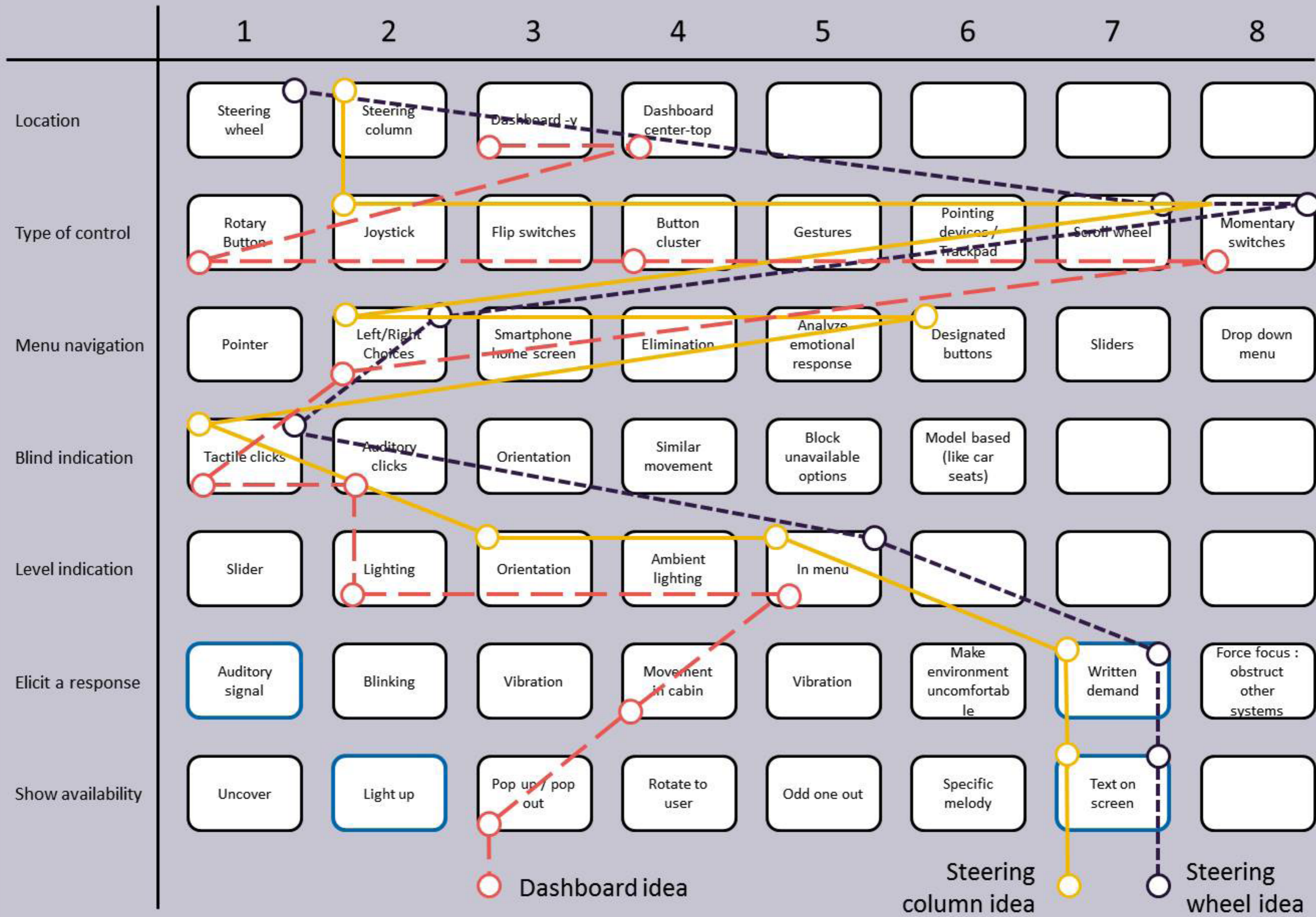




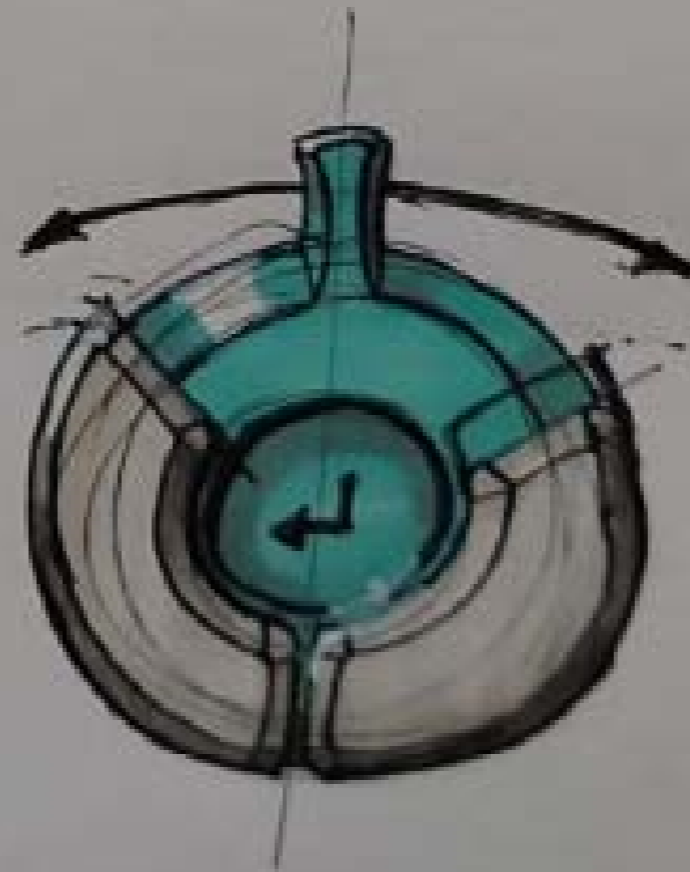
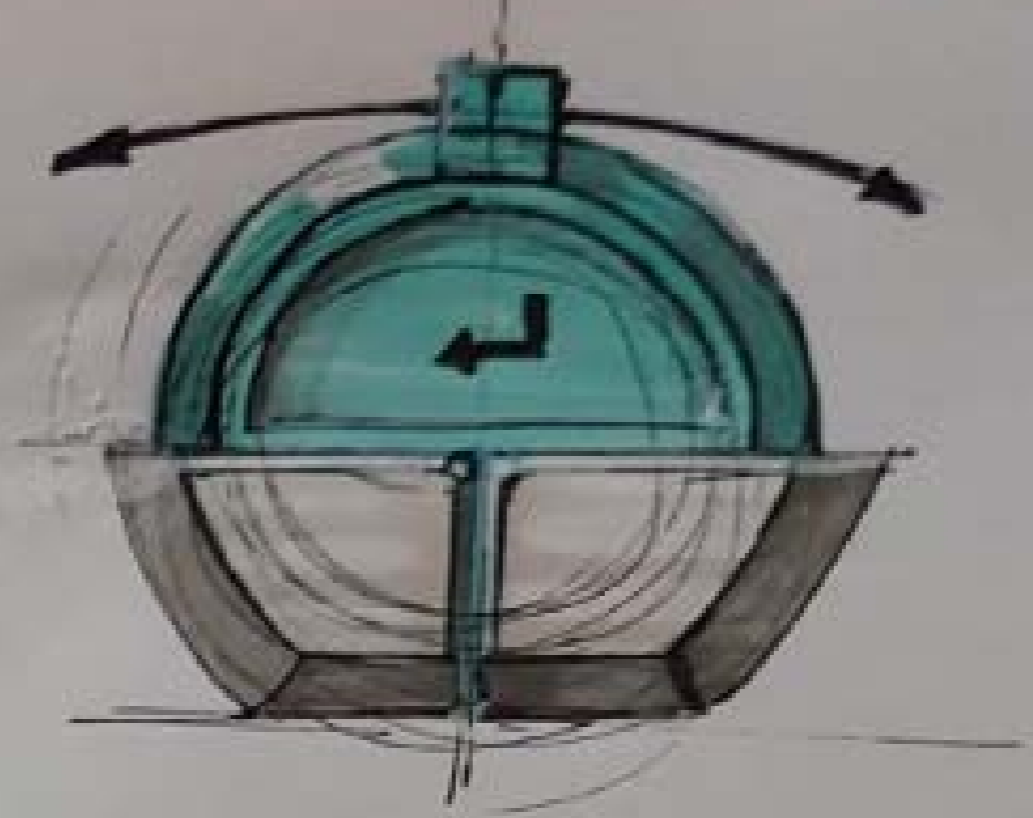
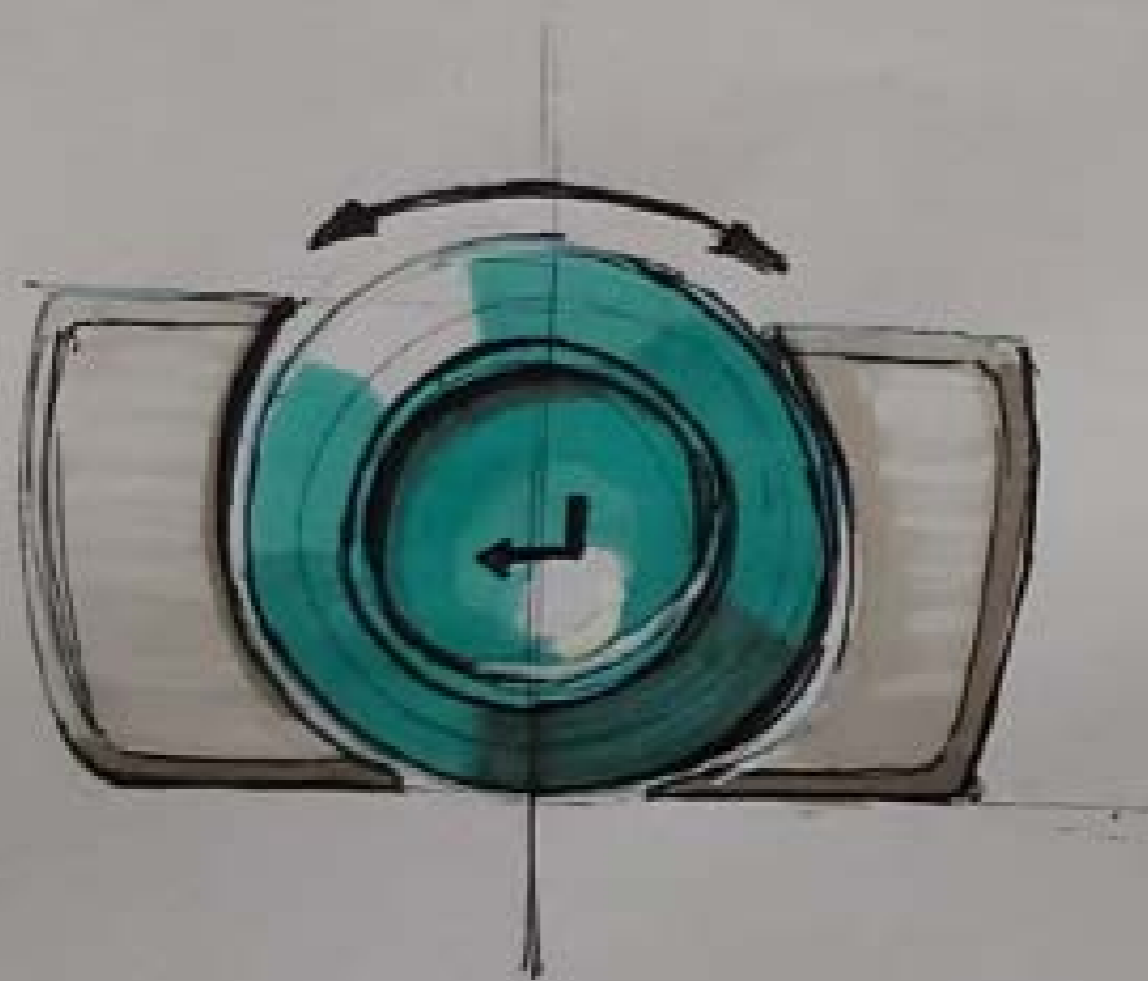
The image features a complex abstract composition. A large white shape, resembling a stylized letter 'A' or a similar geometric form, is the central focus. It is set against a dark background. To the right of the white shape, there is a large yellow shape that also resembles a stylized letter 'A'. This yellow shape is partially enclosed by a purple-outlined diamond shape. The background is filled with various geometric elements: black triangles and lines, and purple lines that create a sense of depth and movement. The overall aesthetic is modern and graphic.

Ideation

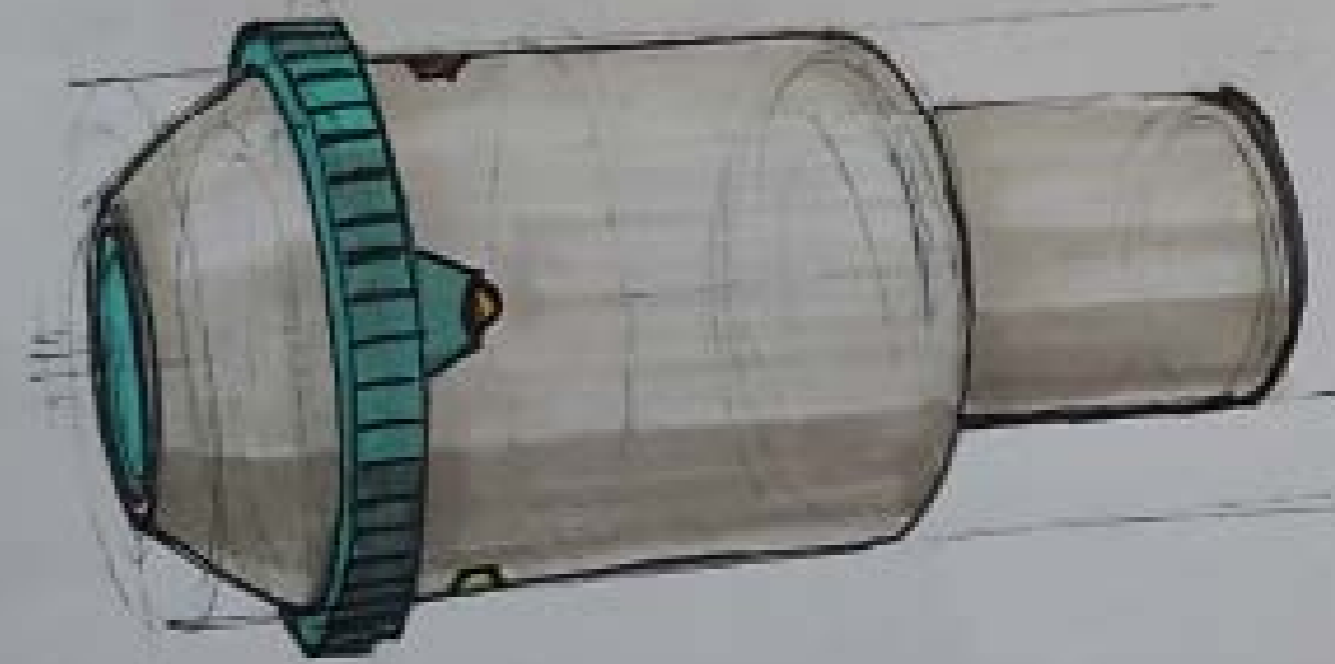
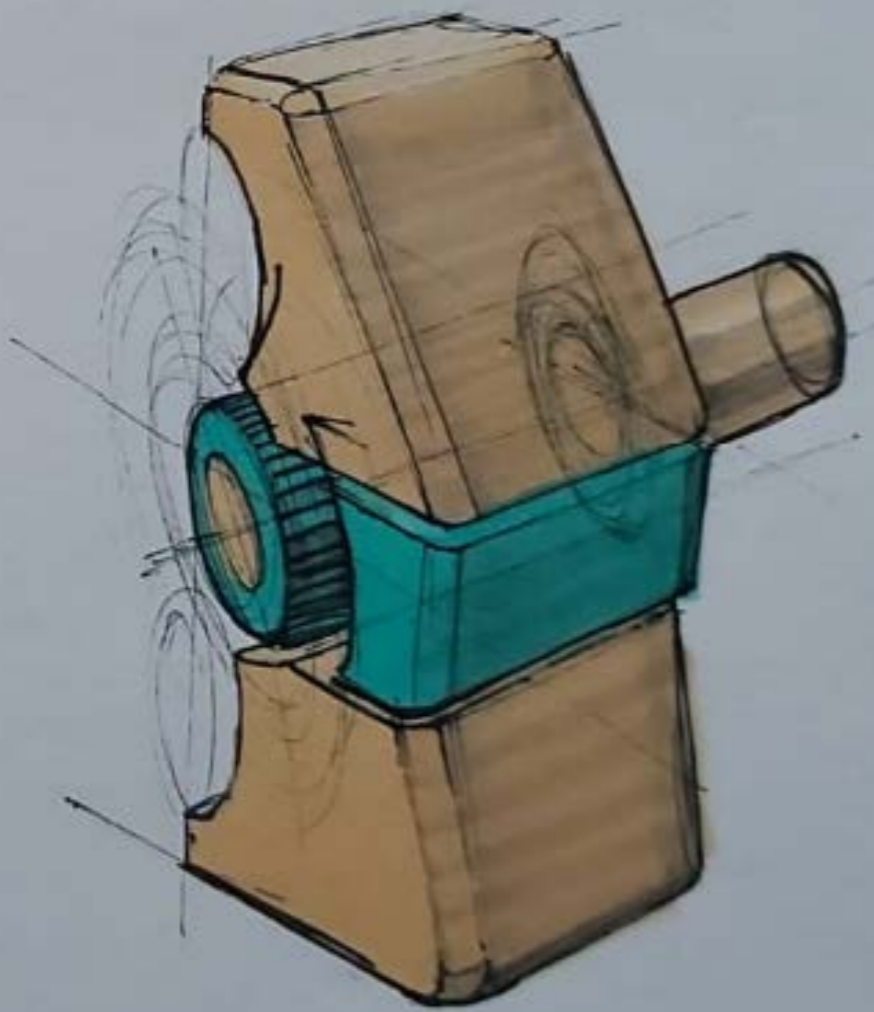
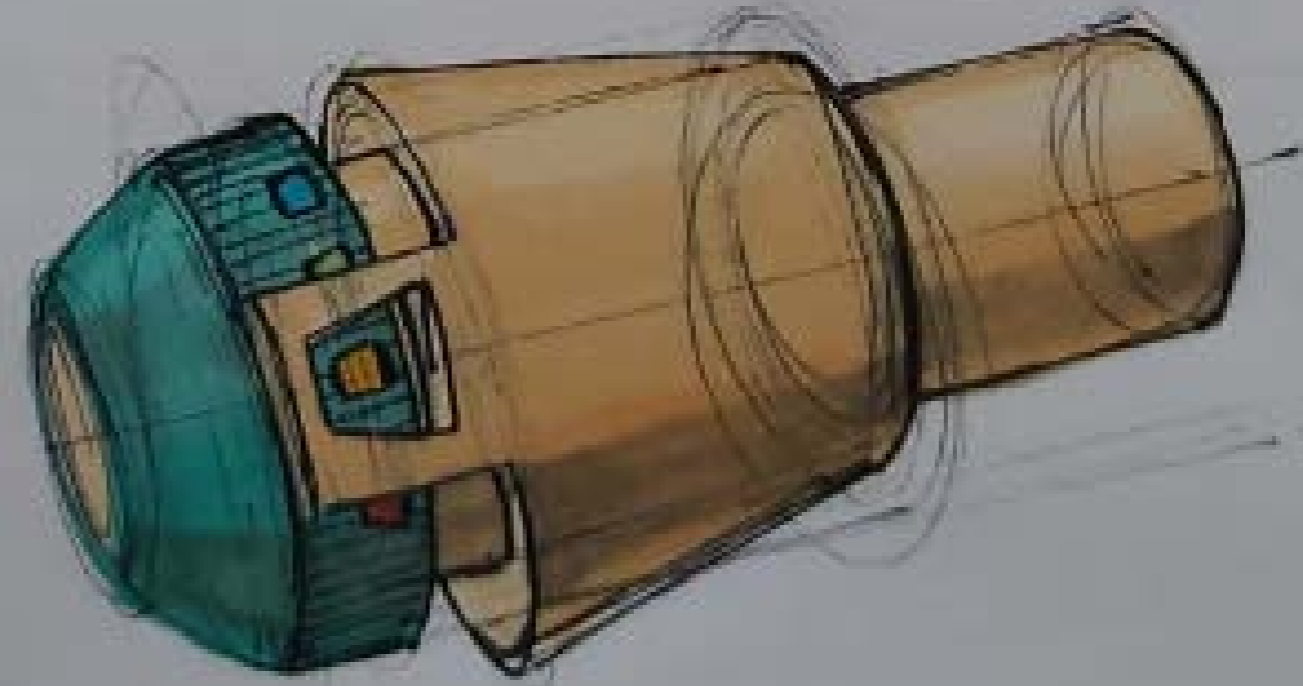
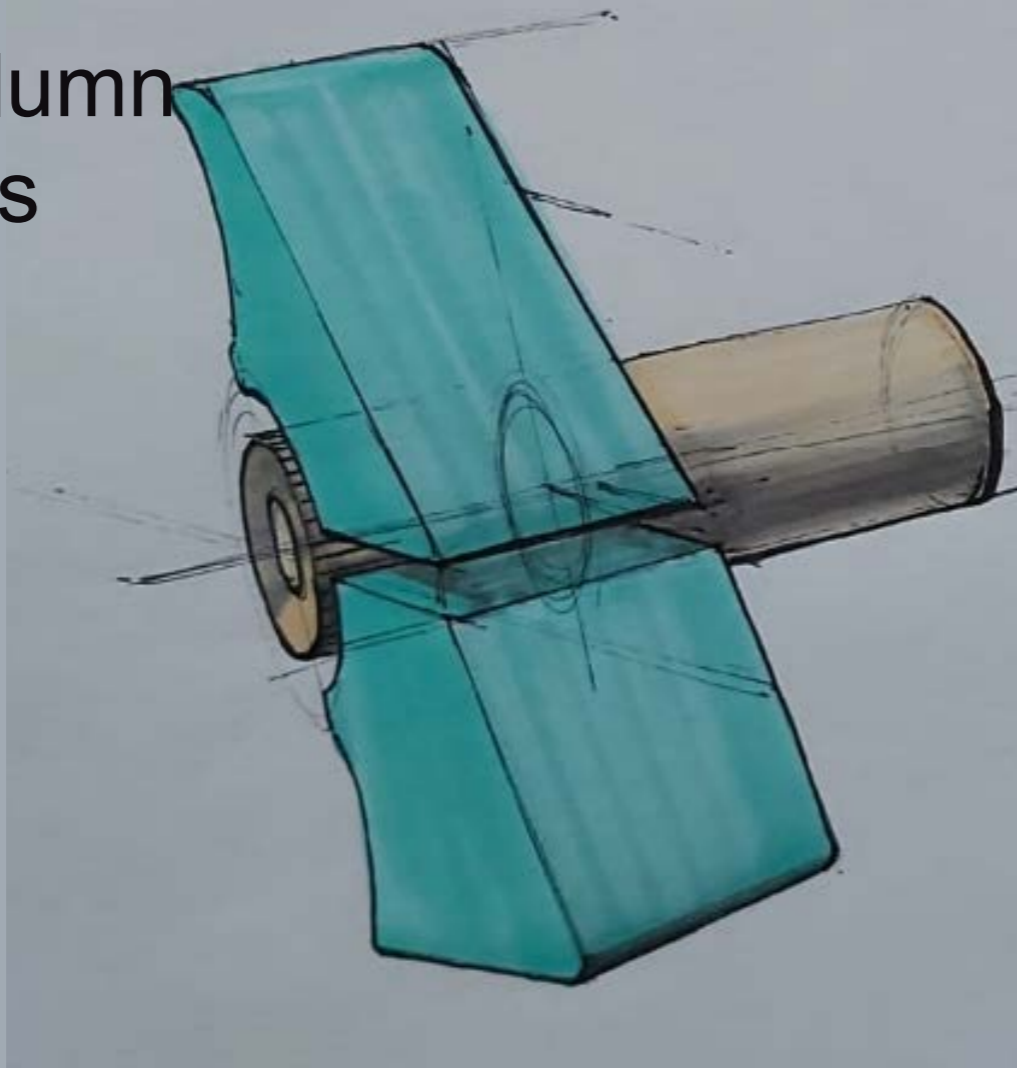
	1	2	3	4	5	6	7	8
Location	Steering wheel	Steering column	Dashboard -y	Dashboard center-top				
Type of control	Rotary Button	Joystick	Flip switches	Button cluster	Gestures	Pointing devices / Trackpad	Scroll wheel	Momentary switches
Menu navigation	Pointer	Left/Right Choices	Smartphone home screen	Elimination	Analyze emotional response	Designated buttons	Sliders	Drop down menu
Blind indication	Tactile clicks	Auditory clicks	Orientation	Similar movement	Block unavailable options	Model based (like car seats)		
Level indication	Slider	Lighting	Orientation	Ambient lighting				
Elicit a response	Auditory signal	Blinking	Vibration	Movement in cabin	Vibration	Make environment uncomfortable	Written demand	Force focus : obstruct other systems
Show availability	Uncover	Light up	Pop up / pop out	Rotate to user	Odd one out	Specific melody	Text on screen	



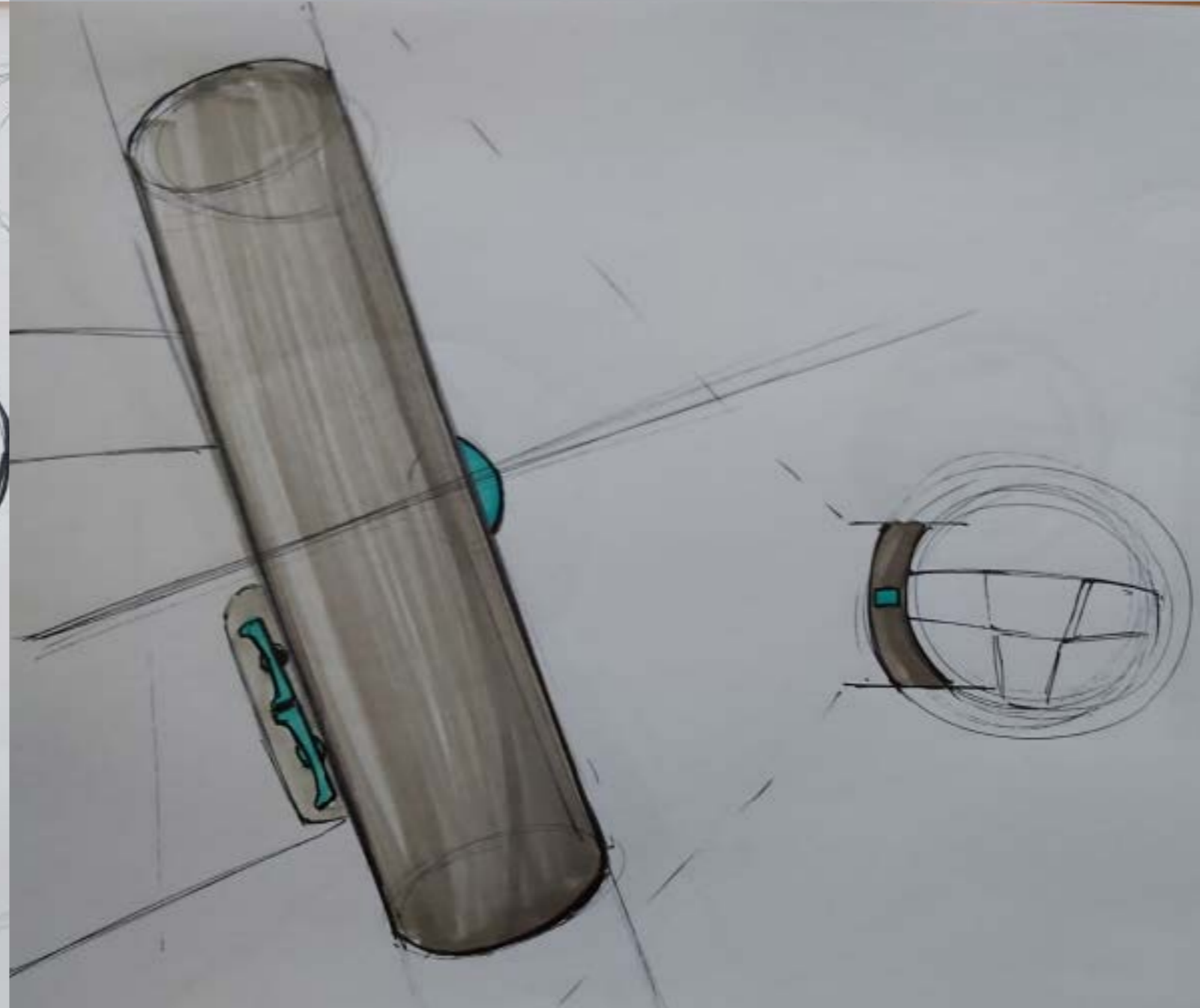
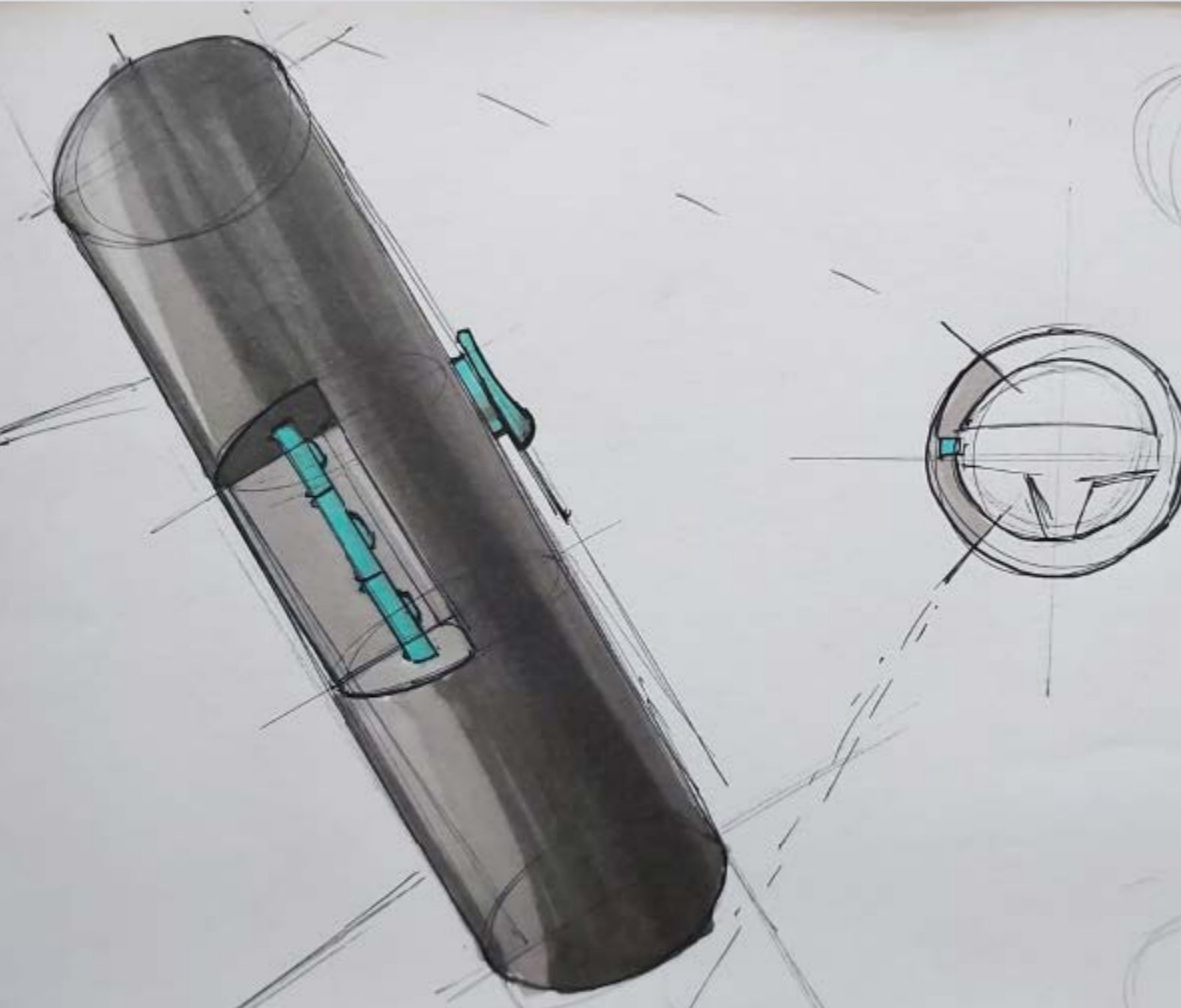
Dashboard idea variants



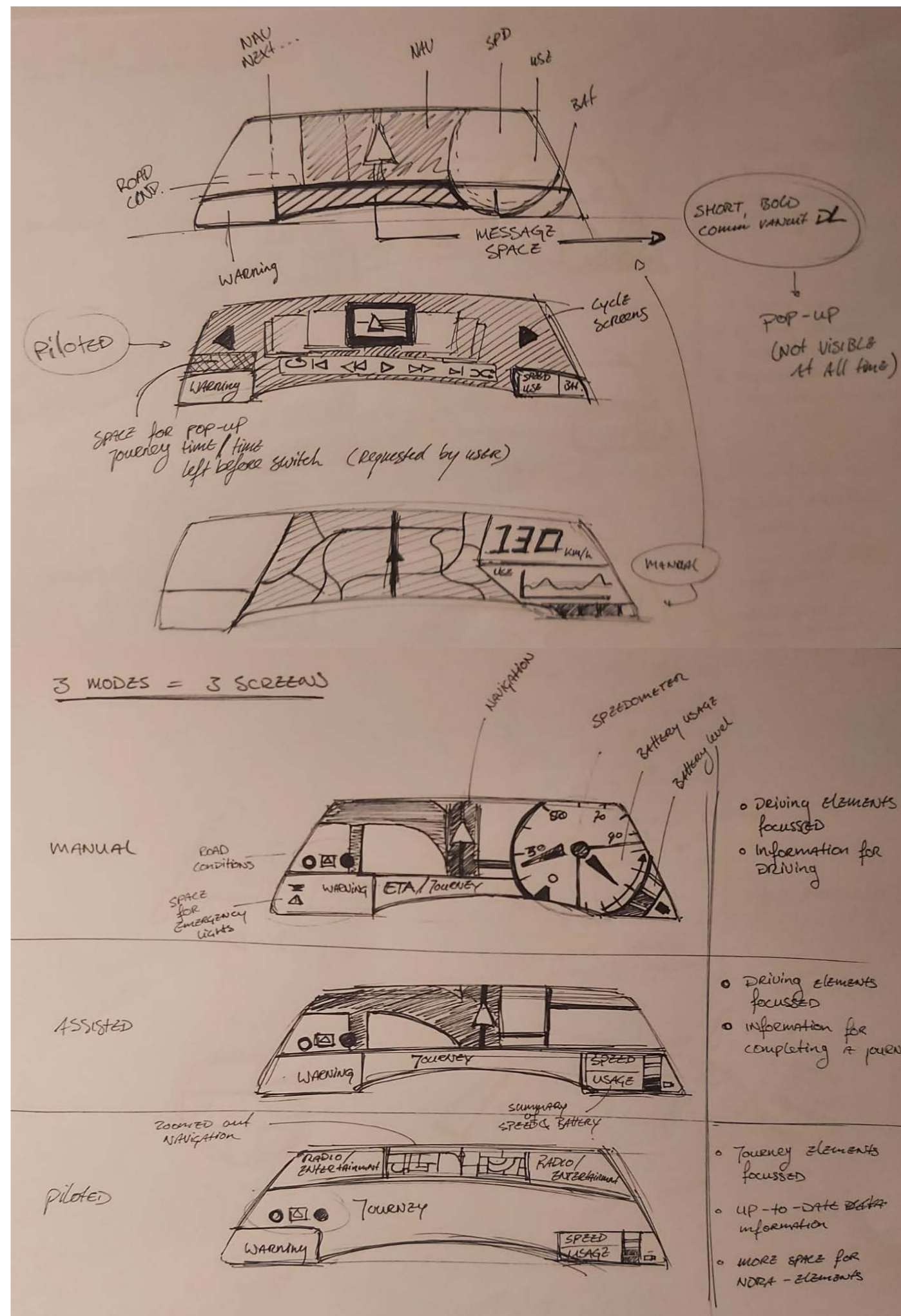
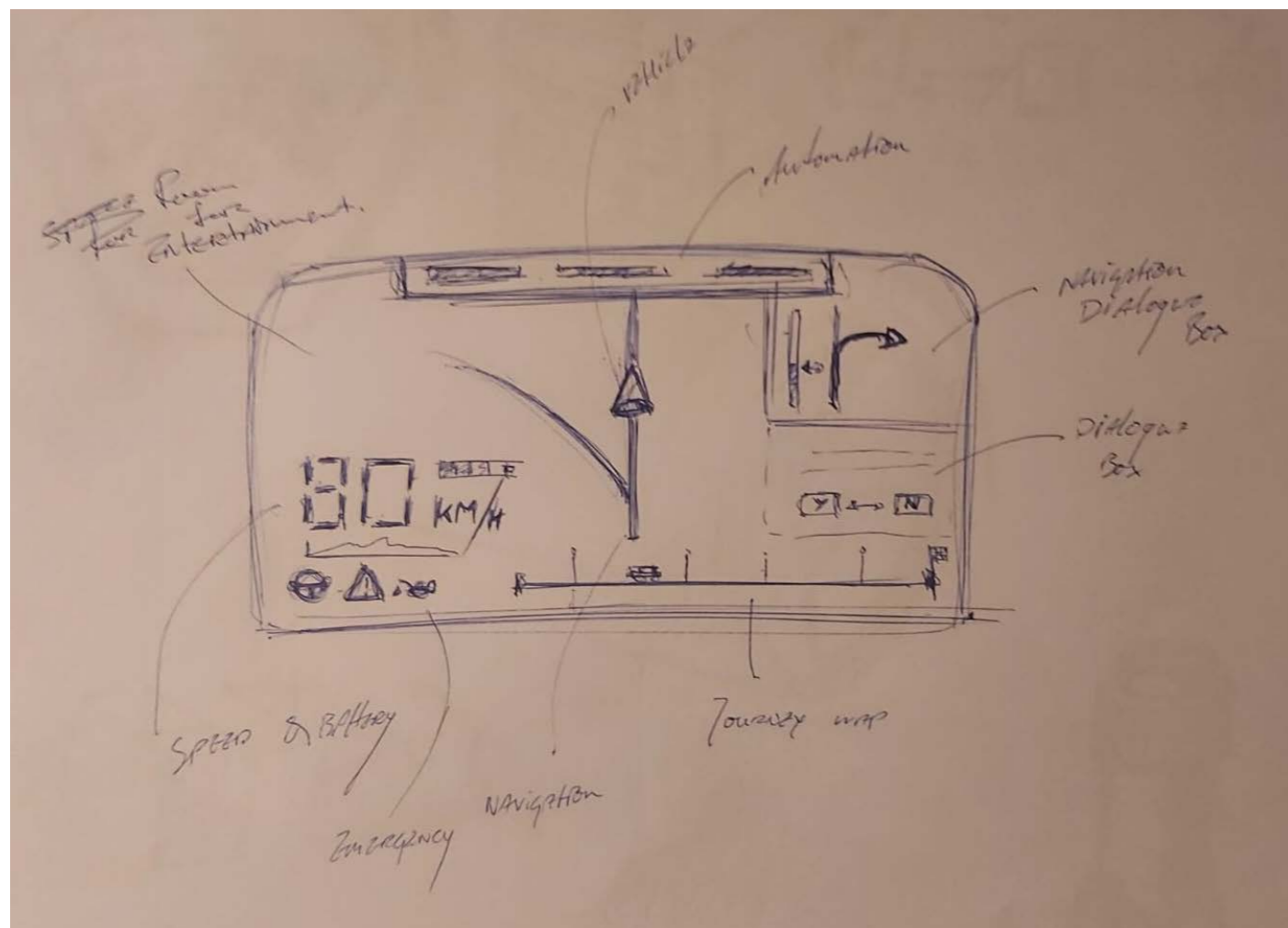
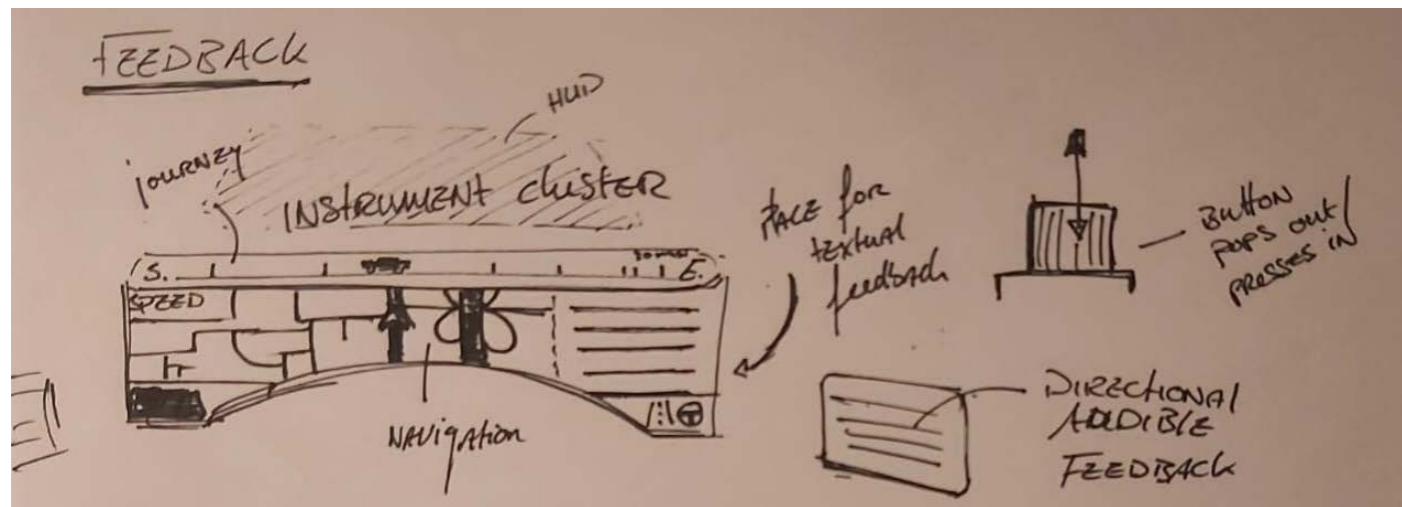
Steering column
idea variants



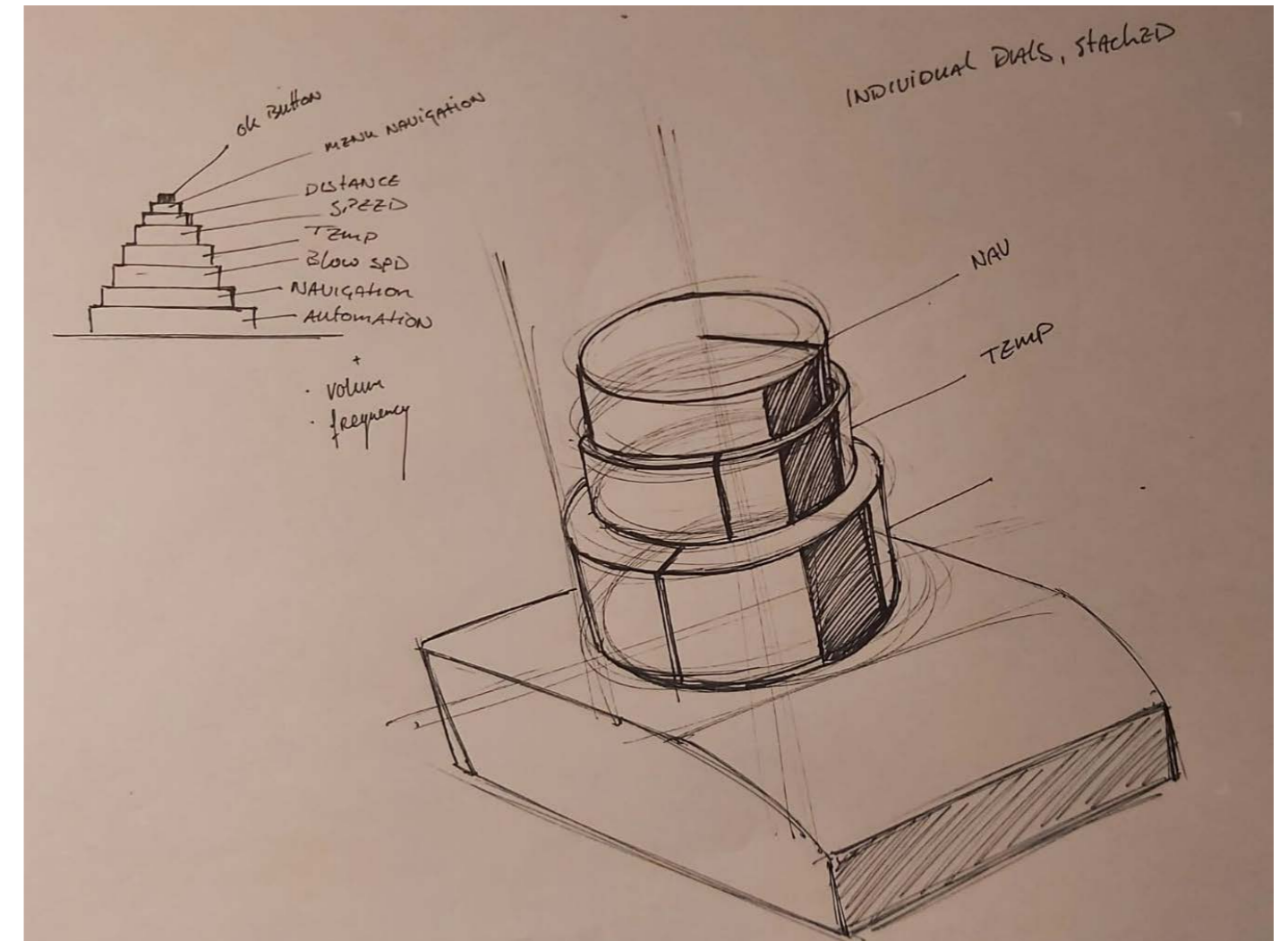
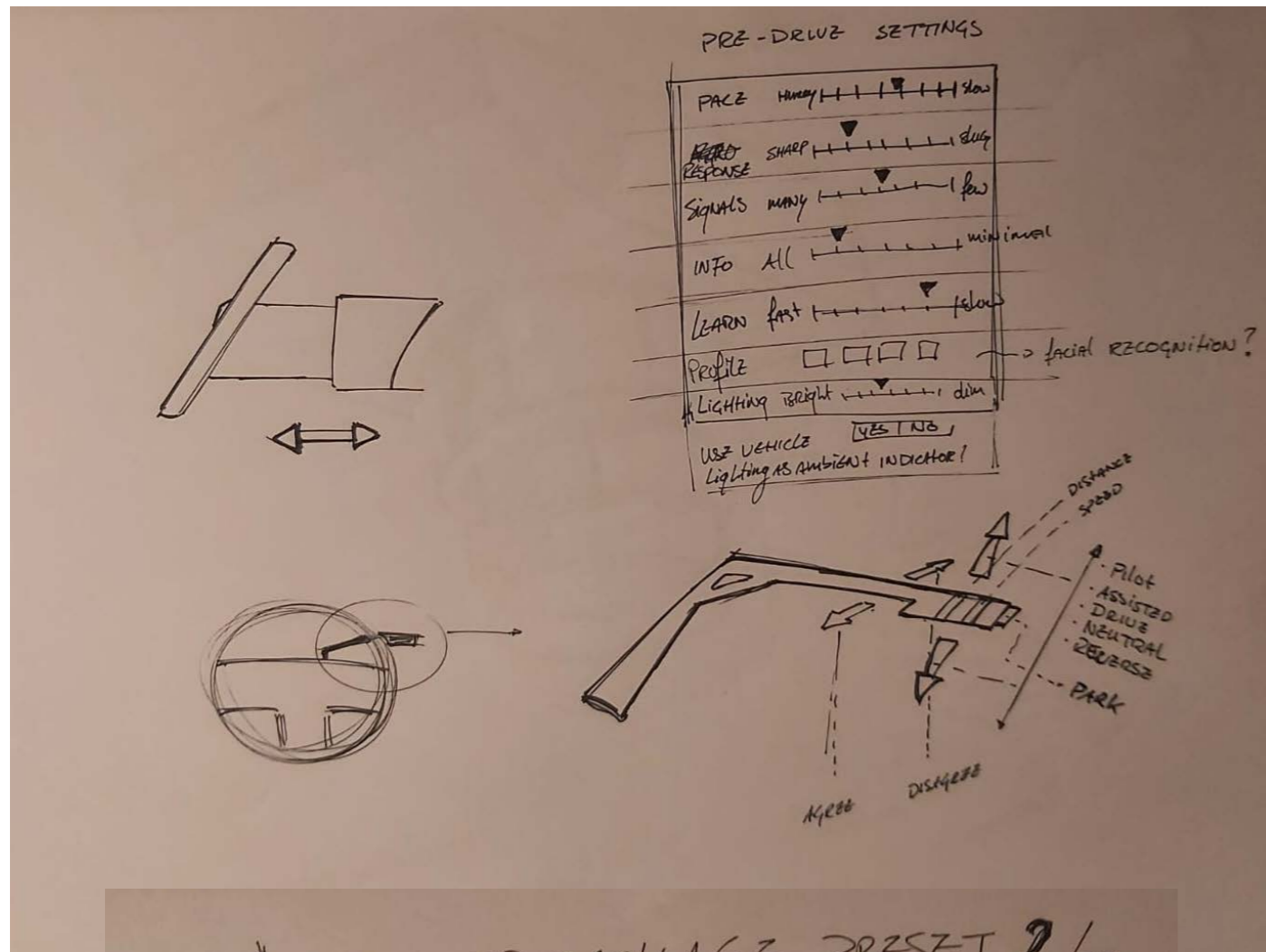
Steering wheel idea variants



Feedback ideation

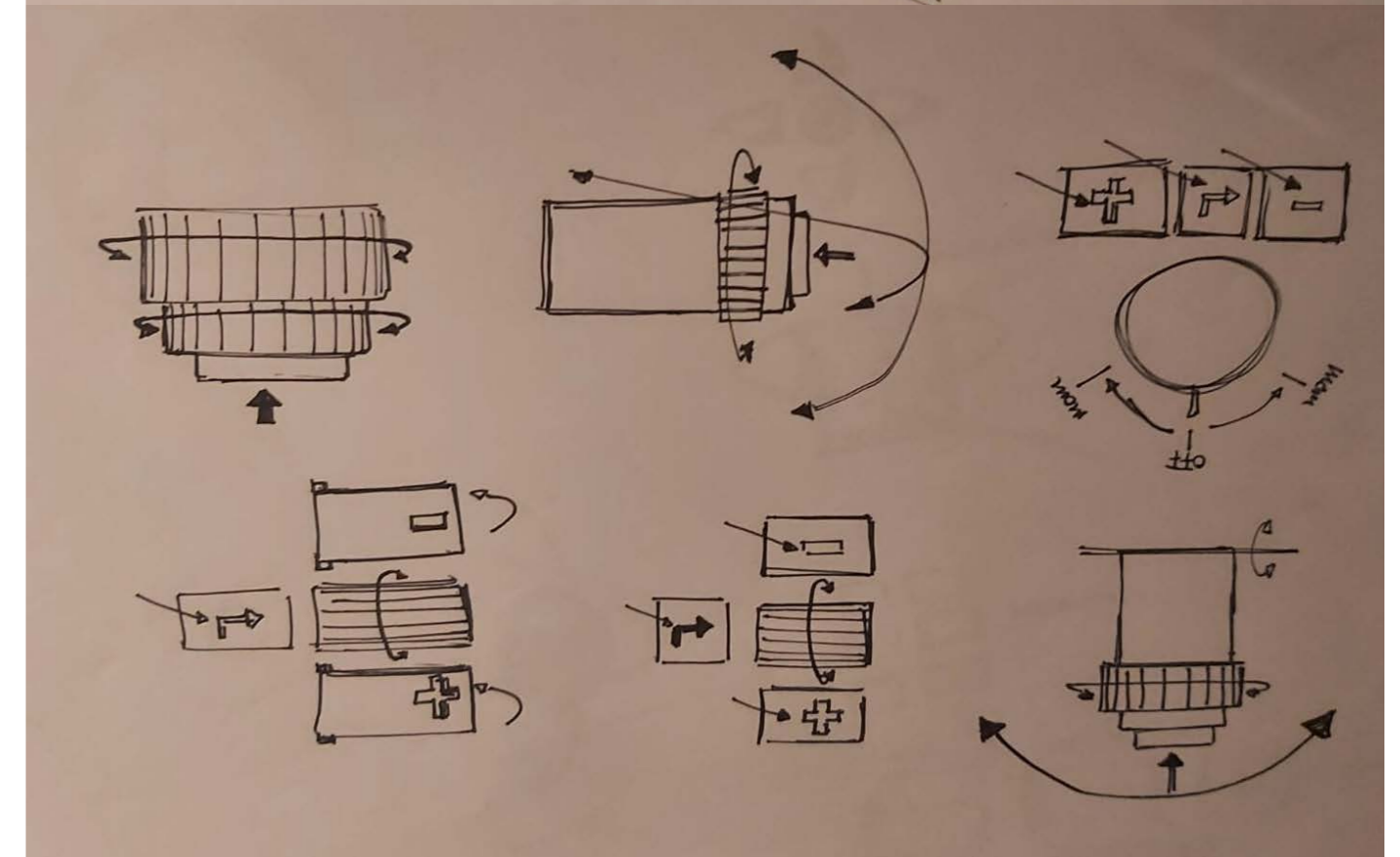


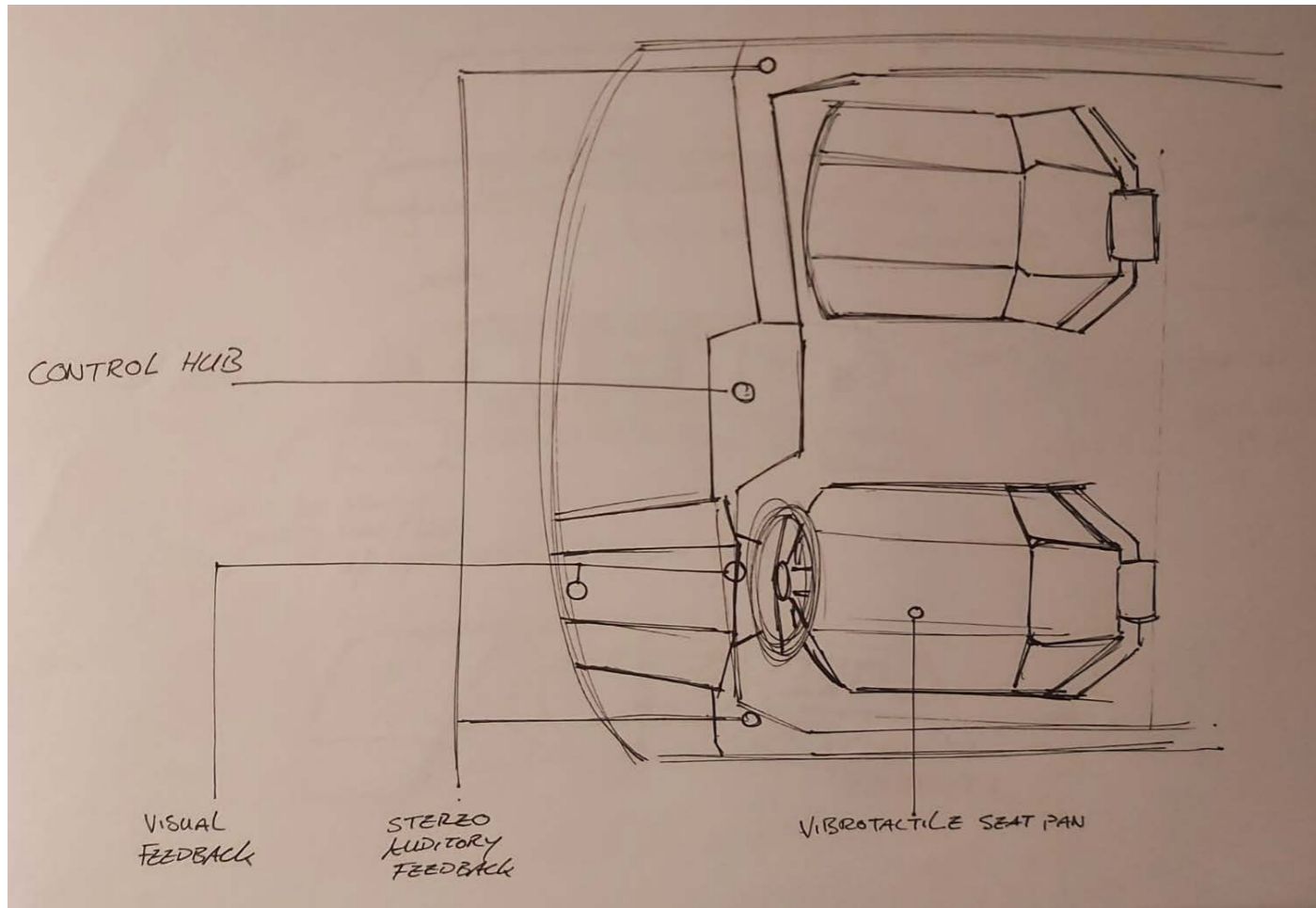
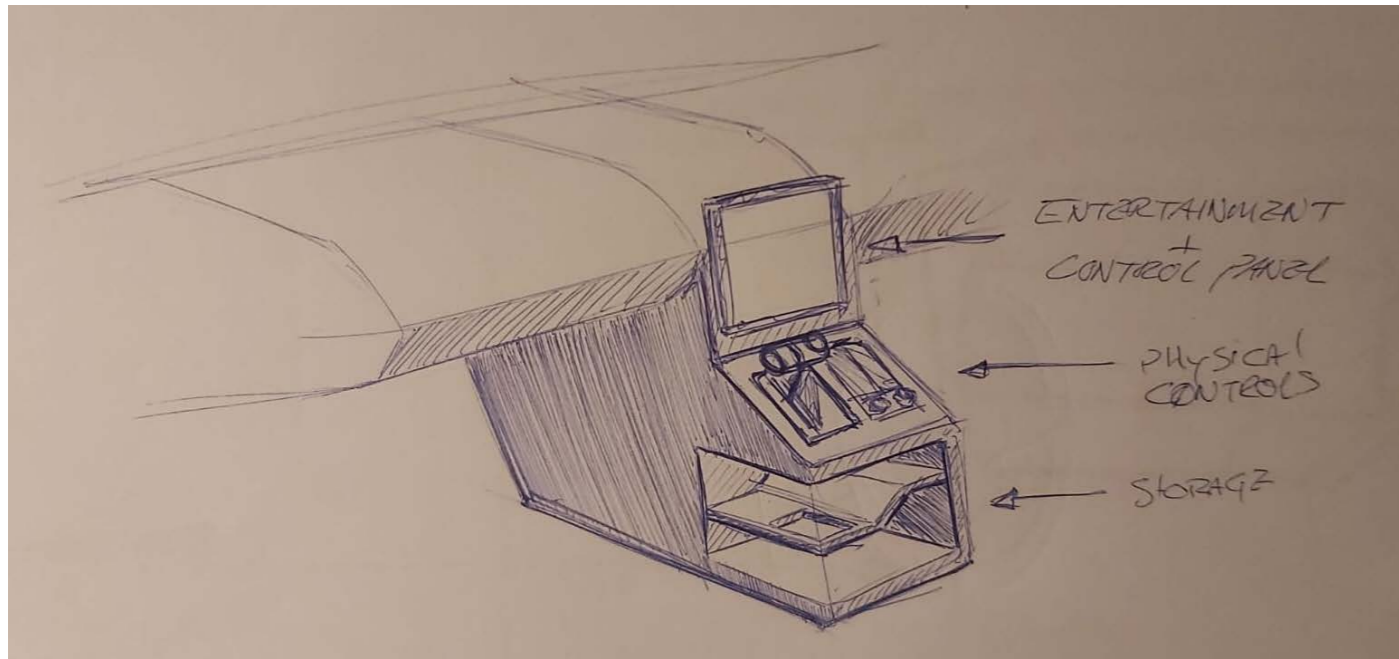
Ideation sketches (selection)



ASSISTED PACKAGE PRESET 2/3

MAXIMUM SPEED	50	2	70
ROAD/ROUTE COMPLEXITY	▲	1	▶ Below AVG
ON-ROAD AGENCY	NO oversteering	5	▶
IN VEHICLE ADJUSTMENTS	NO IN-VEHICLE LIGHTING	4	▶ with climate control
	REMAINING POINTS		E





Objective

To attain a wider perspective on possible solutions to the question of what the input device can look like. This opens up new possible insights into possible bottlenecks, memes, intuitive controls, pros and cons, and placement. This session might affirm current ideas and/or steer towards new ones. The main goal is to fuel my own ideation with ideas from others. This will allow for a wider spectrum of solutions that can be used in a morphological chart.

Agenda

<i>Agenda</i>	<i>Time:</i>	<i>Total time:</i>
1. Open	1 minutes	0.01 hr
2. Warming up	9 minutes	0.10 hr
3. Introduction	4 minutes	0.15 hr
4. How to's	30 minutes	0.45 hr
5. Ideation	35 minutes	1.20 hr
6. Discussion	10 minutes	1.30 hr
7. Close	1 minute	1.31 hr

Procedure

Because of COVID-19, in-room meetings are avoided to limit the spread of the virus. The solution is a Skype call with a decreased amount of participants (to maintain control). During the skype-call, the participants can send their drawings/text via Whatsapp to the Webwhatsapp on the laptop and the participants can receive drawings/text via Whatsapp. The participants have their drivers licence.

During the call, whilst the timer runs, I will too participate in the session. However, I will not share anything until the discussion as not to influence the participants. If important events happen, such as a critical comment/discussion or the timer runs out, it is noted and solved. This will not pause/stop the session.

Open: 1 min

Warming up:

- Explain the exercise 2 min
- Design your own UFO cockpit 5 min
- Explain what choices have been made and why (choose 2) 2 min

Introduction:

Building a device to select a mode of assistance when driving a personal vehicle. Scales from manual to assisted to automated. A driver is either conscious of the driving and the road (manual and assisted) or not (automated). We'll do a how-to session to explore this domain. 4 min

How-to's:

GOAL: Get a wide variety of options to use in a morphological chart

- 1. How to indicate a level/mode? 5 min
- 2. How to choose a level/mode? 5 min
- 3. How to demand action? (machine to human) 5 min
- 4. How to show a duration? (time left/to go) 5 min
- 5. How to bargain with a machine? 5 min
- (one minute to switch between each) 5 min

Ideation:

GOAL: Get interesting ideas / twists / products / controls

- Evaluate (share) how-to's 5 min
- Acquaint the participants with the main functions of the control: 4 min
 - Automation mode selection
 - Confirmation/Declination
 - Engage/Disengage
- Explain the analogy: BARMAN 5 min
- Merge how-to's to ideas:
 - Choose two a solution belonging to two different How-To's, create a concept with that. 10 min
 - Preferrably no storyboarding, but an actual control to interact with. 10 min
 - One minute to switch 1min
 - Repeat with different solutions (and how-to's) for a second concept. 10 min

Discussion:

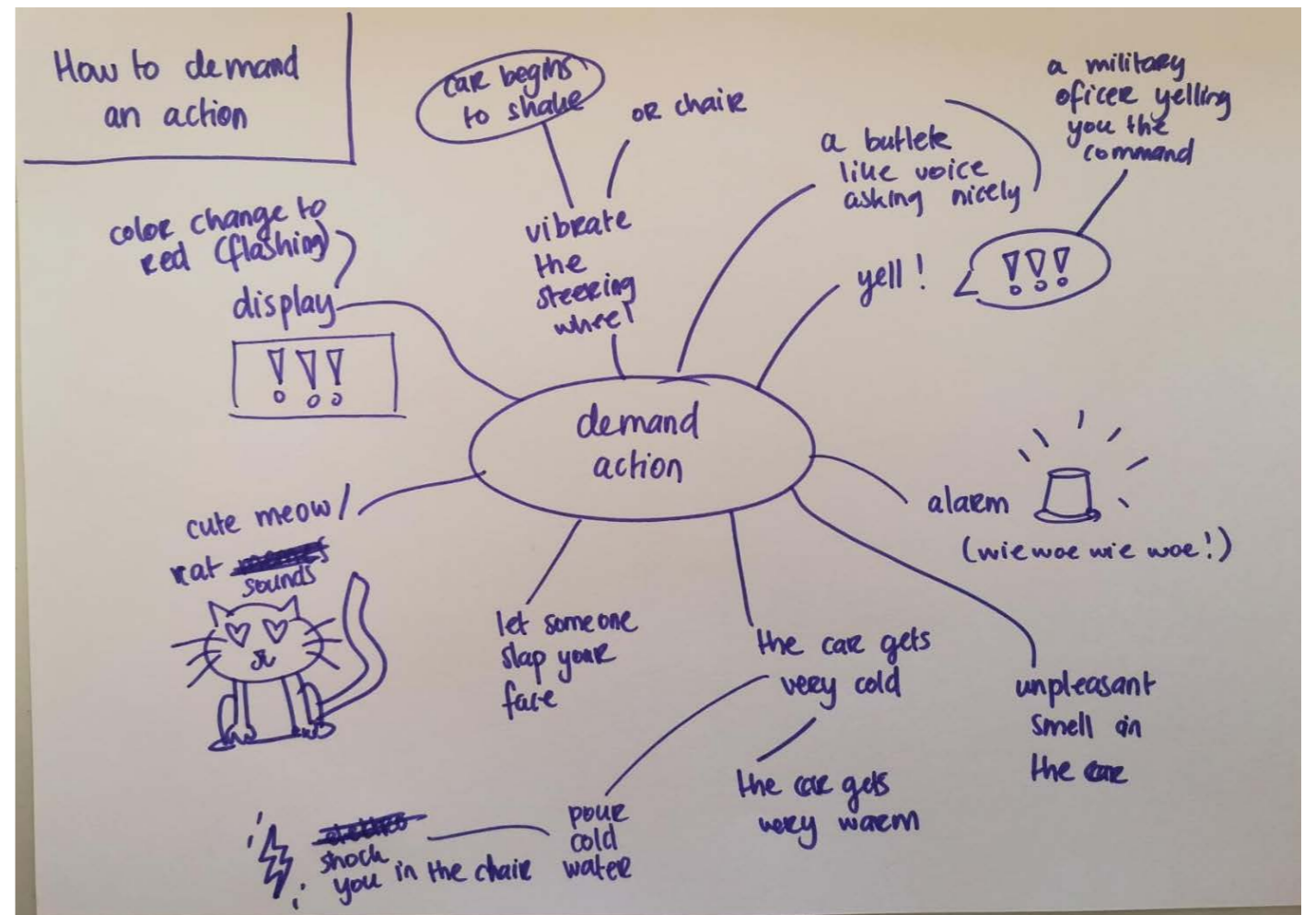
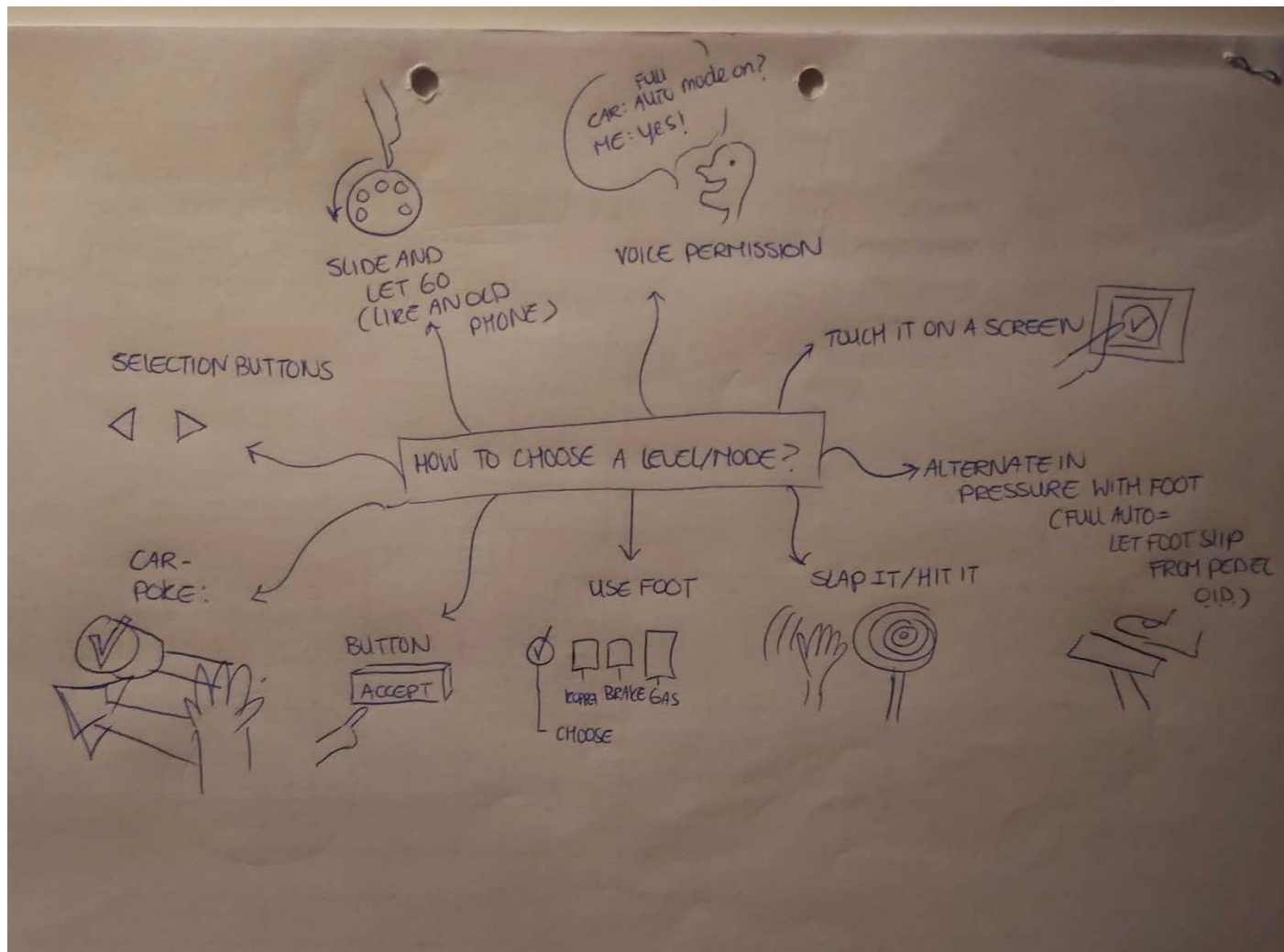
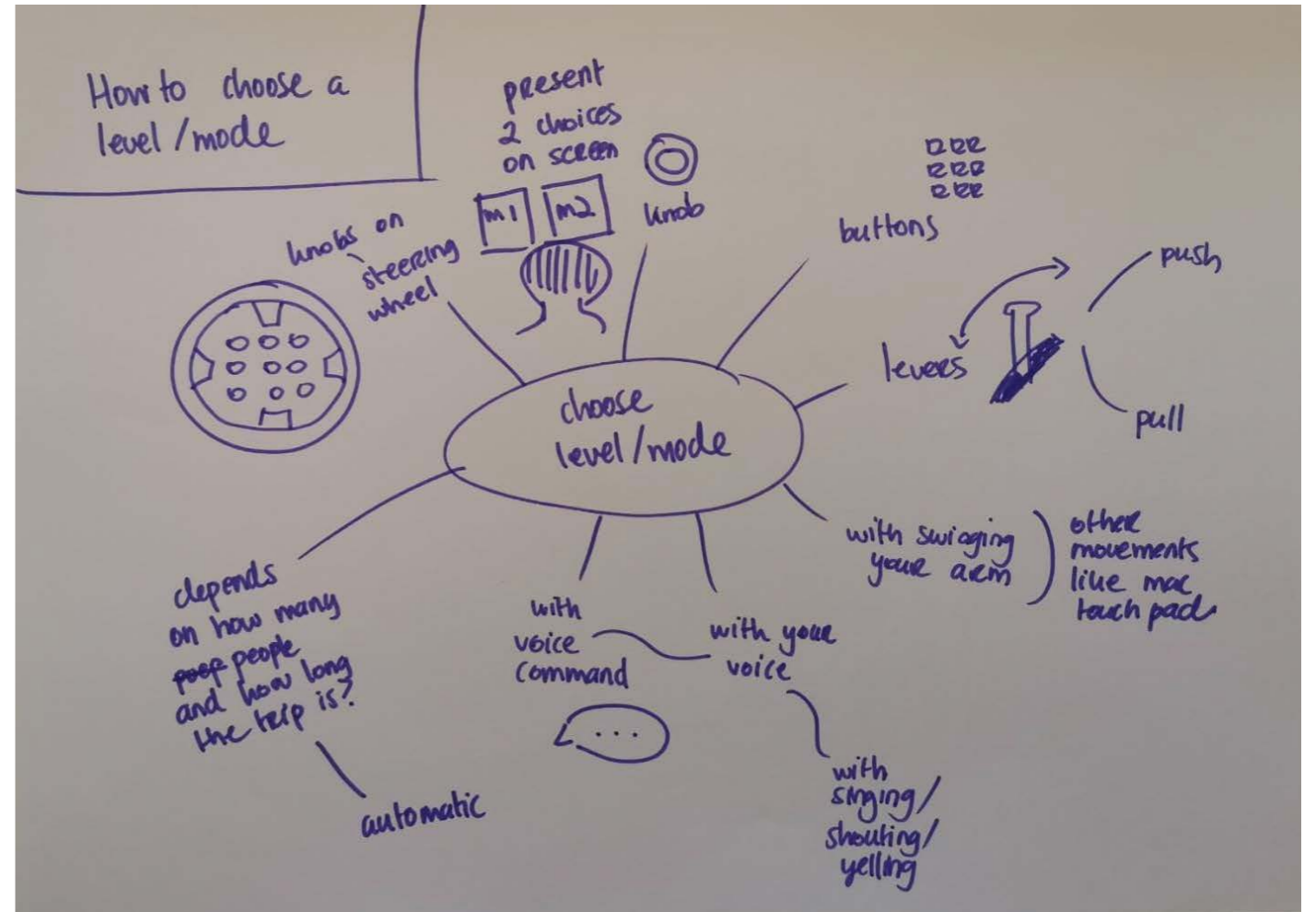
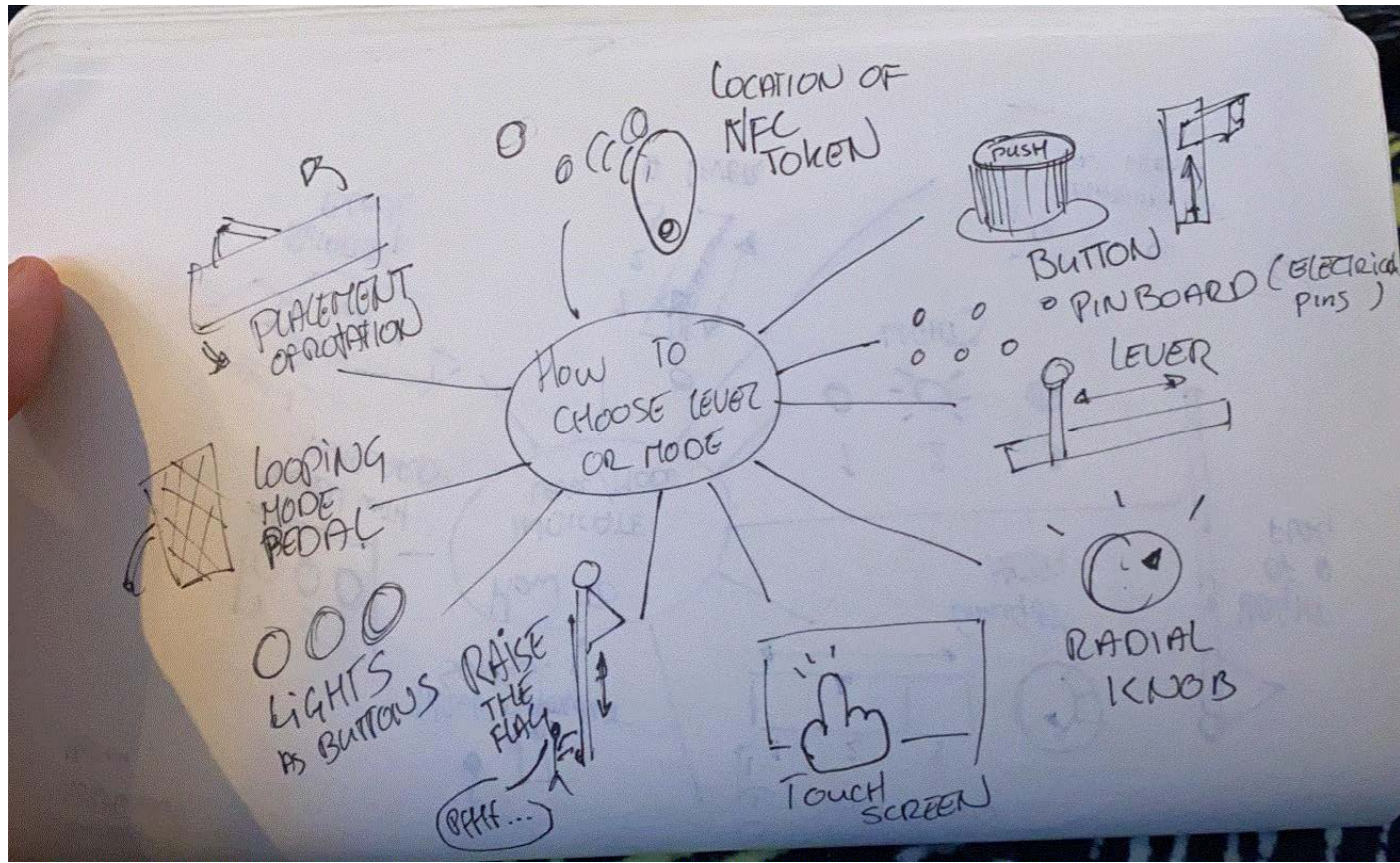
- Share the ideas that one has made; present the best 2. 10 min

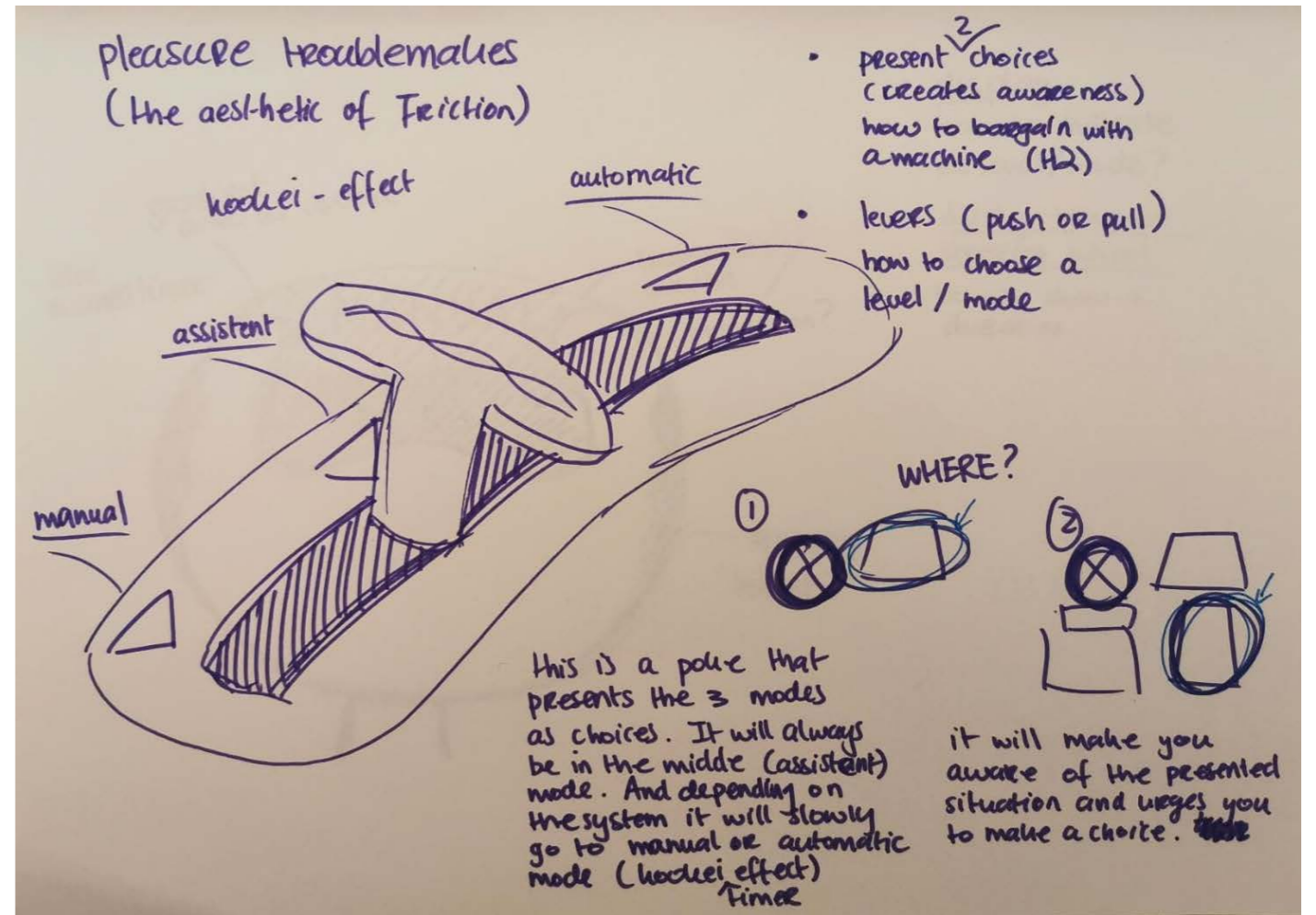
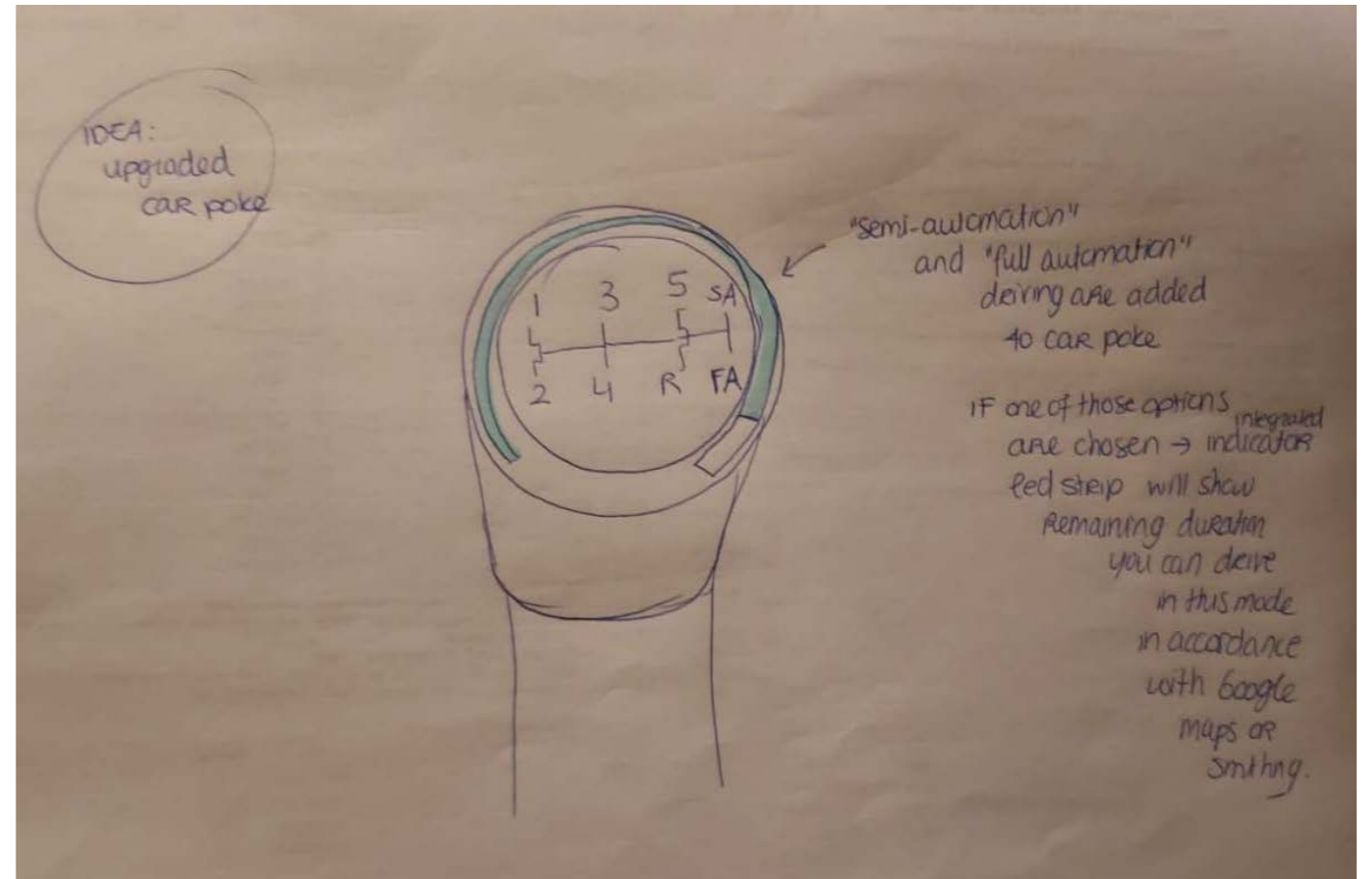
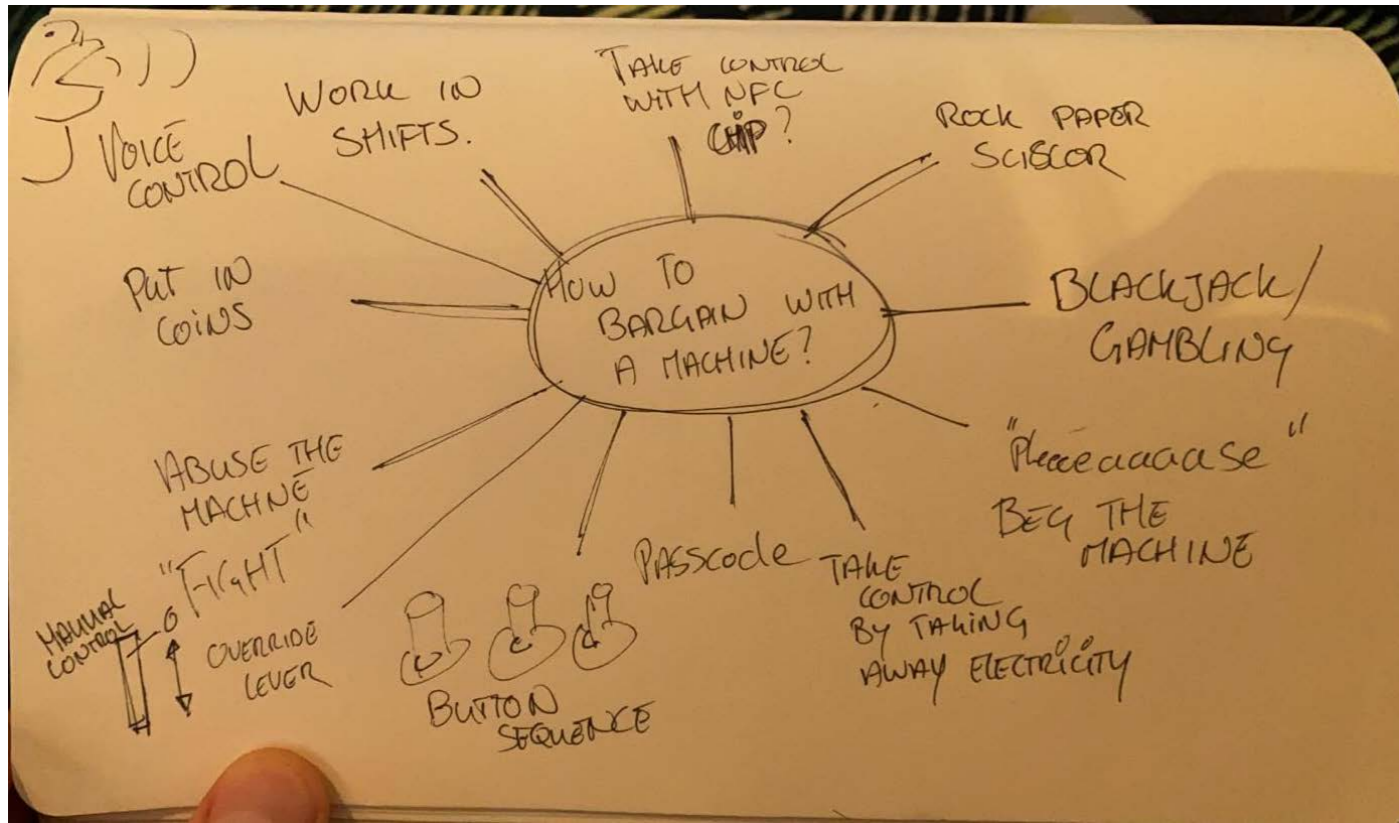
Close session

1 min

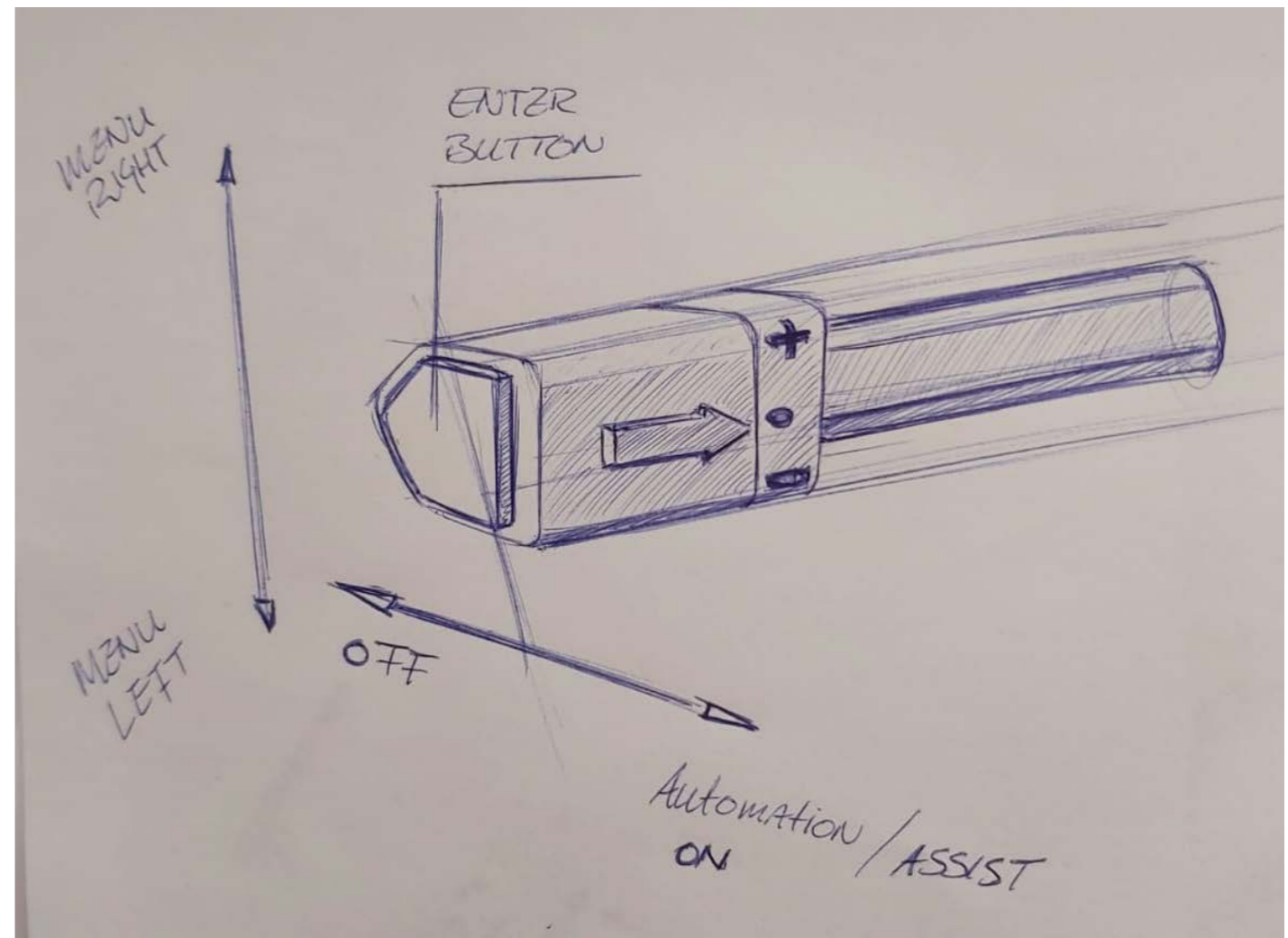
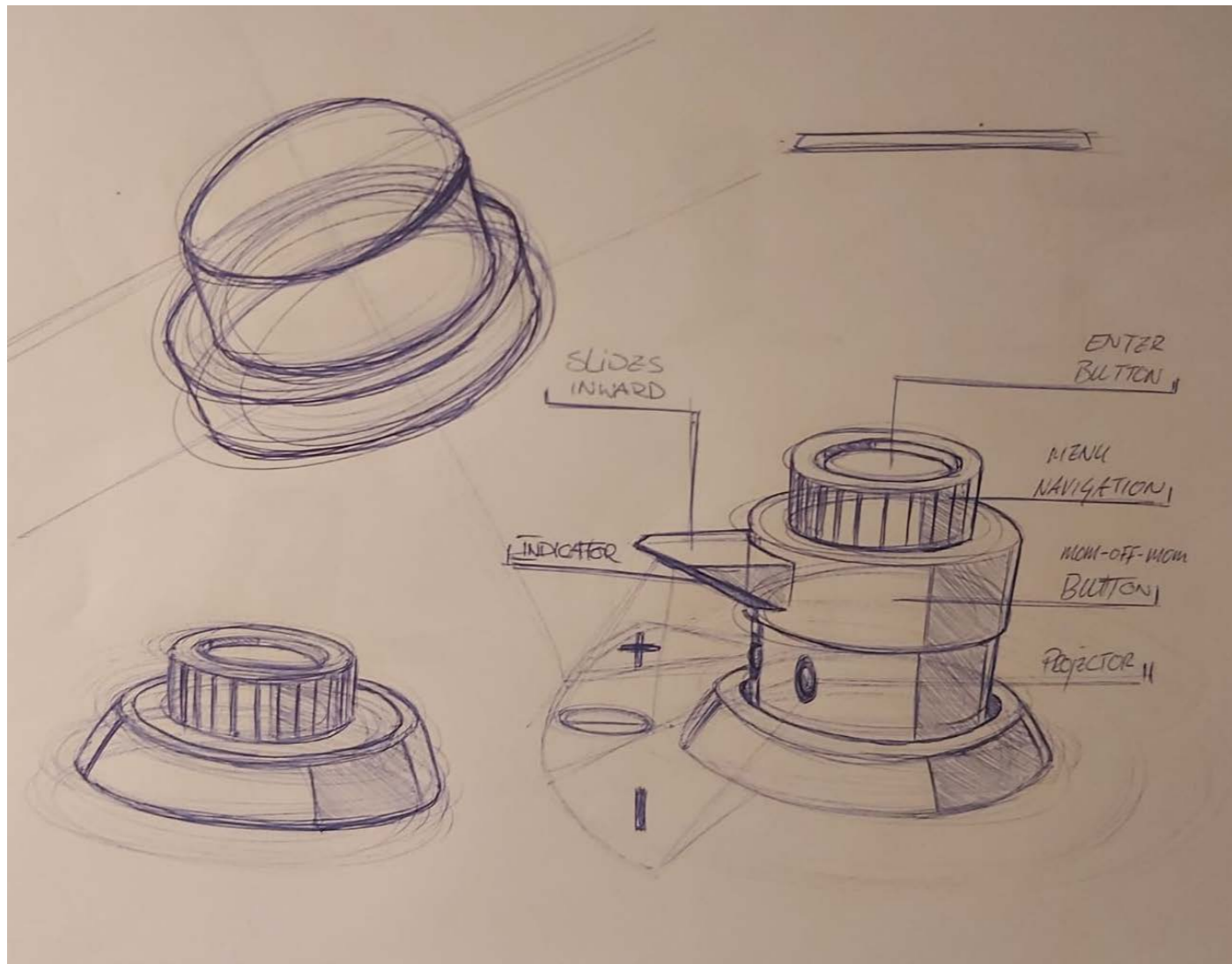
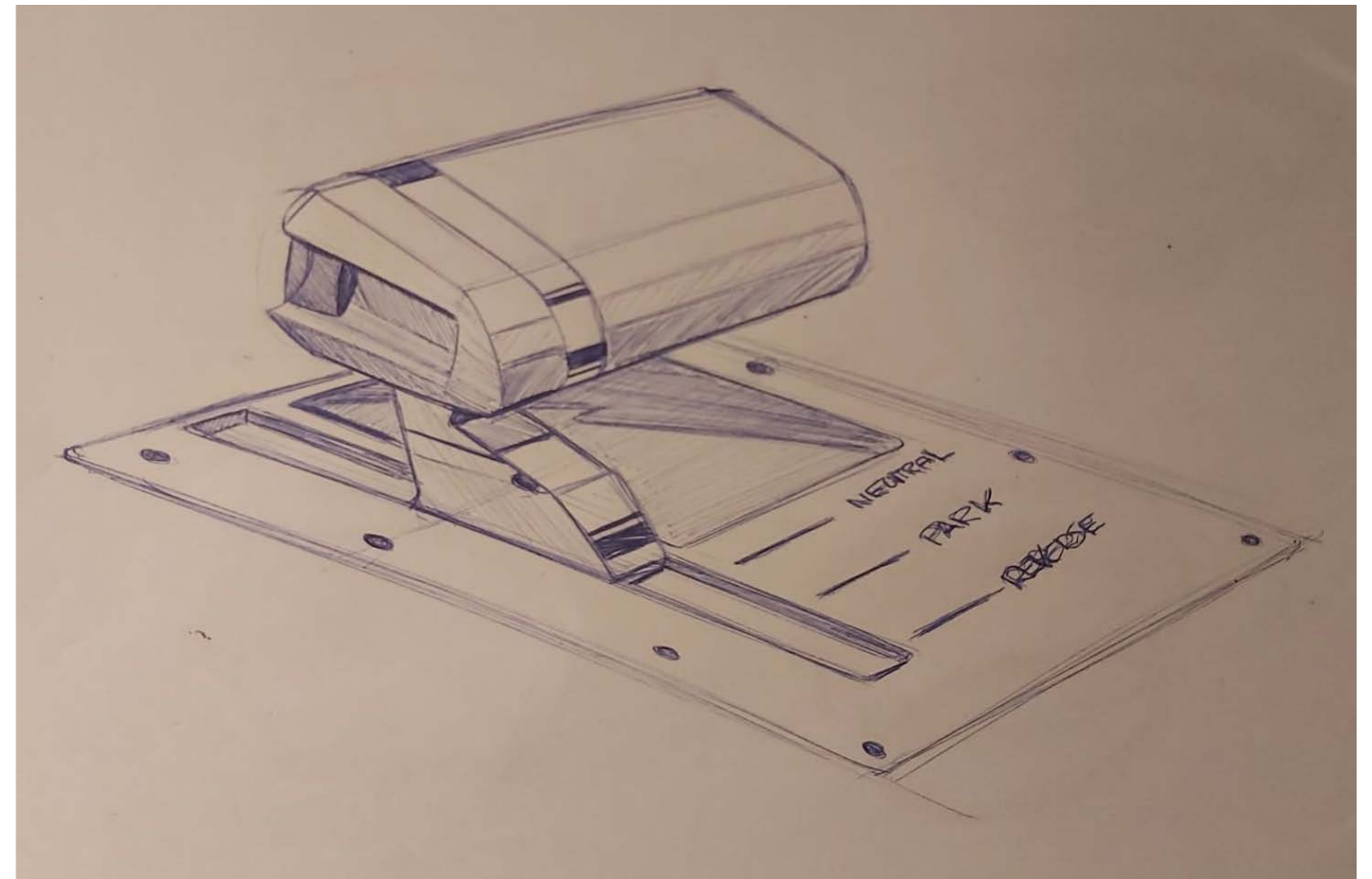
For those that are willing to hang out/stay, the discussion can go more in depth or wider, depending on the flow of the conversation.

Comments:





Concept sketches



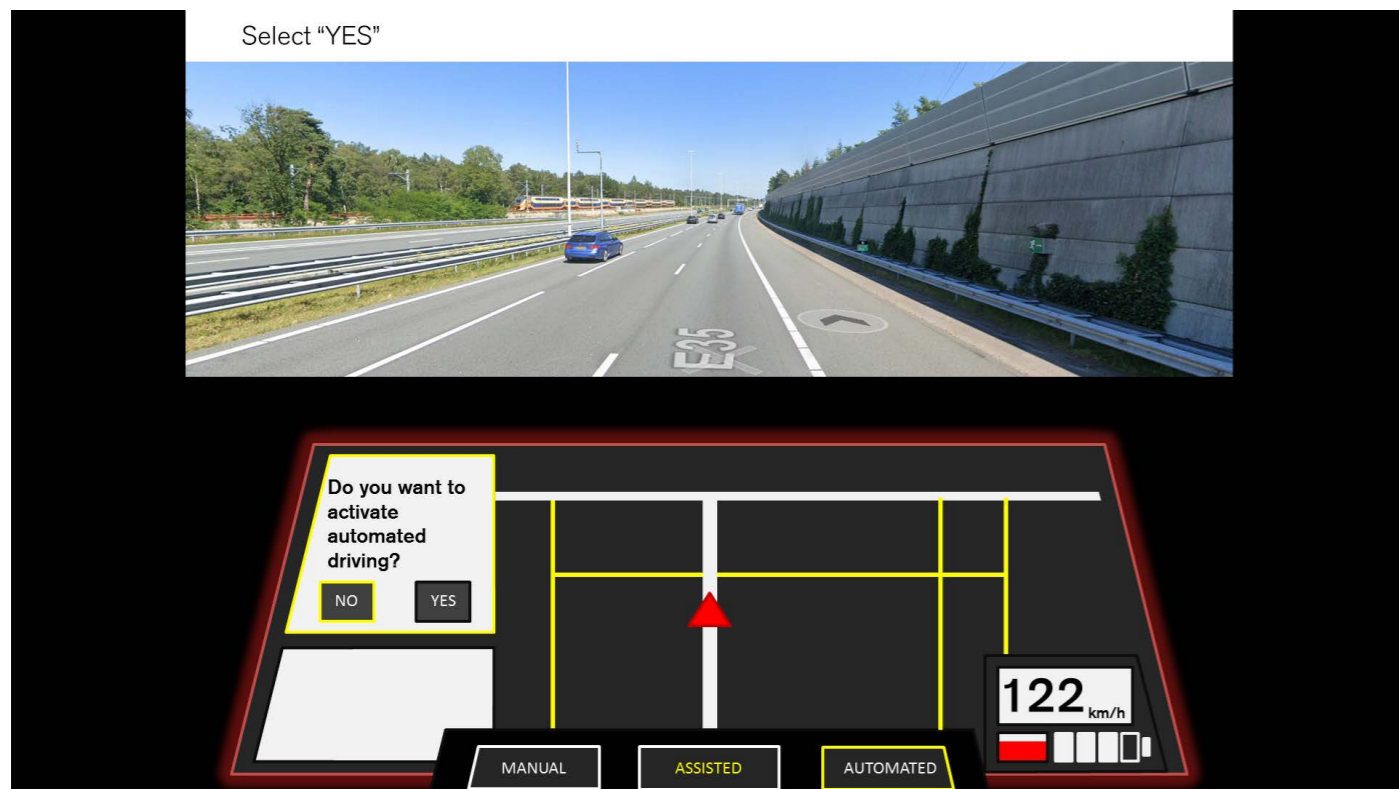
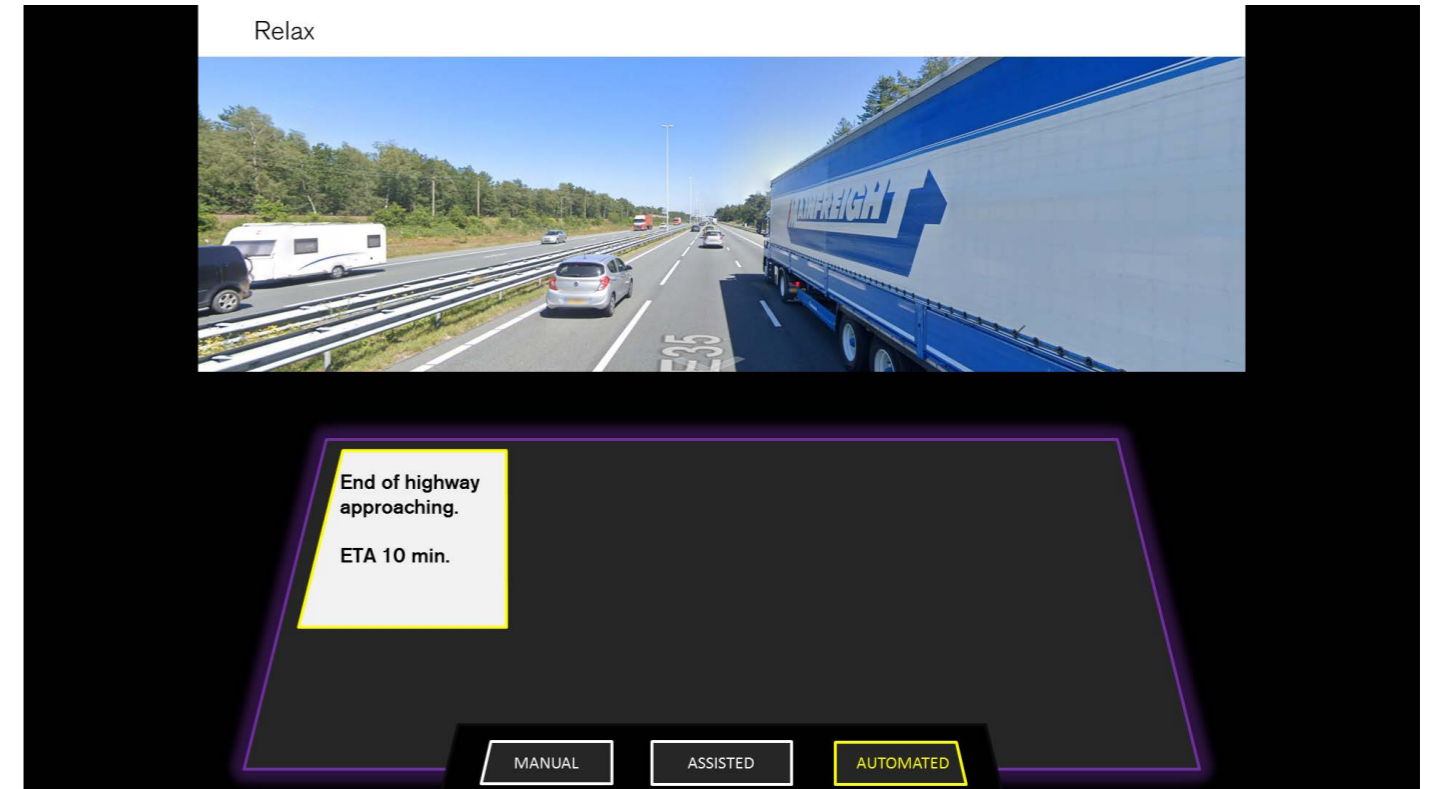
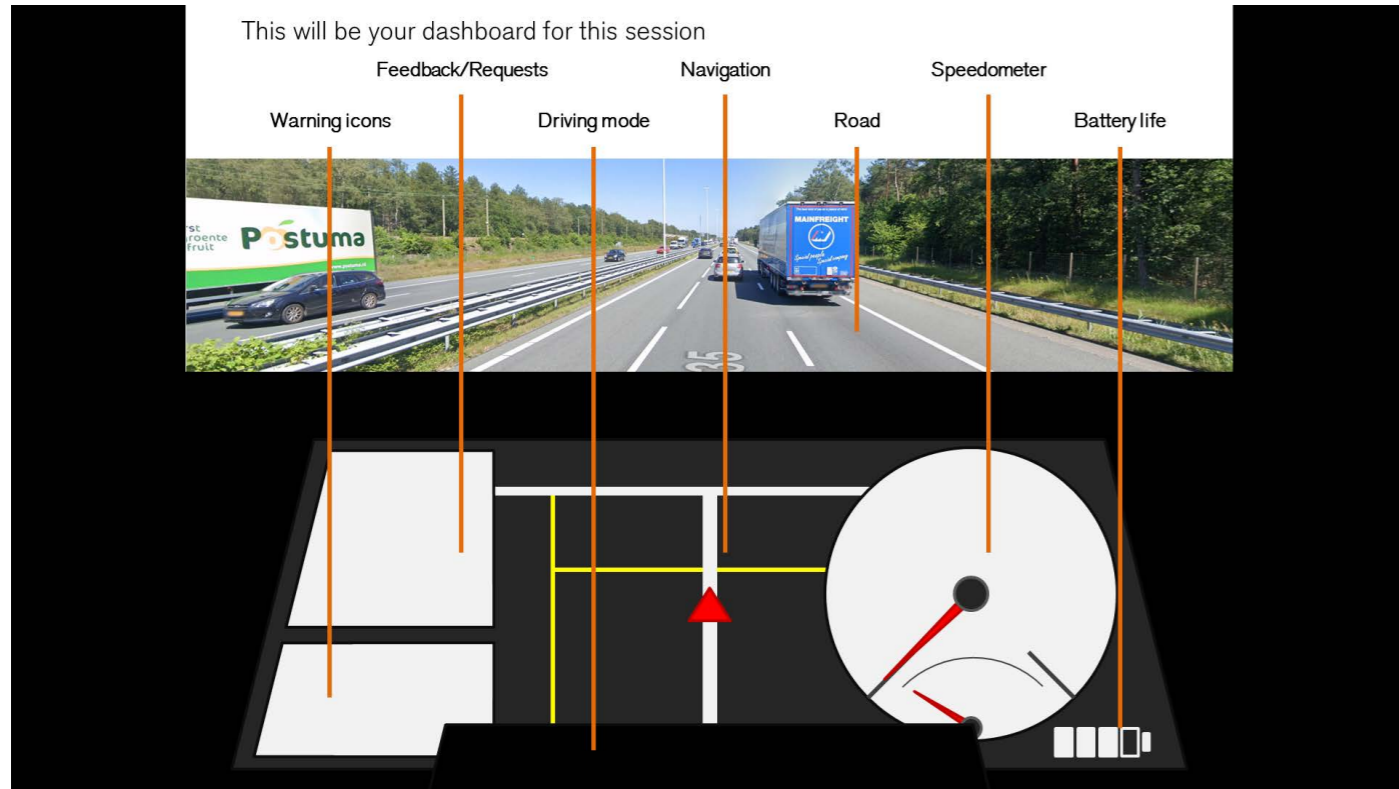


User Tests

Concept prototypes and user test setup



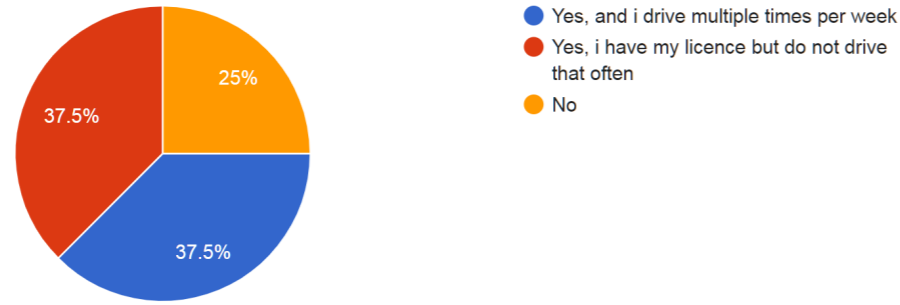
Scenario of user test (snippits)



Results

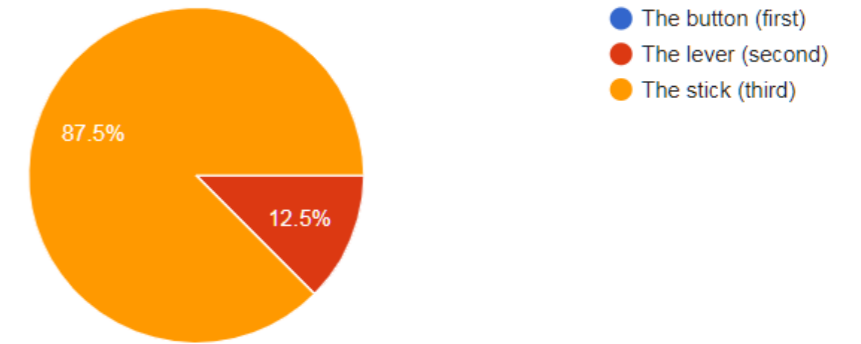
Do you have a drivers licence?

8 responses



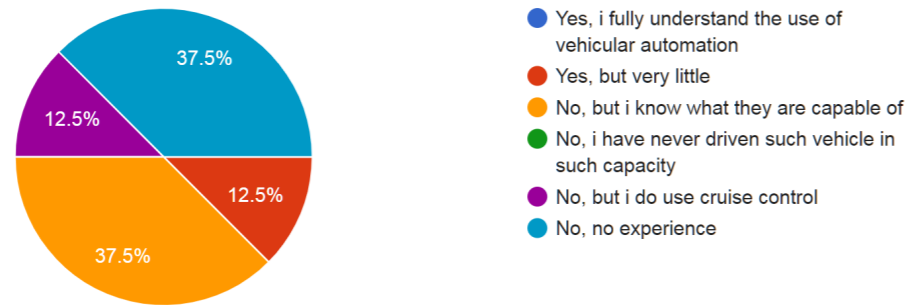
What was your favorite concept?

8 responses



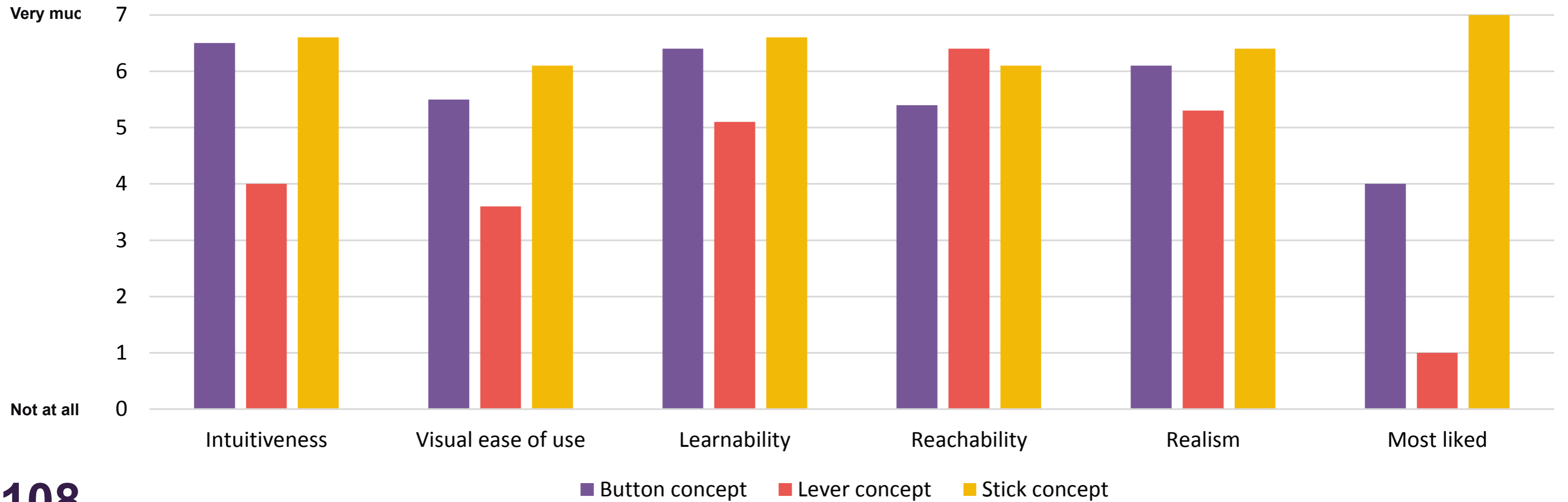
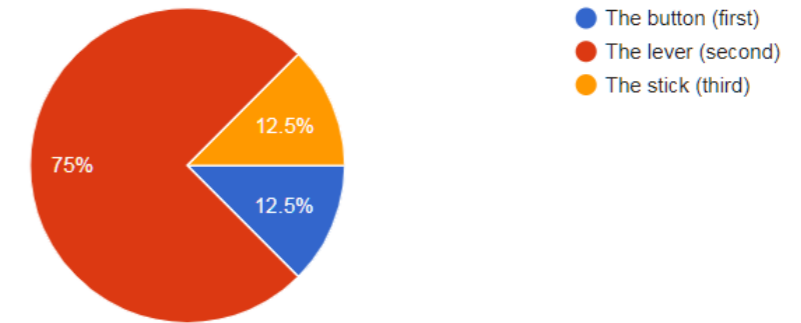
Do you have any experience with automated vehicles (such as Tesla Autopilot)

8 responses



What concept did you like the least? (which was the worst?)

8 responses



CTR Prototype testing - Graduation

This is the questionair to accompany the three conceptual interaction devices devolped during the graduation of T.Q. Mallon for the project "Design of Control Transfer Rituals for Automated Vehicles" in 2020.

Initial questions aim to gain insight in the knowledge and experience of the participants. The other questions relate to the prototypes to allow further development and selection.

Do you have a drivers licence?

- Yes, and i drive multiple times per week
- Yes, i have my licence but do not drive that often
- No
- Other: _____

Do you have any experience with automated vehicles (such as Tesla Autopilot)

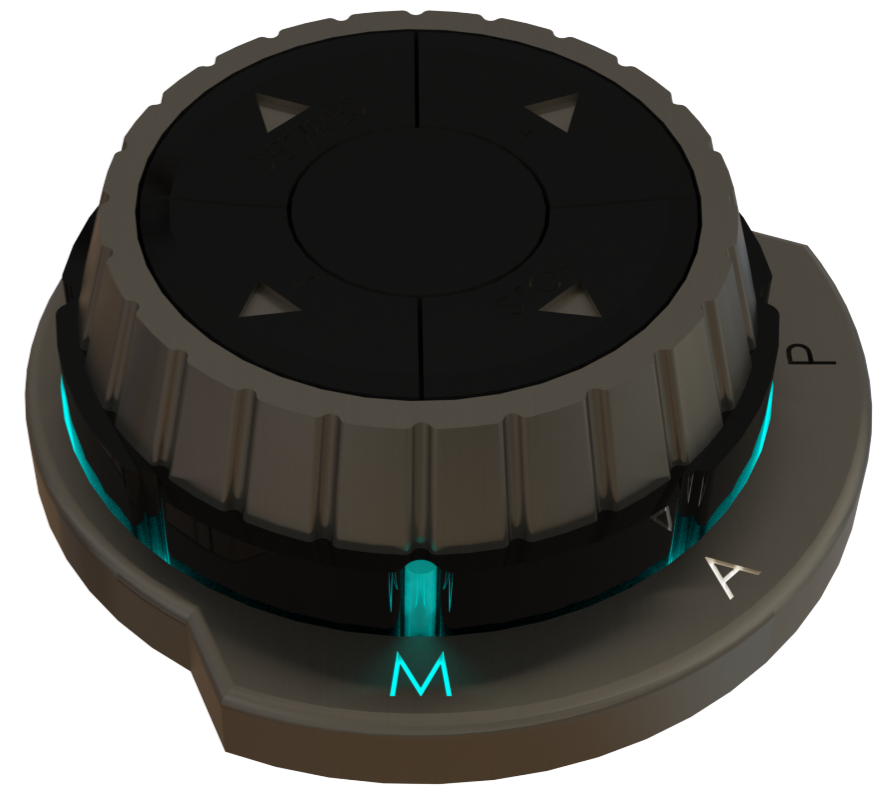
- Yes, i fully understand the use of vehicular automation
- Yes, but very little
- No, but i know what they are capable of
- No, i have never driven such vehicle in such capacity
- No, but i do use cruise control
- No, no experience

How good of a driver are you?

1 2 3 4 5 6 7

Horrible Excellent

Prototype 1: the button concept



I felt in control

1 2 3 4 5 6 7

Not at all Very much so

This concept looked very complex

1 2 3 4 5 6 7

Very simplistic Very complex

The amount of buttons / switches was overwhelming

1 2 3 4 5 6 7

Very unclear Very clear

The concept is intuitive to use

1 2 3 4 5 6 7

Very unintuitive Very intuitive

It will be easy to learn the functions of this concept

1 2 3 4 5 6 7

Not at all Very much so

It was clear when I had to act

1 2 3 4 5 6 7

Not at all Very much so

The scenario was clear to me

1 2 3 4 5 6 7

Very unclear Very clear

The feedback informed me why the events in the scenario happened

1 2 3 4 5 6 7

Very unclear Very clear

The control was easy to reach

1 2 3 4 5 6 7

Not at all Very much so

The interactions with the concept were familiar

1 2 3 4 5 6 7

Not at all Very much so

Do you think this form of interaction is realistic?

1 2 3 4 5 6 7

Not at all Very much so

Do you think this form of input device is realistic?

1 2 3 4 5 6 7

Not at all Very much so

Do you have any comments / recommendations relating to the experience?

wanneer gevraagd wordt om alertheid is het intuïtiever om te vragen naar een actie (zoals scrollen naar het antwoord om door te mogen rijden) zo test de auto meteen de alertheid van de bestuurder. Meer dan een ja/nee vraag wordt lastig te beantwoorden.

Prototype 2: the lever concept



I felt in control

1 2 3 4 5 6 7

Not at all Very much so

This concept looked very complex

1 2 3 4 5 6 7

Very simplistic Very complex

The amount of buttons / switches was overwhelming

1 2 3 4 5 6 7

Very unclear Very clear

The concept is intuitive to use

1 2 3 4 5 6 7

Very unintuitive Very intuitive

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Not at all Very much so

Do you think this form of input device is realistic?

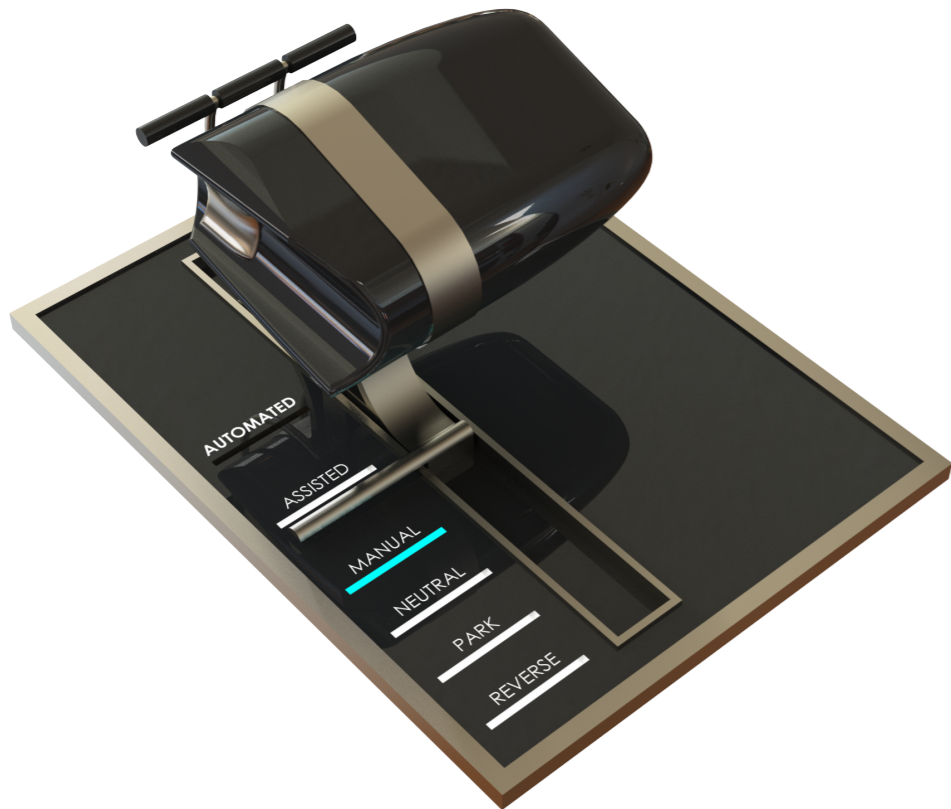
1 2 3 4 5 6 7

Not at all Very much so

Do you have any comments / recommendations relating to the experience?

de lever is lastiger te bereiken wanneer je niet je handen aan het stuur hebt, zoals in de pilot modus.

Prototype 3: the stick concept



I felt in control

1 2 3 4 5 6 7

Not at all Very much so

This concept looked very complex

1 2 3 4 5 6 7

Very simplistic Very complex

The amount of buttons / switches was overwhelming

1 2 3 4 5 6 7

Very unclear Very clear

The concept is intuitive to use

1 2 3 4 5 6 7

Very unintuitive Very intuitive

It will be easy to learn the functions of this concept

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It was clear when I had to act

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Not at all Very much so

The scenario was clear to me

1 2 3 4 5 6 7

Very unclear Very clear

The feedback informed me why the events in the scenario happened

1 2 3 4 5 6 7

Very unclear Very clear

The control was easy to reach

1 2 3 4 5 6 7

Not at all Very much so

The interactions with the concept were familiar

1 2 3 4 5 6 7

Not at all Very much so

Do you think this form of interaction is realistic?

1 2 3 4 5 6 7

Not at all Very much so

Do you think this form of input device is realistic?

1 2 3 4 5 6 7

Not at all Very much so

Do you have any comments / recommendations relating to the experience?

.....

Wrap-up

What was your favorite concept?

- The button (first)
- The lever (second)
- The stick (third)

Can you elaborate why?

zowel button als stick zijn erg intuïtief, de stick voelt echter iets natuurlijker met de technologie die er al is. de knop voelt meer als een menuinput en vraagt dus ook wat meer aandacht naar het scherm ipv de weg.

.....

What concept did you like the least? (which was the worst?)

- The button (first)
- The lever (second)
- The stick (third)

Can you elaborate why?

te complex en anders dan gebruikelijke functies.

.....

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- Yes, i have my licence but do not drive that often
- No
- Other:

Do you have any experience with automated vehicles (such as Tesla Autopilot)

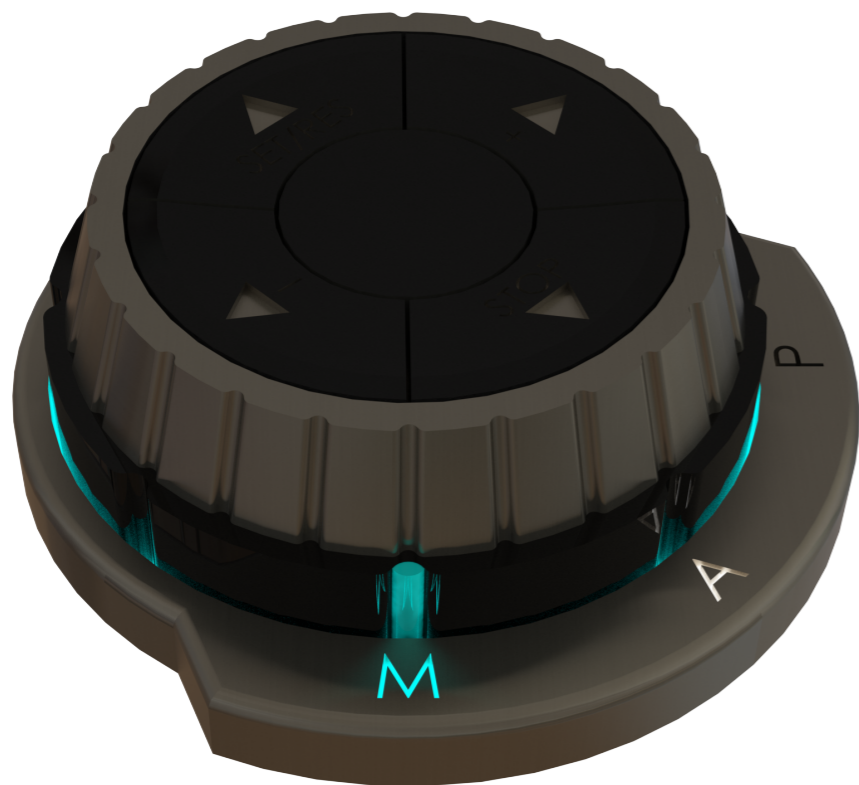
- Yes, i fully understand the use of vehicular automation
- Yes, but very little
- No, but i know what they are capable of
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- No, but i do use cruise control
- No, no experience

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The control was easy to reach

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Not at all Very much so

The interactions with the concept were familiar

1 2 3 4 5 6 7

Not at all Very much so

Do you think this form of interaction is realistic?

1 2 3 4 5 6 7

Not at all Very much so

Do you think this form of input device is realistic?

1 2 3 4 5 6 7

Not at all Very much so

Do you have any comments / recommendations relating to the experience?

Moet het eerst een keer samen met iemand hebben gedaan om het goed door te hebben, en mogelijk ook eerst een paar keer oefenen met iemand voordat het zelfstandig mogelijk is

Prototype 2: the lever concept



I felt in control

1 2 3 4 5 6 7

Not at all Very much so

This concept looked very complex

1 2 3 4 5 6 7

Very simplistic Very complex

The amount of buttons / switches was overwhelming

1 2 3 4 5 6 7

Very unclear Very clear

The concept is intuitive to use

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Not at all Very much so

Do you think this form of interaction is realistic?

1 2 3 4 5 6 7

Not at all Very much so

Do you think this form of input device is realistic?

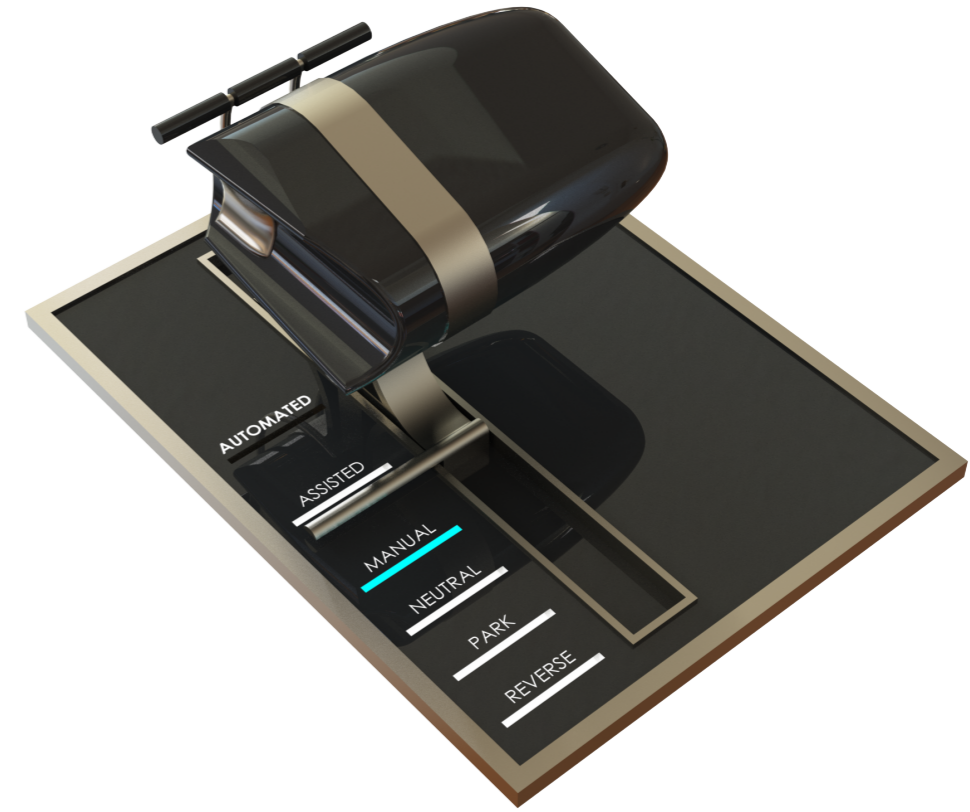
1 2 3 4 5 6 7

Not at all Very much so

Do you have any comments / recommendations relating to the experience?

Selectie links/rechts van het menu niet duidelijk te zien op de lever

Prototype 3: the stick concept



I felt in control

1 2 3 4 5 6 7

Not at all Very much so

This concept looked very complex

1 2 3 4 5 6 7

Very simplistic Very complex

The amount of buttons / switches was overwhelming

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Do you think this form of interaction is realistic?

1 2 3 4 5 6 7

Not at all Very much so

Do you think this form of input device is realistic?

1 2 3 4 5 6 7

Not at all Very much so

Do you have any comments / recommendations relating to the experience?

It feels a bit counterintuitive that the car can work against you when selecting an option. It should be made very clear to the driver that this is occurring, and it should be a possibility to go against this.

Wrap-up

What was your favorite concept?

- The button (first)
- The lever (second)
- The stick (third)

Can you elaborate why?

Het was erg handig dat het in de buurt van het stuur zat, zeker om te wisselen tijdens het rijden.

What concept did you like the least? (which was the worst?)

- The button (first)
- The lever (second)
- The stick (third)

Can you elaborate why?

Het voelde niet alsof ik niet voldoende controle had over de auto aangezien hij zelf het niveau van controle kon aanpassen

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CTR Prototype testing - Graduation

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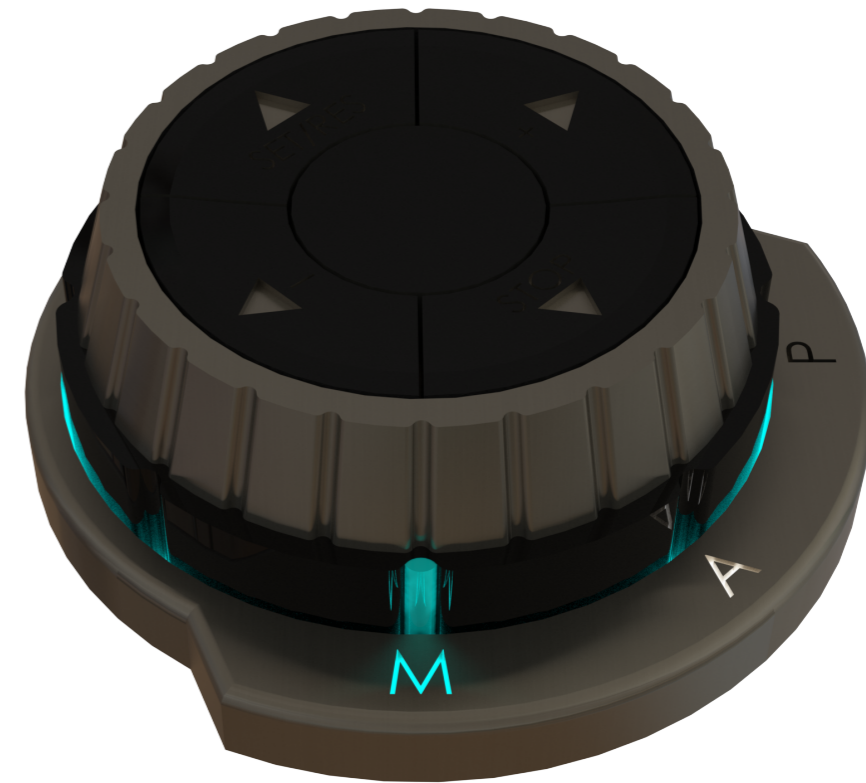
Do you have any experience with automated vehicles (such as Tesla Autopilot)

- Yes, i fully understand the use of vehicular automation
- Yes, but very little
- No, but i know what they are capable of
- No, i have never driven such vehicle in such capacity
- No, but i do use cruise control
- No, no experience

How good of a driver are you?

- 1 2 3 4 5 6 7
- Horrible Excellent

Prototype 1: the button concept



I felt in control

- 1 2 3 4 5 6 7
- Not at all Very much so

This concept looked very complex

1 2 3 4 5 6 7

Very simplistic Very complex

The amount of buttons / switches was overwhelming

1 2 3 4 5 6 7

Very unclear Very clear

The concept is intuitive to use

1 2 3 4 5 6 7

Very unintuitive Very intuitive

It will be easy to learn the functions of this concept

1 2 3 4 5 6 7

Not at all Very much so

It was clear when I had to act

1 2 3 4 5 6 7

Not at all Very much so

The scenario was clear to me

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Very unclear Very clear

The feedback informed me why the events in the scenario happened

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The control was easy to reach

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Not at all Very much so

The interactions with the concept were familiar

1 2 3 4 5 6 7

Not at all Very much so

Do you think this form of interaction is realistic?

1 2 3 4 5 6 7

Not at all Very much so

Do you think this form of input device is realistic?

1 2 3 4 5 6 7

Not at all Very much so

Do you have any comments / recommendations relating to the experience?

The button used felt similar to an entertainment media button, for example from Audi.

Prototype 2: the lever concept



I felt in control

1 2 3 4 5 6 7

Not at all Very much so

This concept looked very complex

1 2 3 4 5 6 7

Very simplistic Very complex

The amount of buttons / switches was overwhelming

1 2 3 4 5 6 7

Very unclear Very clear

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Do you think this form of interaction is realistic?

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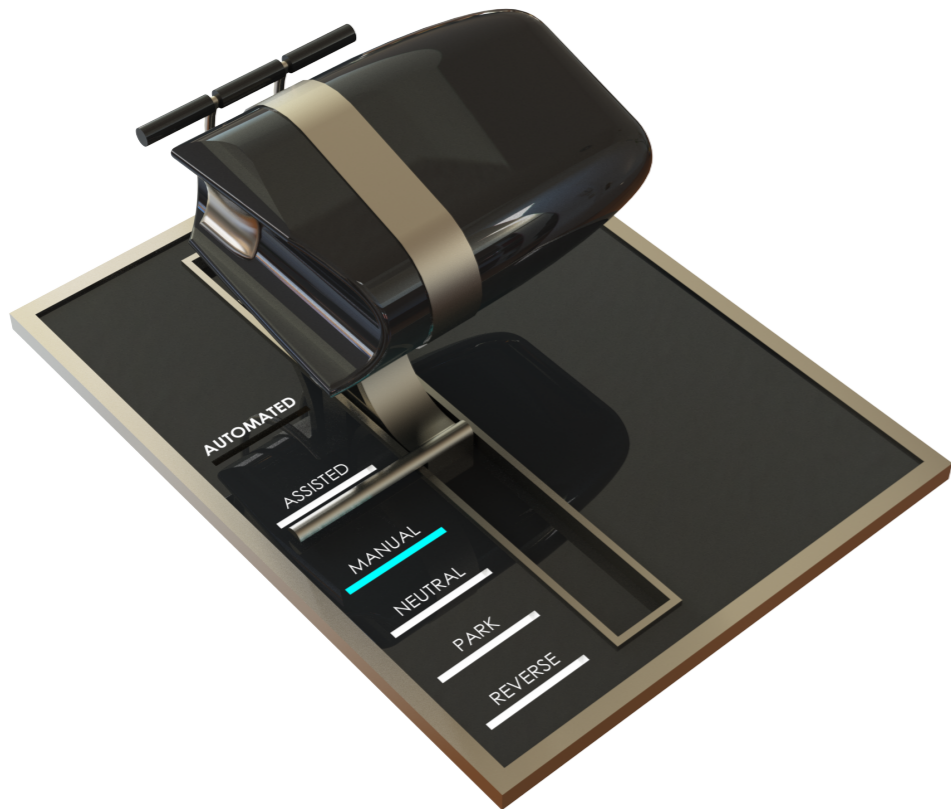
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Not at all Very much so

Do you have any comments / recommendations relating to the experience?

The use of the stalk is easier in terms of reach I feel, but the amount of different button/actions is too convoluted.

Prototype 3: the stick concept



I felt in control

1 2 3 4 5 6 7

Not at all Very much so

This concept looked very complex

1 2 3 4 5 6 7

Very simplistic Very complex

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1 2 3 4 5 6 7

Not at all Very much so

Do you think this form of input device is realistic?

1 2 3 4 5 6 7

Not at all Very much so

Do you have any comments / recommendations relating to the experience?

Wrap-up

What was your favorite concept?

- The button (first)
- The lever (second)
- The stick (third)

Can you elaborate why?

Seems the most intuitive, even more than the button because the stick omits all the cluster stuff.

What concept did you like the least? (which was the worst?)

- The button (first)
- The lever (second)
- The stick (third)

Can you elaborate why?

Too many functions on different buttons/controls.

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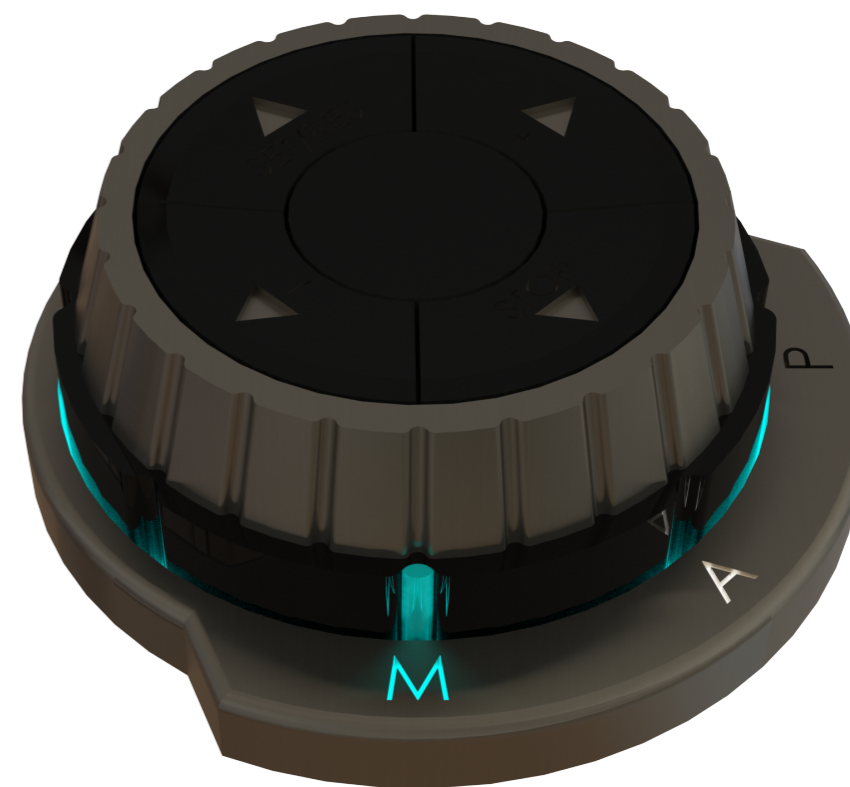
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1 2 3 4 5 6 7

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Do you think this form of input device is realistic?

1 2 3 4 5 6 7

Not at all Very much so

Do you have any comments / recommendations relating to the experience?

het lijkt op het verstellen van de radio,
 ik keek wel naar de knop en lette niet meer op de weg.
 en ik voelde bij het langs de kant zetten van de auto autominiteit.

Prototype 2: the lever concept



I felt in control

1 2 3 4 5 6 7

Not at all Very much so

This concept looked very complex

1 2 3 4 5 6 7

Very simplistic Very complex

The amount of buttons / switches was overwhelming

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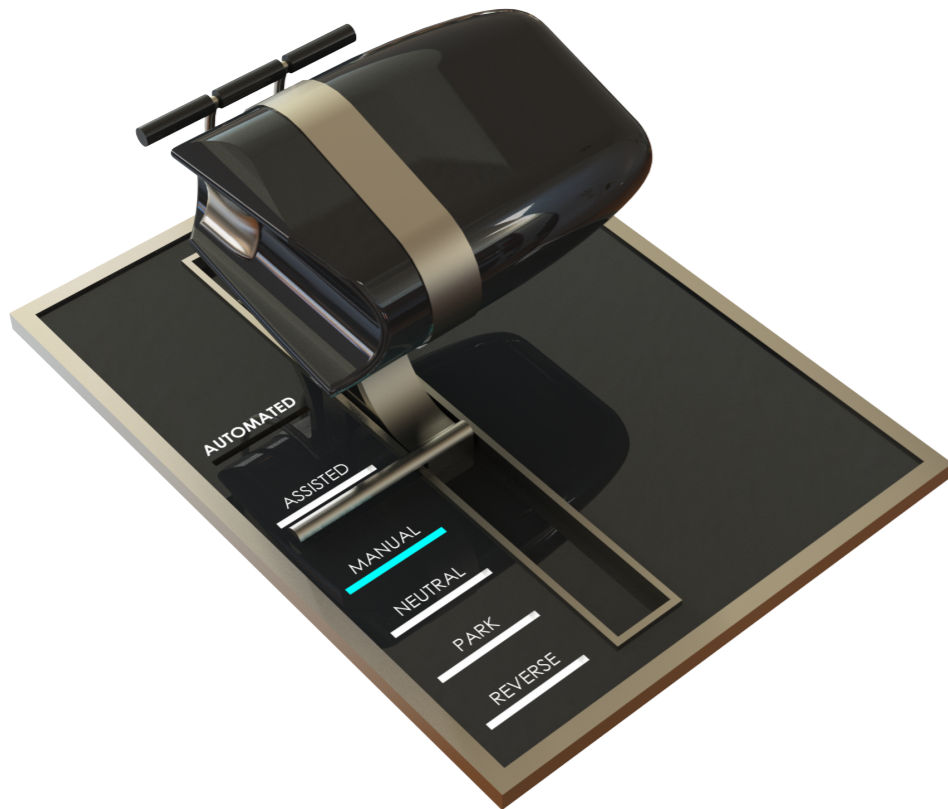
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Do you have any comments / recommendations relating to the experience?

links rechts met controller is niet omhoog omhoog, kwam in mijn hoofd niet overeen.

Prototype 3: the stick concept



I felt in control

1 2 3 4 5 6 7

Not at all Very much so

This concept looked very complex

1 2 3 4 5 6 7

Very simplistic Very complex

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Do you think this form of input device is realistic?

1 2 3 4 5 6 7

Not at all Very much so

Do you have any comments / recommendations relating to the experience?

ik zie waar de koppeling hoort maar nu niet bereikbaar.

Wrap-up

What was your favorite concept?

- The button (first)
- The lever (second)
- The stick (third)

Can you elaborate why?

minste interactie, transitie is geleidelijker waardoor ik meer autonomie ervaar.

What concept did you like the least? (which was the worst?)

- The button (first)
- The lever (second)
- The stick (third)

Can you elaborate why?

ik rij geen auto dus de tweede zie ik me zelf fouten maken en andere ook, want mijn vader heeft wel eens dat het knipperlicht aangezet terwijl die. en daarnaast heb je aan de twee kanten de zelfde besturing kan ook verwarrend zijn.

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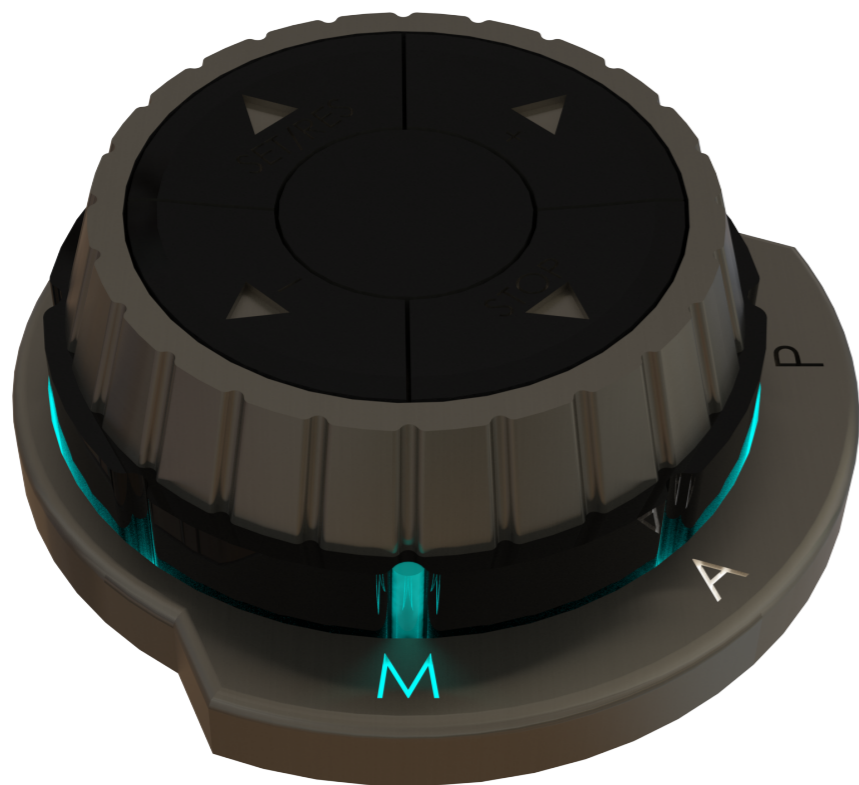
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How good of a driver are you?

1 2 3 4 5 6 7

Horrible 1 2 3 4 5 6 7 Excellent

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Do you think this form of interaction is realistic?

1 2 3 4 5 6 7

Not at all Very much so

Do you think this form of input device is realistic?

1 2 3 4 5 6 7

Not at all Very much so

Do you have any comments / recommendations relating to the experience?

Shift the control 5 cm to the left,

Prototype 2: the lever concept



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Very simplistic Very complex

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Not at all Very much so

Do you have any comments / recommendations relating to the experience?

hardest to understand, scrolling in menus, easy to understand how to change setting with instruction.
easy to use because attached to the steering wheel

Prototype 3: the stick concept



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Do you think this form of input device is realistic?

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Not at all Very much so

Do you have any comments / recommendations relating to the experience?

most similar to actual driving gear shift in normal car. less menu's also made it less distracting.

Wrap-up

What was your favorite concept?

- The button (first)
- The lever (second)
- The stick (third)

Can you elaborate why?

most like actual driving, less menu's. second concept required explanation in order to be able to operate, although it was the easiest to reach.

What concept did you like the least? (which was the worst?)

- The button (first)
- The lever (second)
- The stick (third)

Can you elaborate why?

far away and was difficult to use with the menus.

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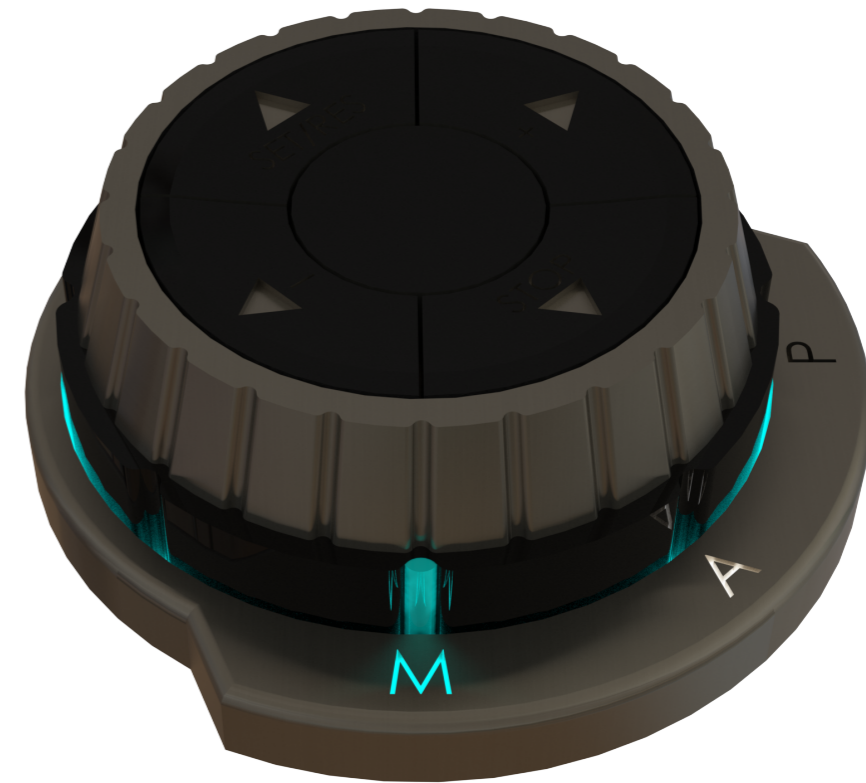
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How good of a driver are you?

- 1 2 3 4 5 6 7
- Horrible Excellent

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Do you think this form of interaction is realistic?

1 2 3 4 5 6 7

Not at all Very much so

Do you think this form of input device is realistic?

1 2 3 4 5 6 7

Not at all Very much so

Do you have any comments / recommendations relating to the experience?

Maybe controlling the system with subtle input from existing control mechanisms such as gas or break pedal might simplify the process. Less proprietary controls might keep you contentrated on the road and on the original steering controls.

Prototype 2: the lever concept



I felt in control

1 2 3 4 5 6 7

Not at all Very much so

This concept looked very complex

1 2 3 4 5 6 7

Very simplistic Very complex

The amount of buttons / switches was overwhelming

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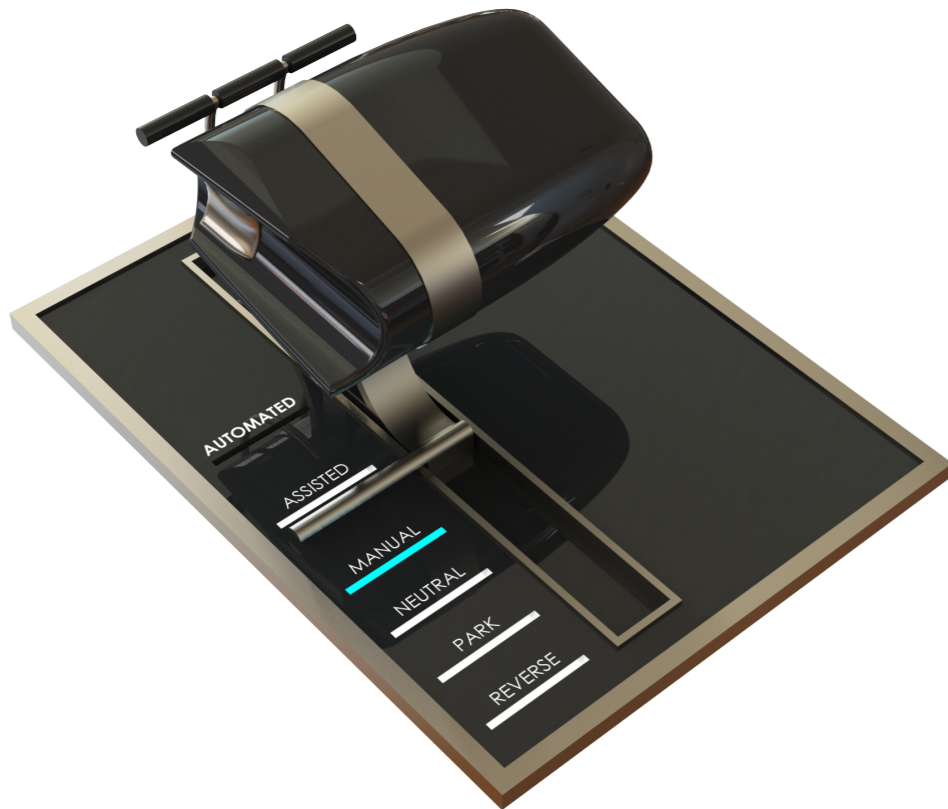
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Not at all Very much so

Do you have any comments / recommendations relating to the experience?

It was sometimes overwhelming to have multiple input options that seemed to be similar. Simplifying the controls can make it more intuitive (less options).

Prototype 3: the stick concept



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Not at all Very much so

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Not at all Very much so

Do you have any comments / recommendations relating to the experience?

Much more simple than the previous concepts, a single degree of freedom (movement) generates less stress for me as a driver. This control is already intuitive since its linked to the gear stick. Other controls (such as buttons) are more intuitive to control extra/additional features. The feeling of pushing and pulling felt like I was in control easily.

Wrap-up

What was your favorite concept?

- The button (first)
- The lever (second)
- The stick (third)

Can you elaborate why?

It was more intuitive since the gear stick is related to driving modes/gears, and other buttons are for extra/additional features.

What concept did you like the least? (which was the worst?)

- The button (first)
- The lever (second)
- The stick (third)

Can you elaborate why?

The amount of possibilities/actions/degrees of freedom made it sometimes confusing, it distracted me from the road and driving.

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Google Forms

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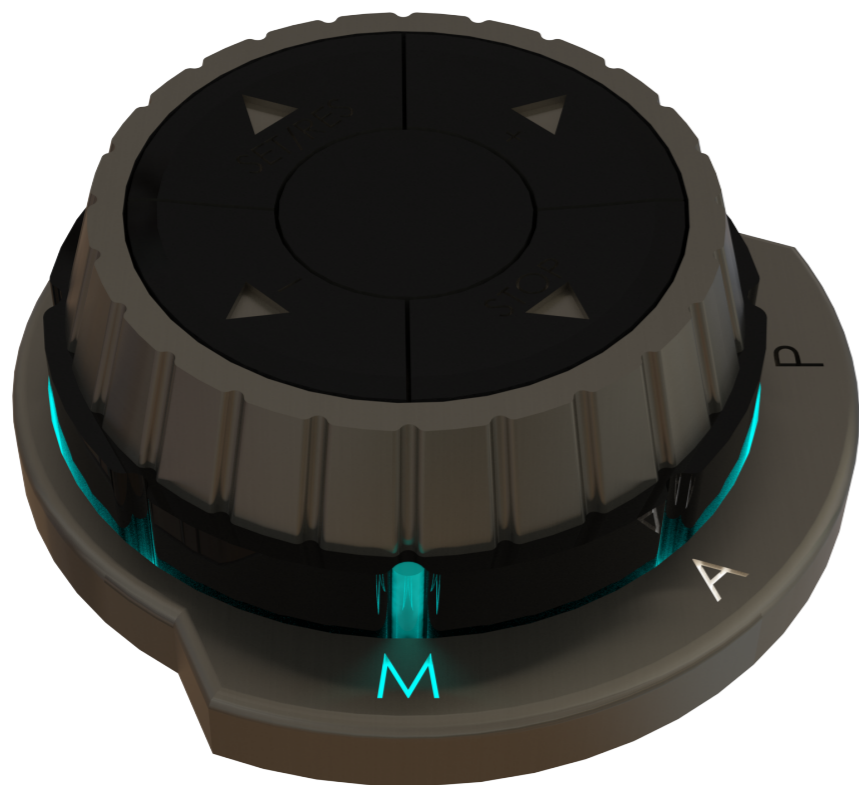
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Do you think this form of interaction is realistic?

1 2 3 4 5 6 7

Not at all Very much so

Do you think this form of input device is realistic?

1 2 3 4 5 6 7

Not at all Very much so

Do you have any comments / recommendations relating to the experience?

* Control was a bit far away, would have liked it when it was more easy to reach/adjustable. Would prefer it where my cruise control is or in the midconsole or chair. // Requests and feedback where on the panel behind the steering wheel in which sometimes I couldn't see it very well without adjusting my posture/position due to the steering wheel. Would have preferred it in the middle or at the left A-pillar (Tomtom position)

Prototype 2: the lever concept



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This concept looked very complex

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Do you think this form of interaction is realistic?

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Not at all Very much so

Do you think this form of input device is realistic?

1 2 3 4 5 6 7

Not at all Very much so

Do you have any comments / recommendations relating to the experience?

Would feel less secure in other people's cars if the menu navigation, selection etc. would be different interactions. Enter button for menu was different from enter button for mode which was confusing and would distract me when I would be driving in real life

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Not at all Very much so

Do you have any comments / recommendations relating to the experience?

Would make it a bit easier to reach. It was better than de button concept, but if I don't have to bend over it would be even better

Wrap-up

What was your favorite concept?

- The button (first)
- The lever (second)
- The stick (third)

Can you elaborate why?

Felt like the least amount of hassle also more friendly interaction, with a bit of personality/sympathy. The concept was kind of "asking"/requesting an user interaction instead of a surprise pop-out (button concept) or nothing at all (poke concept)

What concept did you like the least? (which was the worst?)

- The button (first)
- The lever (second)
- The stick (third)

Can you elaborate why?

Has no personality at all... and if it had one it would be a bit of a wallflower, merging in the background in which I would forget it was there untill the screen would make me aware of it. The interaction would then be more/only with the screen other than having the perks of an additional product/prop

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Google Forms

CTR Prototype testing - Graduation

This is the questionair to accompany the three conceptual interaction devices devolped during the graduation of T.Q. Mallon for the project "Design of Control Transfer Rituals for Automated Vehicles" in 2020.

Initial questions aim to gain insight in the knowledge and experience of the participants. The other questions relate to the prototypes to allow further development and selection.

Do you have a drivers licence?

- Yes, and i drive multiple times per week
- Yes, i have my licence but do not drive that often
- No
- Other: _____

Do you have any experience with automated vehicles (such as Tesla Autopilot)

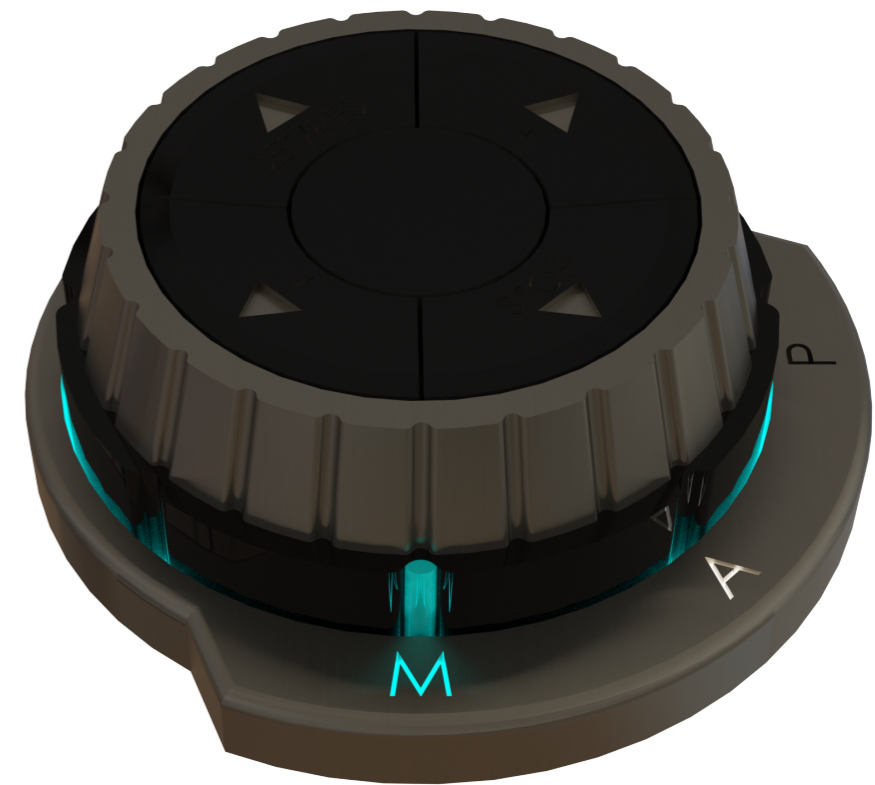
- Yes, i fully understand the use of vehicular automation
- Yes, but very little
- No, but i know what they are capable of
- No, i have never driven such vehicle in such capacity
- No, but i do use cruise control
- No, no experience

How good of a driver are you?

1 2 3 4 5 6 7

Horrible Excellent

Prototype 1: the button concept



I felt in control

1 2 3 4 5 6 7

Not at all Very much so

This concept looked very complex

1 2 3 4 5 6 7

Very simplistic Very complex

The amount of buttons / switches was overwhelming

1 2 3 4 5 6 7

Very unclear Very clear

The concept is intuitive to use

1 2 3 4 5 6 7

Very unintuitive Very intuitive

It will be easy to learn the functions of this concept

1 2 3 4 5 6 7

Not at all Very much so

It was clear when I had to act

1 2 3 4 5 6 7

Not at all Very much so

The scenario was clear to me

1 2 3 4 5 6 7

Very unclear Very clear

The feedback informed me why the events in the scenario happened

1 2 3 4 5 6 7

Very unclear Very clear

The control was easy to reach

1 2 3 4 5 6 7

Not at all Very much so

The interactions with the concept were familiar

1 2 3 4 5 6 7

Not at all Very much so

Do you think this form of interaction is realistic?

1 2 3 4 5 6 7

Not at all Very much so

Do you think this form of input device is realistic?

1 2 3 4 5 6 7

Not at all Very much so

Do you have any comments / recommendations relating to the experience?

.....

Prototype 2: the lever concept



I felt in control

1 2 3 4 5 6 7

Not at all Very much so

This concept looked very complex

1 2 3 4 5 6 7

Very simplistic Very complex

The amount of buttons / switches was overwhelming

1 2 3 4 5 6 7

Very unclear Very clear

The concept is intuitive to use

1 2 3 4 5 6 7

Very unintuitive Very intuitive

It will be easy to learn the functions of this concept

1 2 3 4 5 6 7

Not at all Very much so

It was clear when I had to act

1 2 3 4 5 6 7

Not at all Very much so

The scenario was clear to me

1 2 3 4 5 6 7

Very unclear Very clear

The feedback informed me why the events in the scenario happened

1 2 3 4 5 6 7

Very unclear Very clear

The control was easy to reach

1 2 3 4 5 6 7

Not at all Very much so

The interactions with the concept were familiar

1 2 3 4 5 6 7

Not at all Very much so

Do you think this form of interaction is realistic?

1 2 3 4 5 6 7

Not at all Very much so

Do you think this form of input device is realistic?

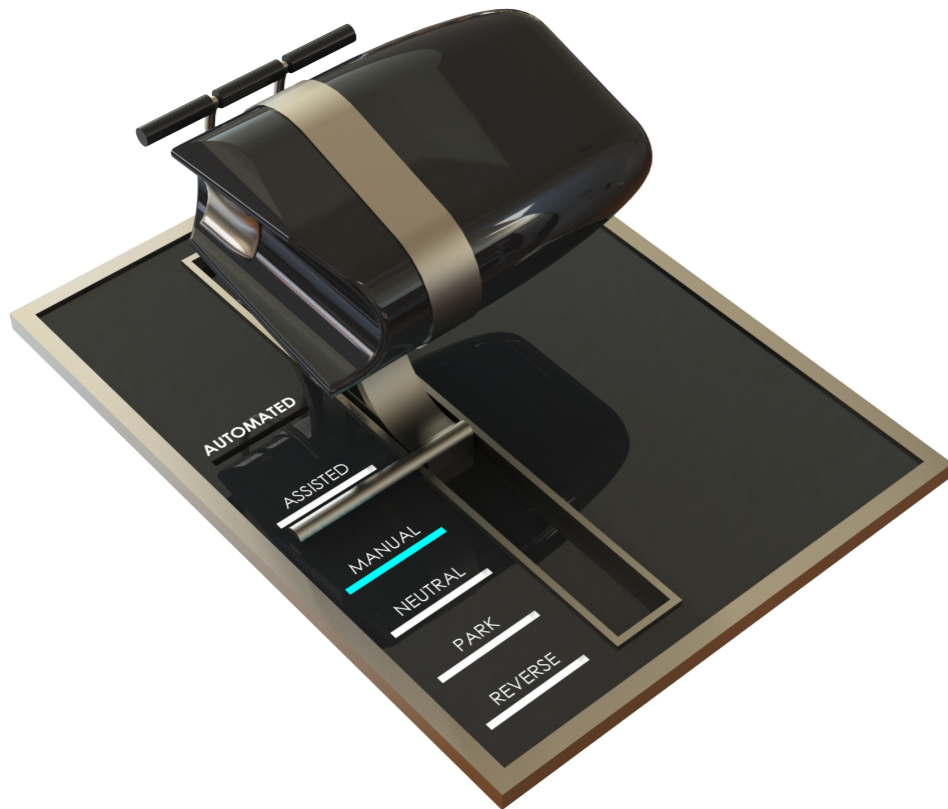
1 2 3 4 5 6 7

Not at all Very much so

Do you have any comments / recommendations relating to the experience?

Maybe swap around the functions of the buttons ea when you select mode or navigate through the menu

Prototype 3: the stick concept



I felt in control

1 2 3 4 5 6 7

Not at all Very much so

This concept looked very complex

1 2 3 4 5 6 7

Very simplistic Very complex

The amount of buttons / switches was overwhelming

1 2 3 4 5 6 7

Very unclear Very clear

The concept is intuitive to use

1 2 3 4 5 6 7

Very unintuitive Very intuitive

It will be easy to learn the functions of this concept

1 2 3 4 5 6 7

Not at all Very much so

It was clear when I had to act

1 2 3 4 5 6 7

Not at all Very much so

The scenario was clear to me

1 2 3 4 5 6 7

Very unclear Very clear

The feedback informed me why the events in the scenario happened

1 2 3 4 5 6 7

Very unclear Very clear

The control was easy to reach

1 2 3 4 5 6 7

Not at all Very much so

The interactions with the concept were familiar

1 2 3 4 5 6 7

Not at all Very much so

Do you think this form of interaction is realistic?

1 2 3 4 5 6 7

Not at all Very much so

Do you think this form of input device is realistic?

1 2 3 4 5 6 7

Not at all Very much so

Do you have any comments / recommendations relating to the experience?

.....

Wrap-up

What was your favorite concept?

- The button (first)
- The lever (second)
- The stick (third)

Can you elaborate why?

It was nice and easy to use. Furthermore the feedback is really clear and easy to comprehend

What concept did you like the least? (which was the worst?)

- The button (first)
- The lever (second)
- The stick (third)

Can you elaborate why?

Fiddely and I did not like how the lever operated, this might be because the lever is too much like a turn signal stick.

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Functional Requirements

Feedback

Visual

- Concise, clear, unambiguous messages need to be displayed for every signal. This text must be readable within two seconds
- Ambient lighting implemented in the A-pillars will indicate what is required from the human driver.
- Icons that indicate that an action is required must be visible at all times, see “The Measure of Man and Woman” on the next page.
- Icons must be designed along the regulations in EU Directive 78/316/EEC
- All in-vehicle visual presentation must abide to ISO 15008;2017
- Visual feedback must allow for shift in urgency by changing brightness, frequency or movement
- Detailed feedback text can be summoned on a proper screen during OotL automation or after the drive
- Automation modes must be indicated as modes that people understand, not SAE levels. Recommended are the modes Manual, Assisted, and Handsfree

Auditory

- Warning alarms should only sound during take over requests with urgency
- Warning alarms can be scaled to fit the urgency of the situation using frequency, ISI, amplitude.
- An unambiguous confirmation alert should sound when switching between automation modes
- An unambiguous error alert should sound when an error occurs
- Alerts and alarms should be distinguishable, even when sounded at the same time
- Automation related alerts and alarms should be distinguishable from other types of alerts within the vehicle (e.g. seatbelt alarms)
- Alerts and alarms must sound within the audible spectrum (20-20,00 Hz)
- Alerts and alarms are preferably within the audible range of 2000 - 5000 Hz
- The amplitude of alerts and alarms should not cause hearing damage, but should be audible. This correlates to a decibel range of 85 dB - 100 db, over a maximum timespan of 15 minutes
- Auditory feedback is always explained with an explicit message (voice or text)

Haptic

- Crucial feedback is communicated through the seat-pan
- Urgent haptic feedback has a higher frequency and peak amplitude than similar non-urgent feedback.
- Haptic feedback frequency ranges between 0.4 [s⁻¹] and 800 [s⁻¹]
- Extended exposure to 30 Hz vibrations must be avoided
- Haptic feedback peak amplitude ranges between
- The location of the feedback is linked to the desired task (e.g. steering to steering wheel, shifting to stick shift, seat orientation to seat pan and back)
- Haptic feedback is always explained with an explicit message (voice or text)

Input device

The input device allows for:

- Automation mode selection
 - Confirmation/Declination
 - Engage/Disengage
 - Turn on automation modes, similar to activation of Cruise Control
-
- The input device must be able to be operated with one hand
 - The input device must not interfere with the driving tasks of the human driver
 - The input device is either visible or visually represented via visual feedback mechanics such as a screen or lighting
 - The driver should never have to put his hands through the steering wheel during driving
 - The input device is mounted on a surface within the reach envelopes of the vehicle:
 - Horizontal envelopes are a maximum of 400 mm outboard and 600 mm inboard in relation to the drivers vertical centre line
 - Vertical envelopes are a maximum of 400 mm outboard and 600 mm inboard in relation to the drivers horizontal centre line
 - The input device is fitted with a safety catch to prevent accidental operation.

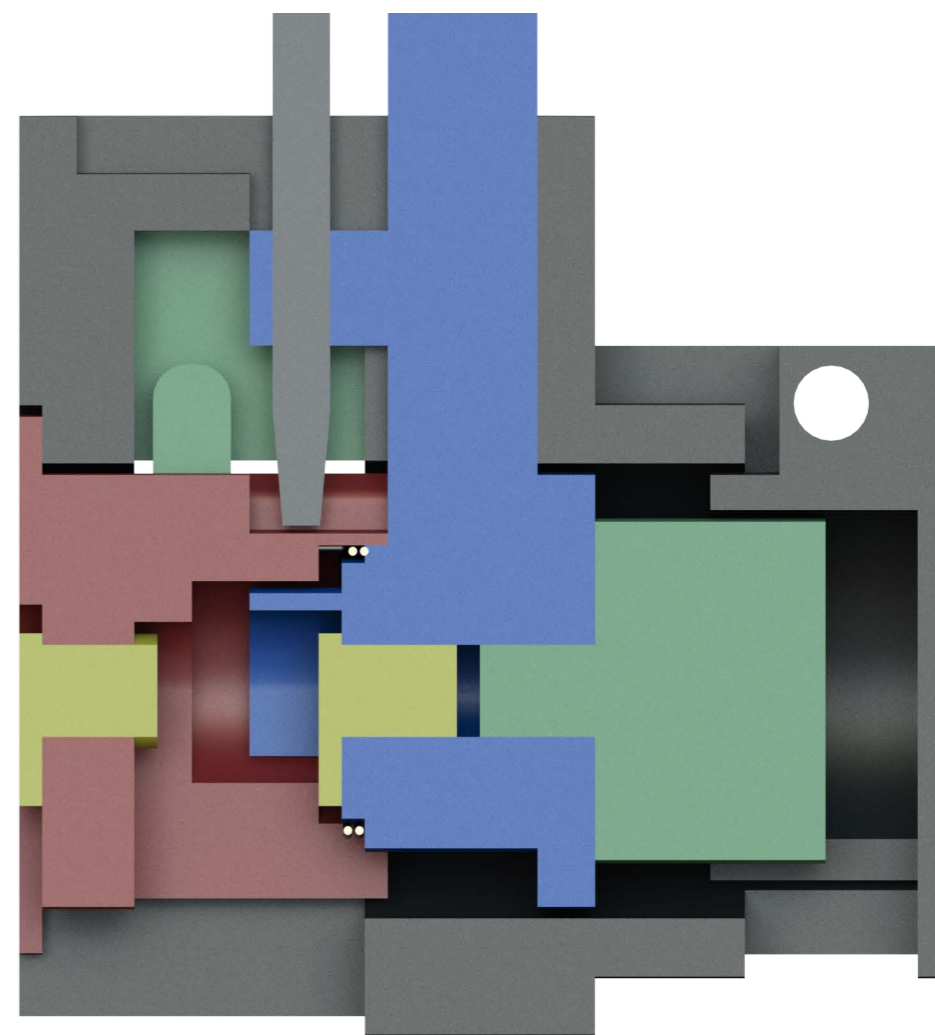
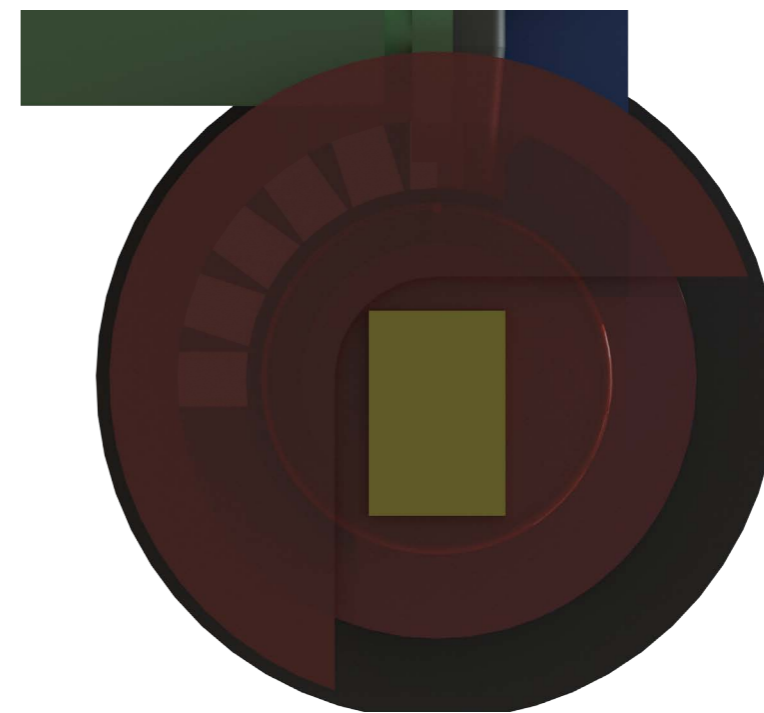
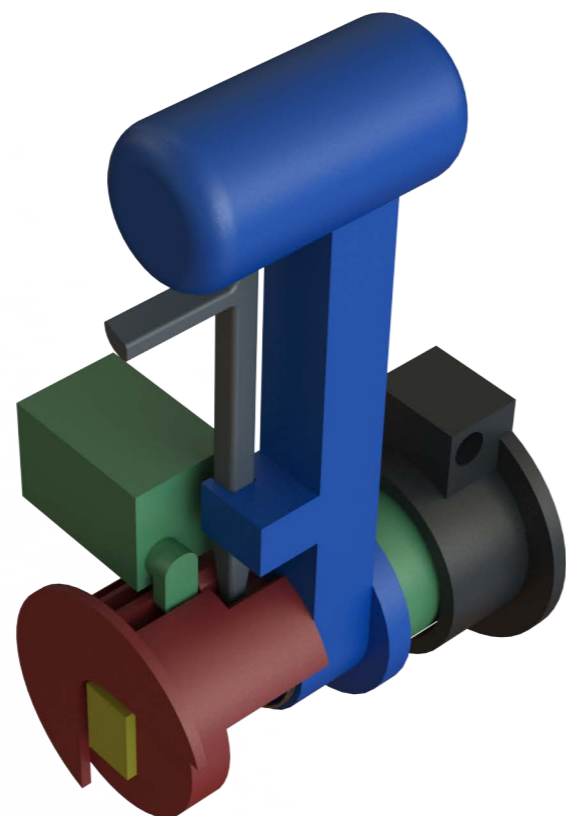
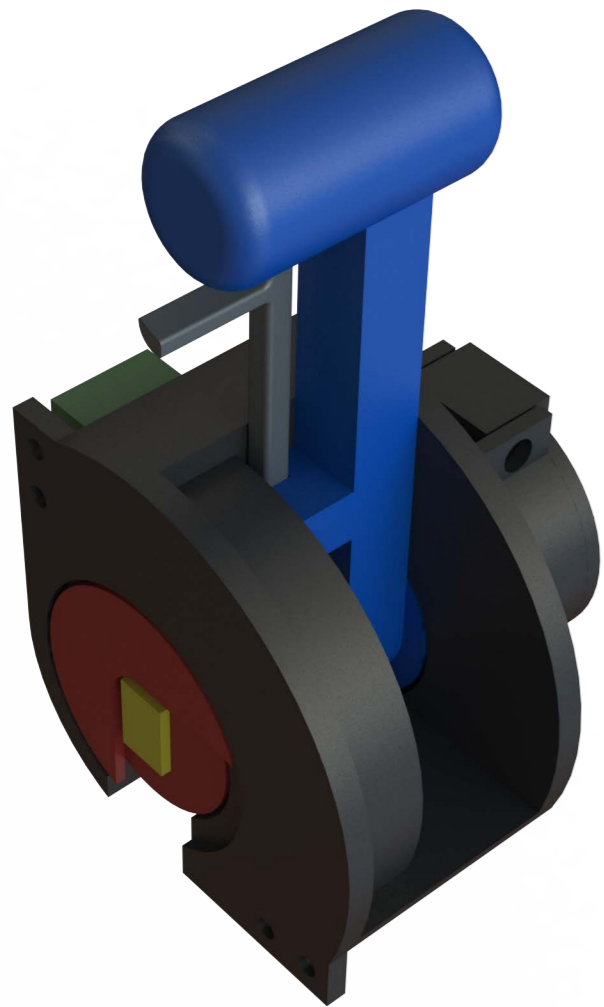
The Measure of Man and Woman

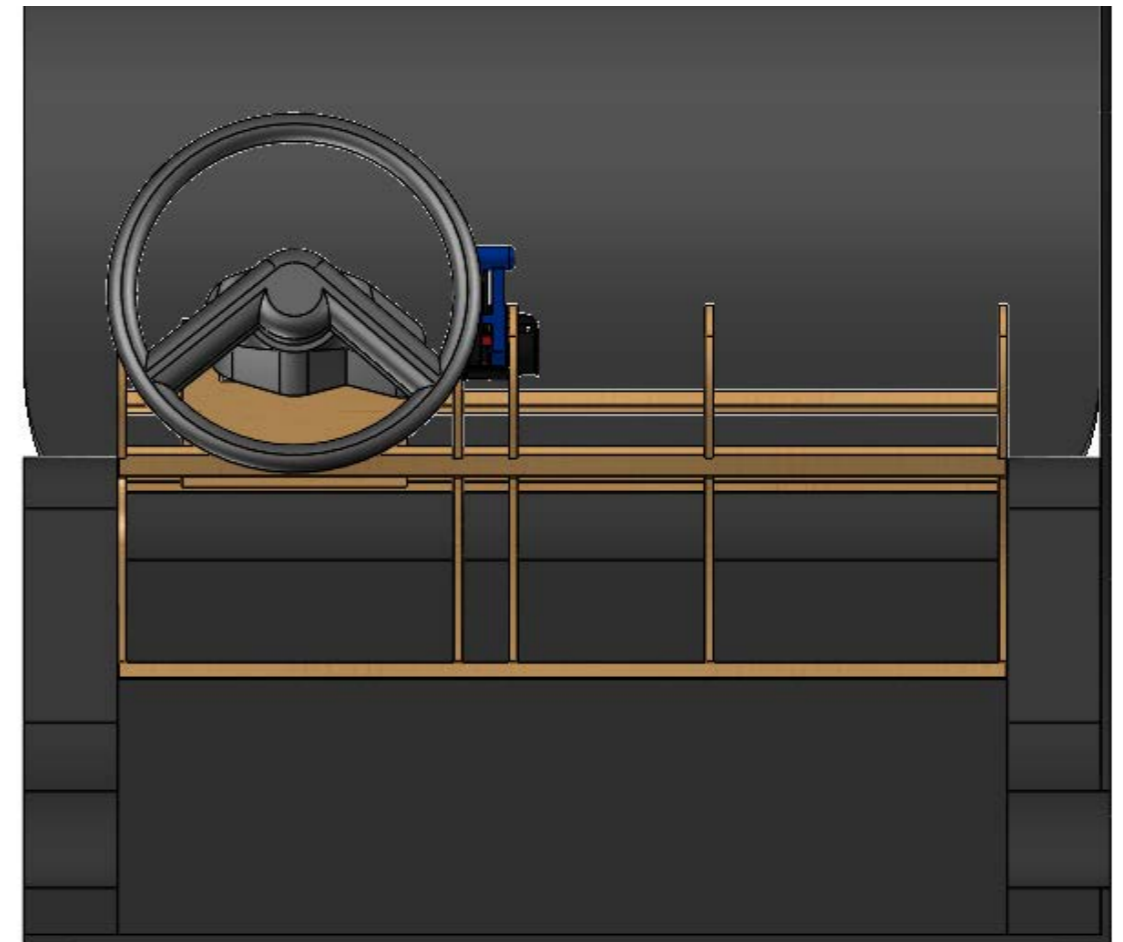
Henry Dreyfuss' The Measure of Man and Woman dictate nearly all ergonomic constraints and is advised to be read before product development. Over the next few pages, the most critical images can be found. Of these images the following constraints are utmost relevant for this graduation project. :

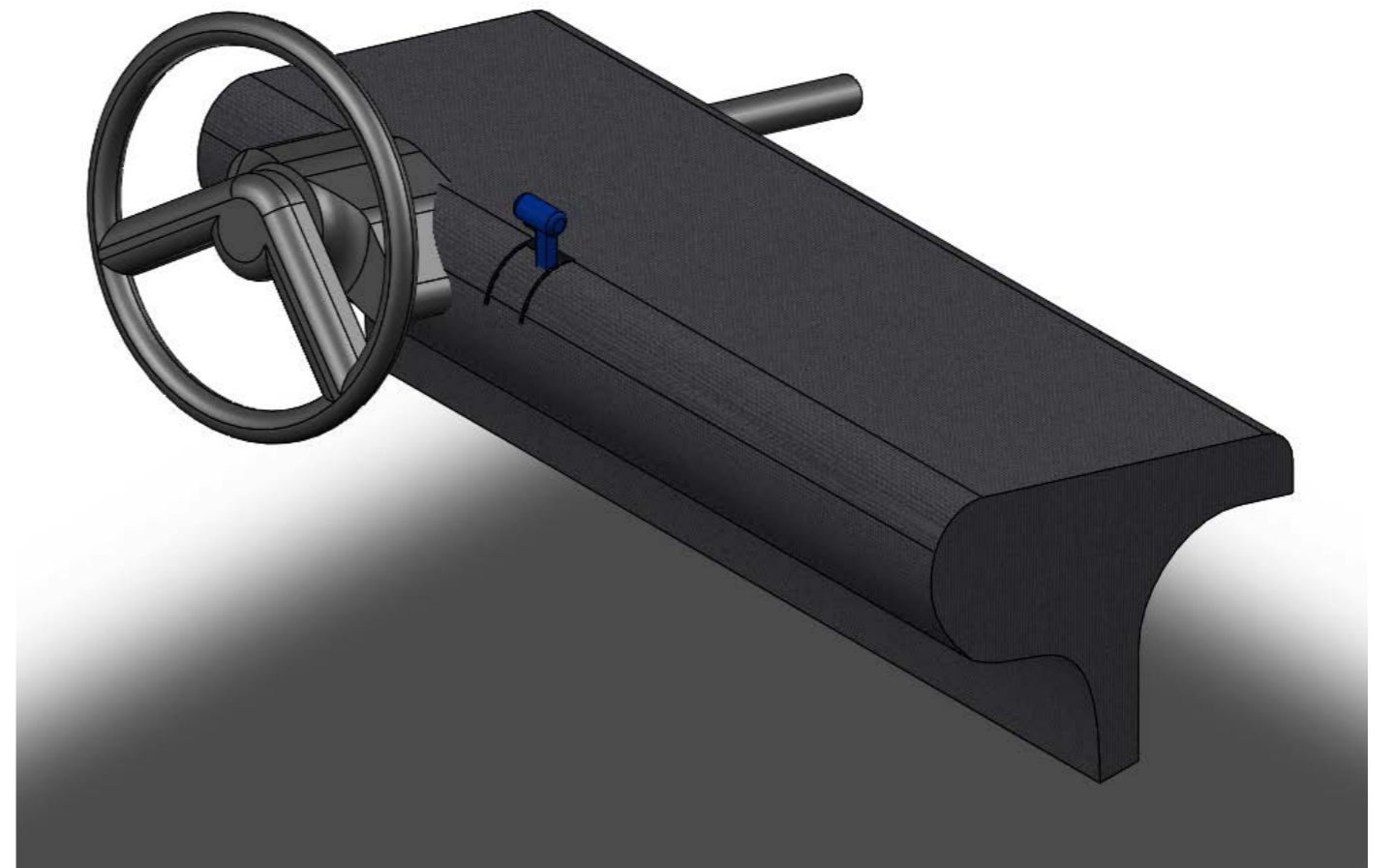
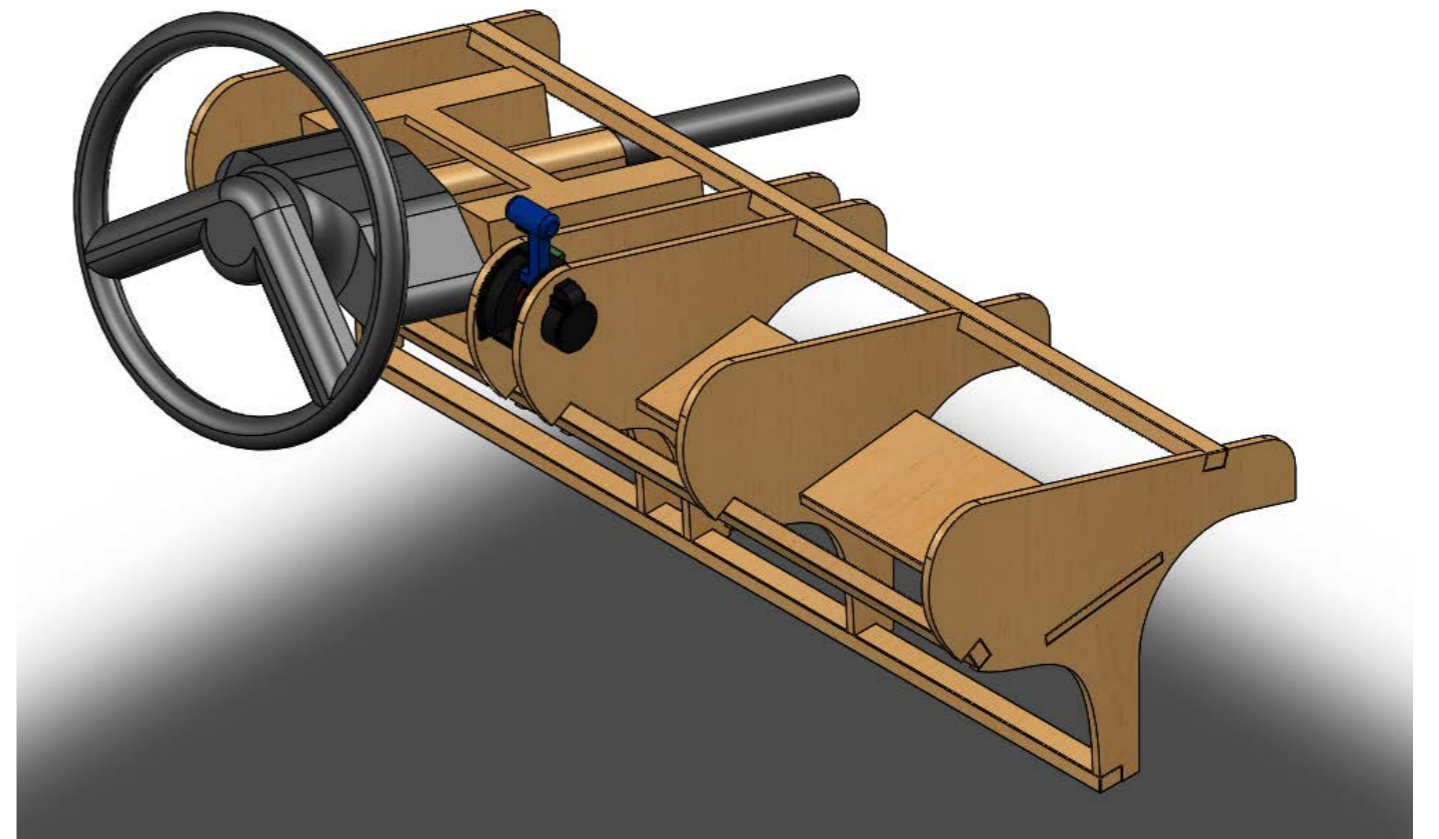
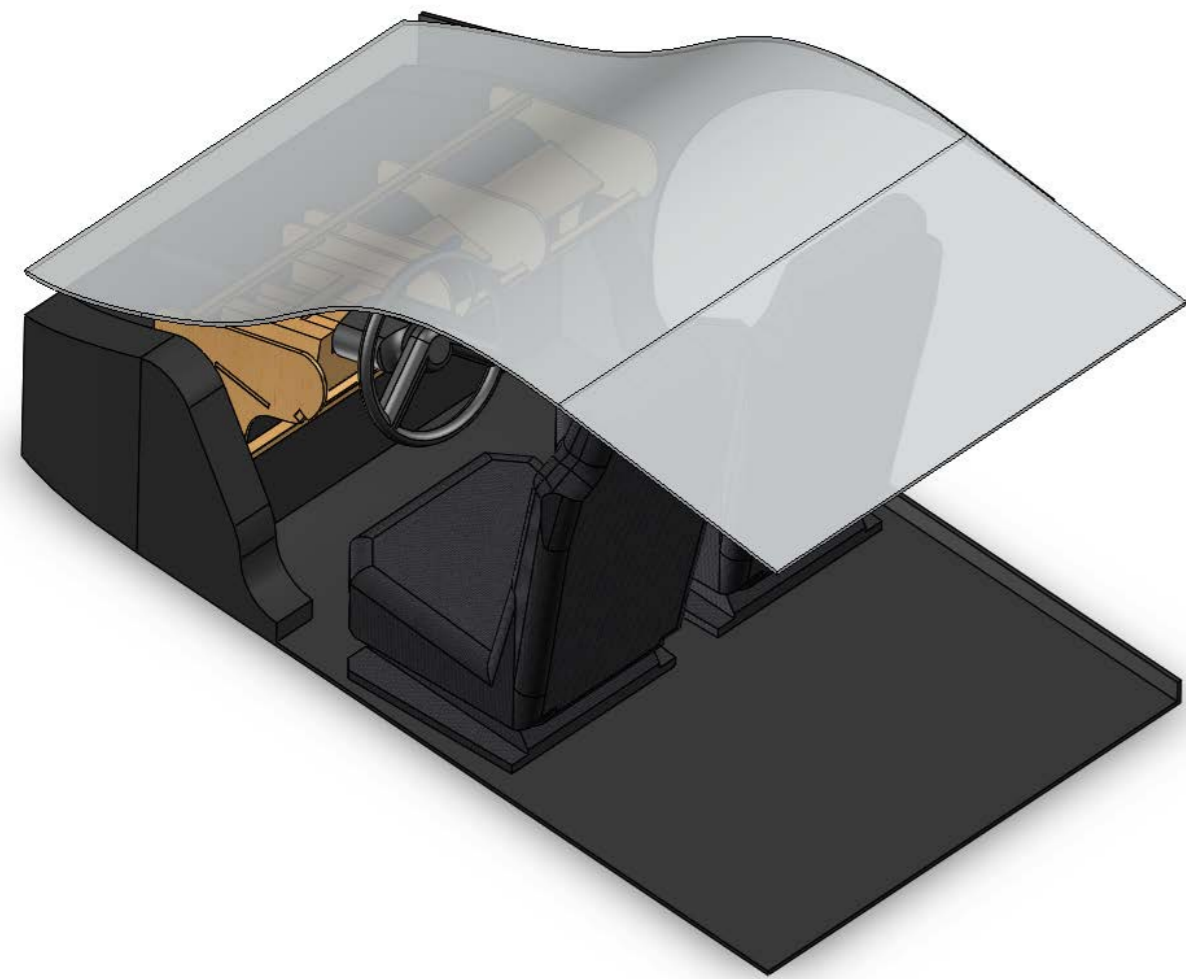
- Displays must be built within 30 degrees sideways offset to the centre of the line of sight.
- Primary displays must be build within 10 degrees sideways offset to the centre of the line of sight
- Displays must be built within an up-down envelope of 5 degrees upward and 35 degrees downward in relation to the horizontal sight line.
- The optimal angle for displays is 15 degrees downward from the horizontal sight line.
- At maximum reach (697 mm), the maximum force required to act on an input device cannot exceed 147 Newton. This reduces to 102 Newton up close to the body.

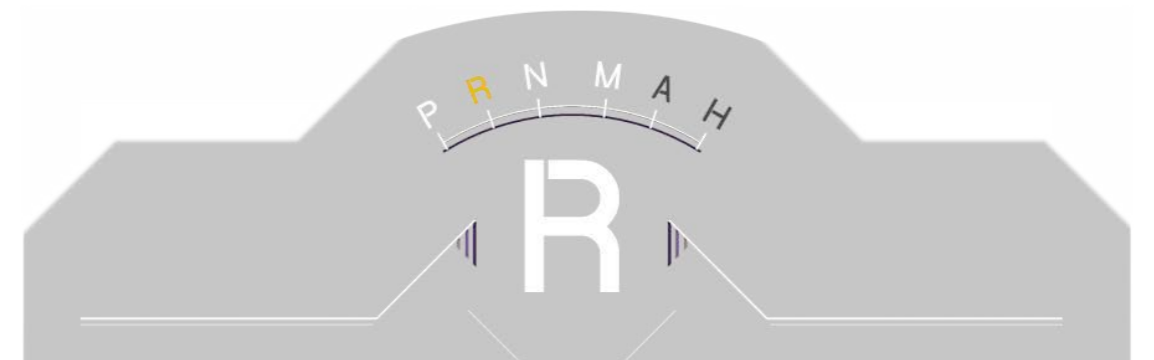
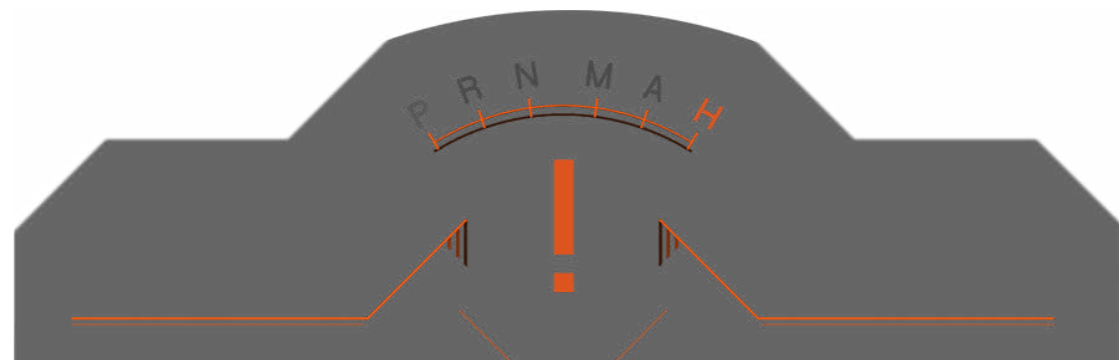
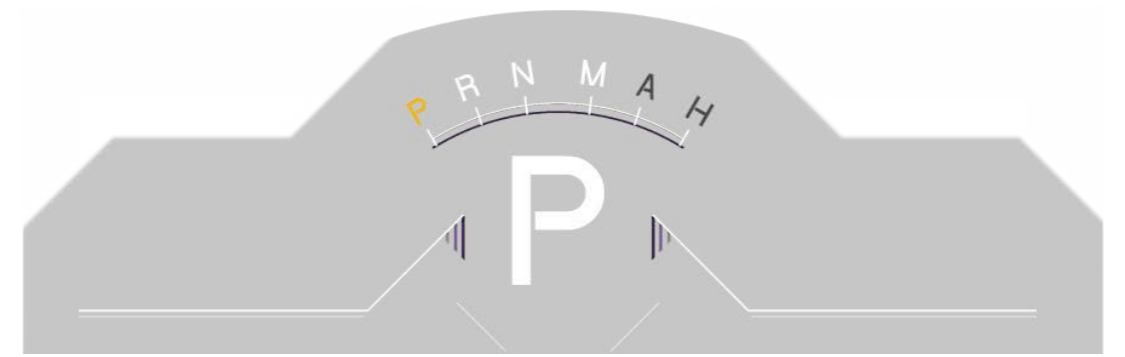


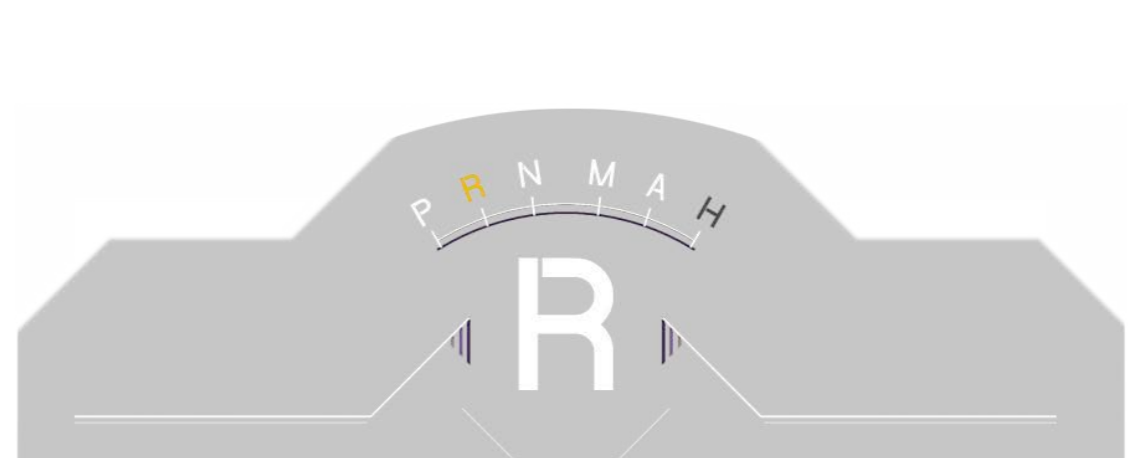
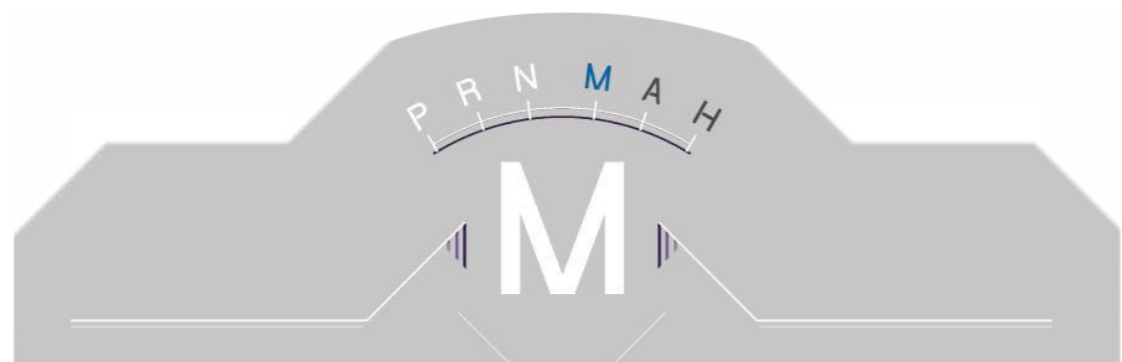
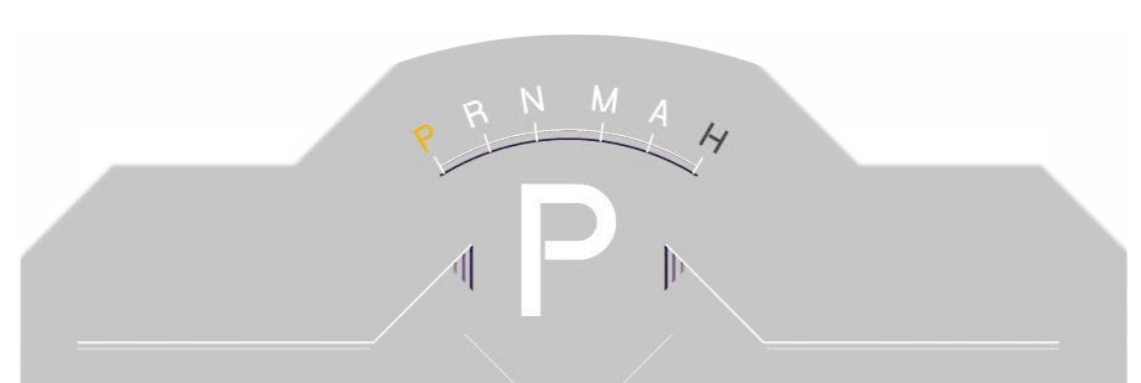
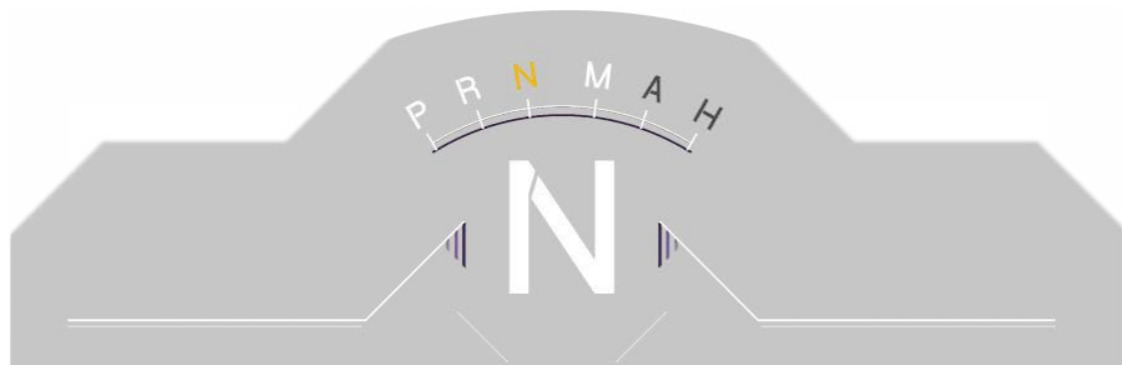
Prototype

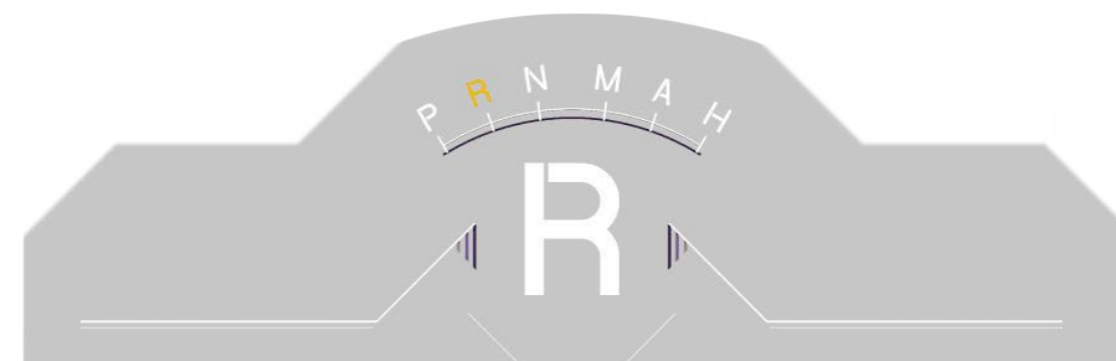
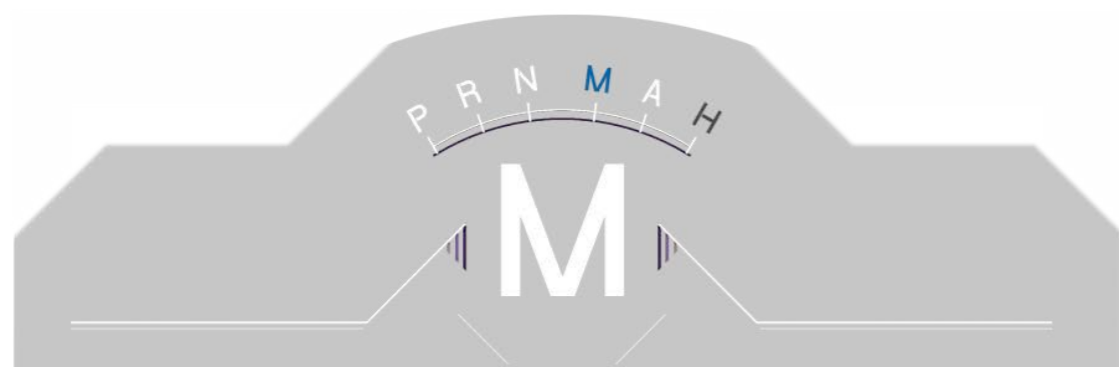
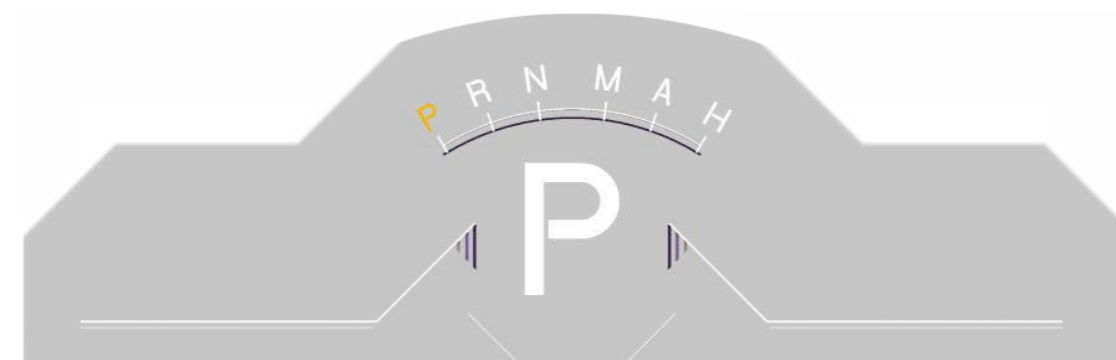
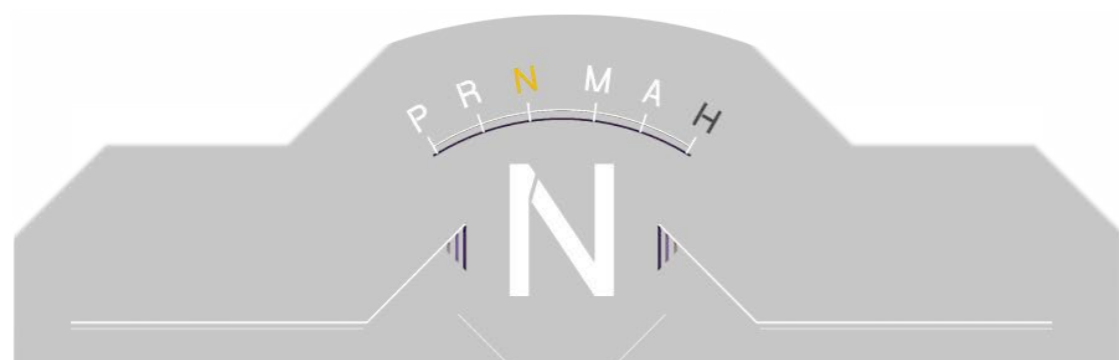


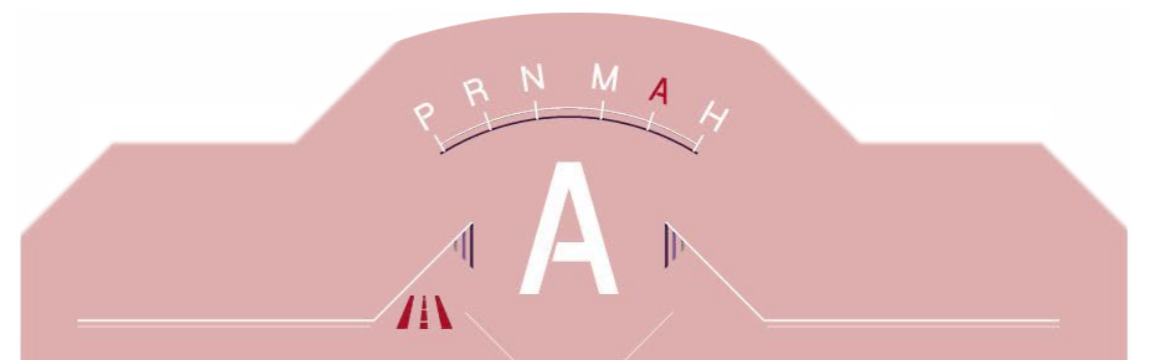
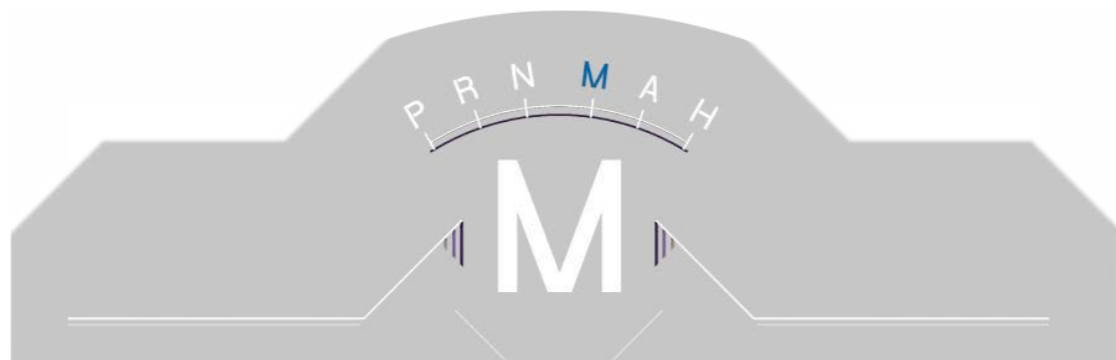
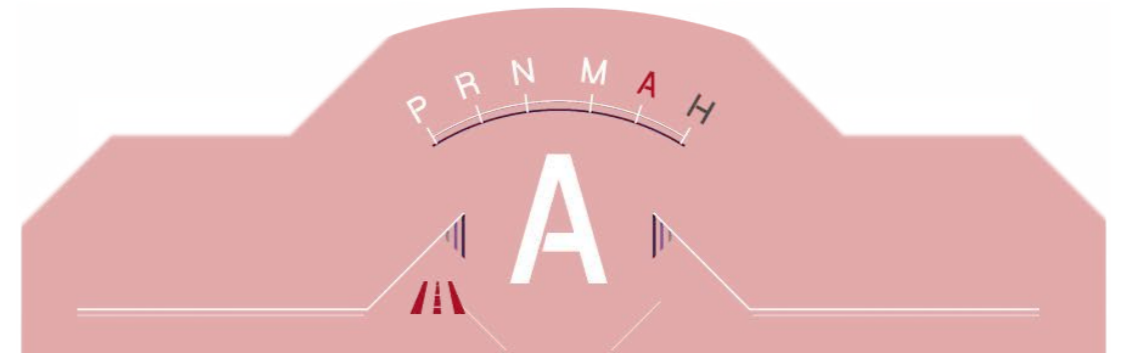
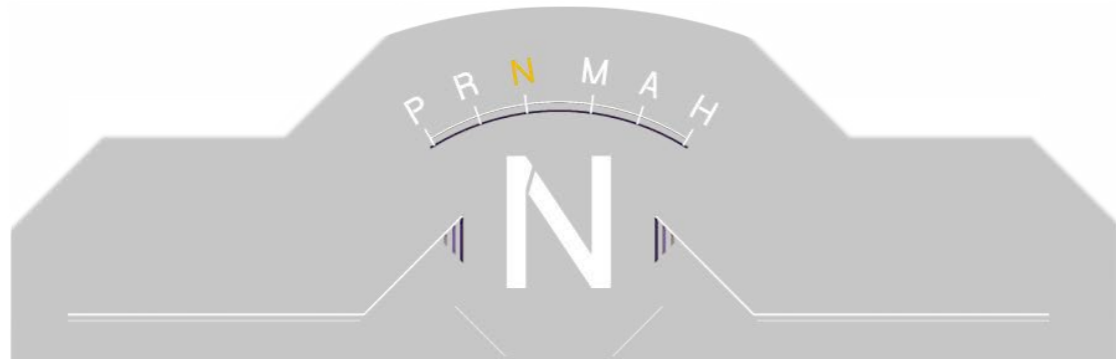


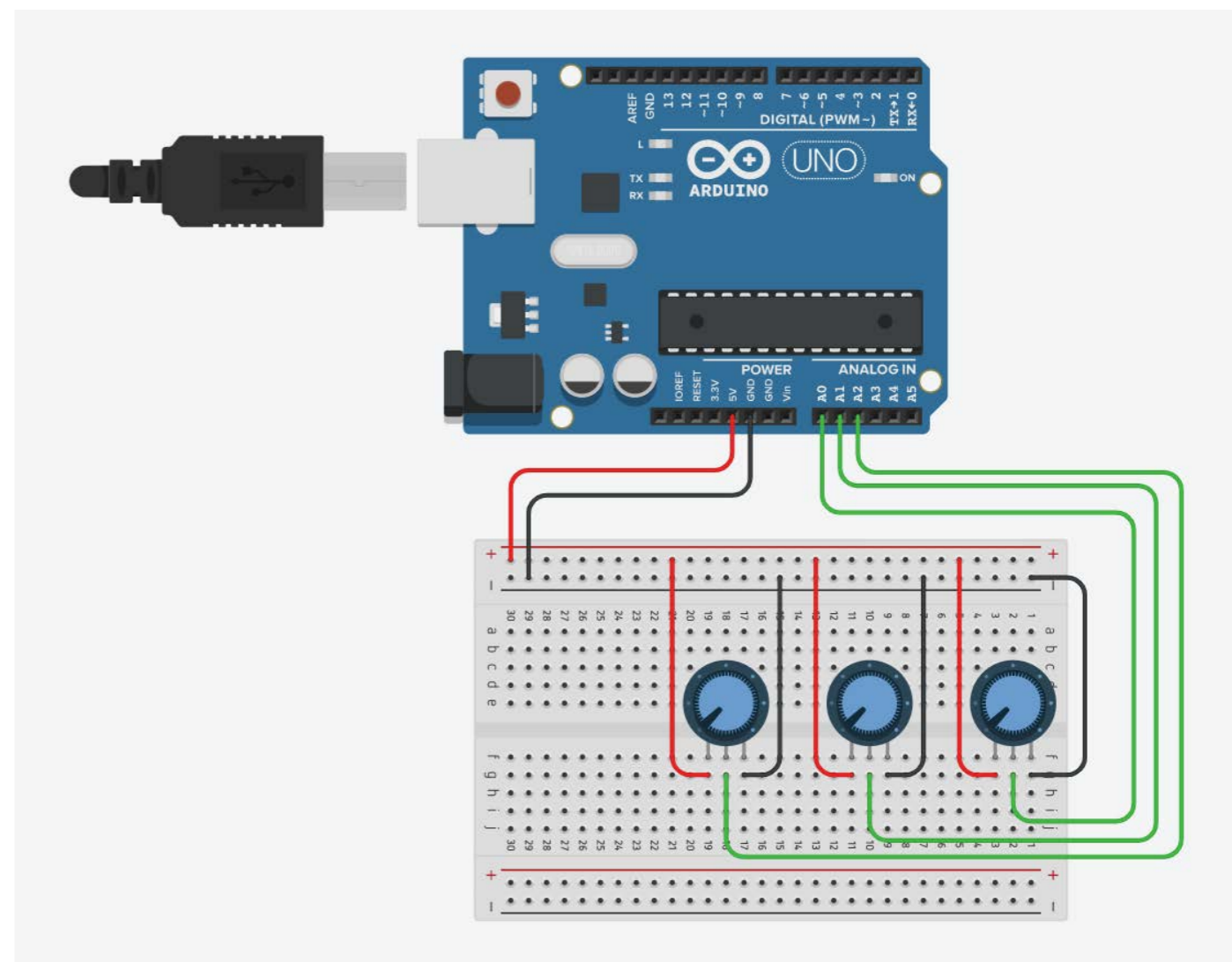
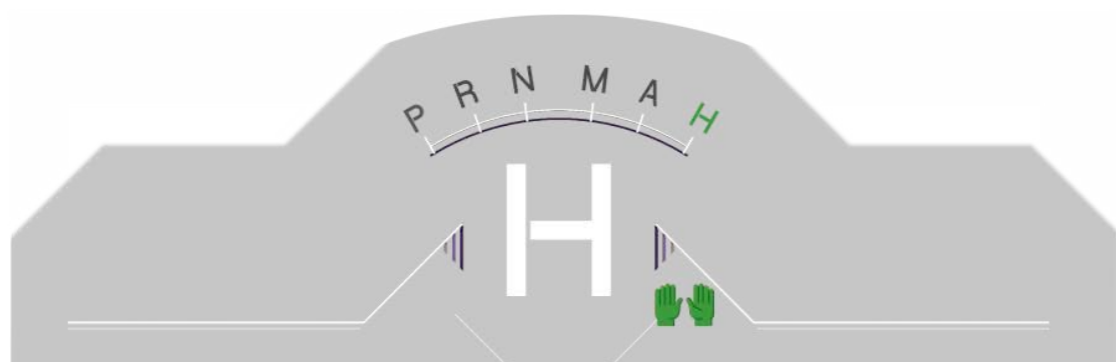
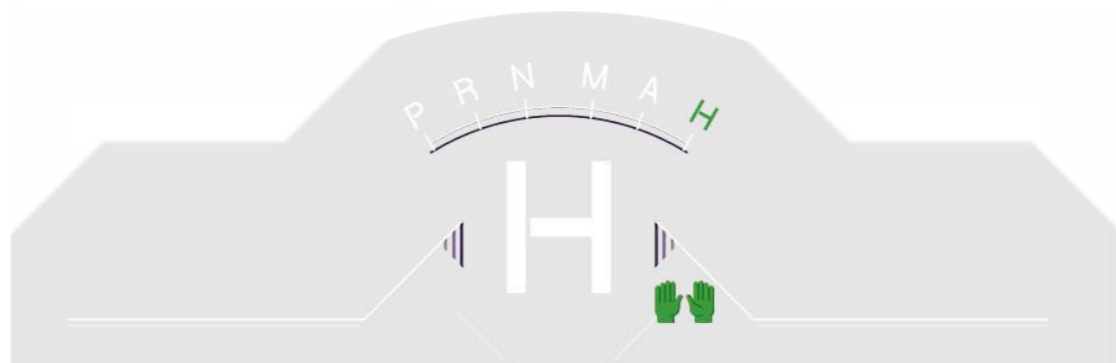


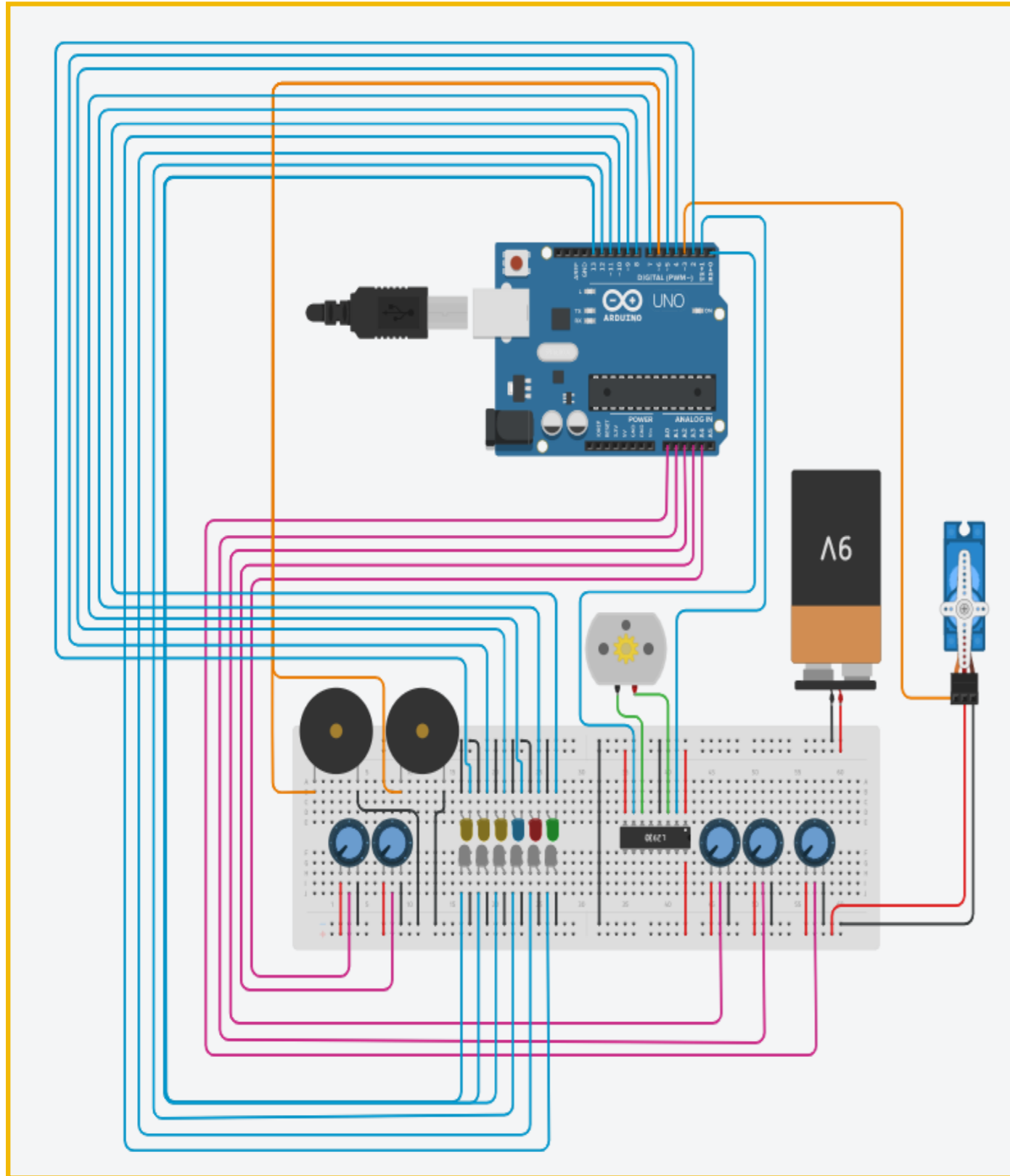












Arduino Code:

```
//Libaries
#include <Servo.h>

//Servo
Servo servo1;
//int testPot = A13;
//int testPotValue;
int servoMode;
int servoValue;

//Motor
int moveMotorUp = 9;
int moveMotorDown = 10;

//Potmeters
int actualAnglePot = A7;
int setAnglePot = A5;
int setAngle;
int actualAngle;
int oldAngle;
int motorActualAngle;
int motorSetAngle;
int manualMovement;
int mappedManualMovement;
int movementTo; //0 = no movement, 1 = Up, 2 = Down
int currentMode;

//LED's
int led_whitesP = 52; //White LEDs for PRNM
int led_whitesR = 51;
```

```

int led_whitesN = 48;
int led_whitesM = 47;
int led_white_assisted = 44;
int led_white_handsfree = 43;
int led_park = 34;
int led_reverse = 33;
int led_neutral = 30;
int led_color_manual = 29;
int led_color_assisted = 26;
int led_color_handsfree = 25;
int ledCaseVariable;

//piezos
int piezos = 13;

//Controlbox
int availableModesPot = A0; //|
int availableModesValue; //|
int availableModes; //This is to set the available modes
int movementHandlePot = A1;
int movementHandleValue;
int movementHandle; //|
int moveDown; //This reads the set movement of the command
int motorCaseVariable; //
int moveUp; //
int urgencyPot = A3; //This reads the urgencylevel
int urgency;

//Steering/brakes/gas
int steering;

```

```

int steeringPot = A12;
int steeringValue;
int gas;
int gasPot = A14;
int gasValue;
int brake;
int brakePot = A13;
int brakeValue;
int reverse;

void setup() {
  Serial.begin(9600); //communication speed
  servo1.attach(23); //pin of servo
}

void loop(){
  //noTone(piezos); //mute the piezos

  actualAngle = (analogRead(actualAnglePot));
  actualAngle = map(actualAngle, 0, 1023, 0, 1023)/3.4;
  setAngle = analogRead(setAnglePot);
  setAngle = map(setAngle, 0, 1023, 0, 1023)/3.4;
  /*
  Serial.print(" startingActualAngle = ");
  Serial.print(actualAngle);
  Serial.print(" startingSetAngle = ");
  Serial.print(setAngle);
  */
  if(actualAngle <= 40){currentMode = 2;} //Park
  if(actualAngle > 40 && actualAngle <= 60){currentMode = 3;} //Reverse
  if(actualAngle > 60 && actualAngle <= 80){currentMode = 4;} //Neutral

```

```

if(actualAngle > 80 && actualAngle <= 117){currentMode = 5;} //Manual
if(actualAngle > 117 && actualAngle <= 145){currentMode = 6;} //Assisted
if(actualAngle > 130){currentMode = 7;} //Handsfree
//Serial.print(" CurrentMode = ");
// Serial.print(currentMode);

oldAngle = actualAngle; //is used in the motorCaseControl (but needs to be
measured upfront)

availableModesValue = analogRead(availableModesPot);

availableModes = map(availableModesValue, 0, 1023, 0, 5); // 0 & 1 = up to manual, 2
= up to assisted, 3 = up to handsfree, 4 & 5 = MRM
if(availableModes == 0){availableModes = 1;}

availableModes = availableModes - 1;

//Serial.print(" AvailableModes1 = ");
//Serial.print(availableModes);

movementHandle = map(analogRead(movementHandlePot), 0, 1023, 0, 4); //0 & 1 = down, 2
= no movement, 3 & 4 = up
if(movementHandle == 0){movementHandle = 1;}

movementHandle = movementHandle - 1;

urgency = map(analogRead(urgencyPot), 0, 1023, 0, 2); //not urgent 0 or urgent 1
if(urgency == 2){urgency = 1;}

manualMovement = setAngle - actualAngle; //Check which side the Potmeter
is turning, otherwise this could cause problems in servo orientation

measureGas(); //input controls for the driving sim
measureBrake();
measureSteering();

//servoMaintanance();

availableModesVoid();//check for available modes
//Serial.println("Debug1 ");

manuallInputVoid();//check for movement by the user

```

```

//Serial.println("Debug2 ");

switchMotorMode();//turn the motor

//Serial.println("Debug3 ");

determineLEDCase();// determine the current LED configuration
//Serial.println("Debug4 ");

reverseEngage();//is the car in reverse?

//if(analogRead(testPot) >= 900){servoMaintanance();}
//Serial.println("Debug5 ");

ledCaseVoid();//print the LED configuration
//Serial.println("Debug6 ");

printString();//print all values in one string/line for Unity:

if(servoValue <= 120){servoMode = 1;}
if(servoValue > 120){servoMode = 0;}

Serial.print(" , ");
//Serial.print("ServoLock = ");
Serial.println(servoMode);

//Serial.println("Debug7 ");
}

void availableModesVoid(){
//automation that reacts to the given information by
the Decision Logic / the control box

//segment to select lighting and movement. Based on
available mode, initiated movement and urgency

```

```

//manual available:
switch(availableModes){
case 0:
if (urgency == 0 && movementHandle == 1){
    motorCaseVariable = 11;

}
else if(urgency == 0 && movementHandle >= 2){
    motorCaseVariable = 12;

}
else if(urgency == 0 && movementHandle == 0){
    motorCaseVariable = 13;

}
else if(urgency == 1 && movementHandle == 1){
    motorCaseVariable = 21;

}
else if(urgency == 1 && movementHandle >= 2){
    motorCaseVariable = 22;

}
else if(urgency == 1 && movementHandle == 0){
    motorCaseVariable = 23;

}
else{
    motorCaseVariable = 11;
}

```

```

//printString();
//Serial.print(", case 0, ");

//assisted available
break;

//Serial.println(motorCaseVariable);

case 1:
if (urgency == 0 && movementHandle == 1){
    motorCaseVariable = 11;

}
else if(urgency == 0 && movementHandle == 2){
    motorCaseVariable = 12;

}
else if(urgency == 0 && movementHandle == 0){
    motorCaseVariable = 13;

}
else if(urgency == 1 && movementHandle == 1){
    motorCaseVariable = 21;

}
else if(urgency == 1 && movementHandle == 2){
    motorCaseVariable = 22;

}
else if(urgency == 1 && movementHandle == 0){
    motorCaseVariable = 23;
}

```



```

}
else{
  motorCaseVariable = 11;
}

//Serial.print(", case 1, ");

//printString();

break;
//Handsfree available

//Serial.println(motorCaseVariable);

case 2:

if (urgency == 0 && movementHandle == 1){
  motorCaseVariable = 11;

}
else if(urgency == 0 && movementHandle == 2){
  motorCaseVariable = 12;

}
else if(urgency == 0 && movementHandle == 0){
  motorCaseVariable = 13;

}
else if(urgency == 1 && movementHandle == 1){
  motorCaseVariable = 21;

}
else if(urgency == 1 && movementHandle == 2){
  motorCaseVariable = 22;

```

```

}
else if(urgency == 1 && movementHandle == 0){
  motorCaseVariable = 23;

}
else{
  motorCaseVariable = 11;
}

//Serial.print(", case 2, ");

//printString();

break;

//Serial.println(motorCaseVariable);

//MRM

case 3:
  motorCaseVariable = 100;

  //Serial.print(" MRM activated ");

}

//Serial.print("wel Void");

}

void determineLEDCase (){

if (currentMode == 2 && availableModes == 0){ //In Park, Manual available
  ledCaseVariable = 1;
}

```

```

else if(currentMode == 3 && availableModes ==0){ //In Reverse, Manual available
    ledCaseVariable = 2;
}
else if(currentMode == 4 && availableModes ==0){ //In Neutral, Manual available
    ledCaseVariable = 3;
}
else if(currentMode == 5 && availableModes ==0){ //In Manual, Manual available
    ledCaseVariable = 4;
}
else if(currentMode == 6 && availableModes ==0){ //In Assisted, Manual available
    = ERROR!
    ledCaseVariable = 0;
}
else if(currentMode == 7 && availableModes ==0){ //In Handsfree, Manual
    available = ERROR!
    ledCaseVariable = 0;
}
else if(currentMode == 2 && availableModes ==1){ //In Park, Assisted available
    ledCaseVariable = 5;
}
else if(currentMode == 3 && availableModes ==1){ //In Reverse, Assisted available
    ledCaseVariable = 6;
}
else if(currentMode == 4 && availableModes ==1){ //In Neutral, Assisted available
    ledCaseVariable = 7;
}
else if(currentMode == 5 && availableModes ==1){ //In Manual, Assisted available
    ledCaseVariable = 8;
}
else if(currentMode == 6 && availableModes ==1){ //In Assisted, Assisted
    available
    ledCaseVariable = 9;

```

```

}
else if(currentMode == 7 && availableModes ==1){ //In Handsfree, Assisted
    available = ERROR!
    ledCaseVariable = 0;
}
else if(currentMode == 2 && availableModes ==2){ //In Park, Handsfree available
    ledCaseVariable = 10;
}
else if(currentMode == 3 && availableModes ==2){ //In Reverse, Handsfree
    available
    ledCaseVariable = 11;
}
else if(currentMode == 4 && availableModes ==2){ //In Neutral, Handsfree
    available
    ledCaseVariable = 12;
}
else if(currentMode == 5 && availableModes ==2){ //In Manual, Handsfree
    available
    ledCaseVariable = 13;
}
else if(currentMode == 6 && availableModes ==2){ //In Assisted, Handsfree
    available
    ledCaseVariable = 14;
}
else if(currentMode == 7 && availableModes ==2){ //In Handsfree, Handsfree
    available
    ledCaseVariable = 15;
}
else if(currentMode >= 0 && availableModes == 3){ //MRM
    ledCaseVariable = 100;
}
}
}

```

```

void manualInputVoid(){
//check the manual input
if(manualMovement >= 30){
    movementTo = 1; //movement up
}
else if(manualMovement <= -30){
    movementTo = 2; //movemen down
}
else{
    movementTo = 0; //no movement
}

//Second, analyse whether the switch can be made
switch(currentMode){
case 2:
    servoUnlock();

    break;
case 3:

    break;
case 4:
    servoUnlock();

    break;

case 5: //Manual
if (movementTo == 1 && availableModes == 0){
    servoLock();
    tone(piezos, 700);
    delay(10);

```

```

    tone(piezos, 500);
    delay(10);
    noTone(piezos);
}
else if (setAngle <= 102){servoUnlock();}
else if (actualAngle >= 106 && availableModes == 0){
    servoLock();
}
if(actualAngle >= 117 && availableModes == 0){
    tone(piezos, 700);
    delay(10);
    tone(piezos, 500);
    delay(10);
    noTone(piezos);
}

    break;
case 6: //Assisted
if (movementTo == 0 && availableModes == 1){
    servoUnlock();

}
else if (movementTo == 1 && availableModes == 1){
    servoLock();
    tone(piezos, 700);
    delay(10);
    tone(piezos, 500);
    delay(10);
    noTone(piezos);
}
}

```

```

else if (movementTo == 2 && availableModes == 1){
  servoUnlock();
}

if (setAngle <= 135){servoUnlock();}
else if (actualAngle >= 130 && availableModes == 1){
  servoLock();
}

if(actualAngle >= 130 && availableModes == 0){
  tone(piezos, 700);
  delay(10);
  tone(piezos, 500);
  delay(10);
  noTone(piezos);
}
/*else{
  servoLock();
  tone(piezos, 700);
  delay(10);
  tone(piezos, 500);
  delay(10);
  noTone(piezos);
}*/

break;

case 7: //Handsfree
if (availableModes == 2){

```

```

  servoUnlock();
}
else{
  servoUnlock();
  tone(piezos, 700);
  delay(10);
  tone(piezos, 500);
  delay(10);
  noTone(piezos);
}
}

}

//inputControl
void measureGas(){
  gasValue = analogRead(gasPot);
  gas = map(gasValue, 0, 1023, 0, 110);
}

void measureBrake(){
  brakeValue = analogRead(brakePot);
  brake = map(brakeValue, 0, 1023, 0, 120);
}

void measureSteering(){
  steeringValue = analogRead(steeringPot);
  steering = map(steeringValue, 0, 1023, -100, 100);
}

```



```

}

void MotorUp(){
  digitalWrite (moveMotorUp, HIGH);
  digitalWrite (moveMotorDown, LOW);
  //Serial.print (" motor UP ");
}

void MotorDown(){
  digitalWrite (moveMotorDown, HIGH);
  digitalWrite (moveMotorUp, LOW);
  //Serial.print(" motor DOWN ");
}

void servoLock(){
  servoValue = 80;
  servo1.write(servoValue);
  delay(100);
}

void servoUnlock(){
  servoValue = 180;
  servo1.write(servoValue);
  delay(100);
}

void servoMaintanance(){
  servo1.write(180);
  //Serial.print("ServoMaintanace Active");

```

```

}

void reverseEngage(){
  if (ledCaseVariable == 2 || ledCaseVariable == 6 || ledCaseVariable == 11){
    reverse = 1;
  }
  else{
    reverse = 0;
  }
}

void switchMotorMode(){
  switch(motorCaseVariable){ //switch to case identified by Urgency and side to move; prefix 1 =
non-urgent, prefix 2 = urgent, suffix 1 = no movement, suffix 2 = up, suffix 3 = down;

    case 11: //nonurgent - no switch (default mode)
      break;

    case 12: //nonurgent - pop up
      servoUnlock();
      tone(piezos, 200);
      tone(piezos, 1000);
      noTone(piezos);
      motorActualAngle = analogRead(actualAnglePot)/3.4;
      motorSetAngle = analogRead(setAnglePot)/3.4;
      //Serial.print("debug 1 :");
      //Serial.print(motorActualAngle);
      //Serial.print(" , ");
      //Serial.print(motorSetAngle);

```

```

//Serial.print(" , ");
MotorUp();

//if (motorSetAngle >= 145){digitalWrite(moveMotorUp, LOW); digitalWrite(moveMotorDown,
LOW);}

/*else*/ if (motorSetAngle <= 35){digitalWrite(moveMotorUp, LOW);
digitalWrite(moveMotorDown, LOW);}

else if (motorActualAngle > oldAngle + 30){

  digitalWrite(moveMotorUp, LOW);
}

else{

  switchMotorMode();
}

break;

case 13: //nonurgern - pop down
servoUnlock();
tone(piezos, 200);
tone(piezos, 1000);
noTone(piezos);
motorActualAngle = analogRead(actualAnglePot)/3.4;
motorSetAngle = analogRead(setAnglePot)/3.4;
//Serial.print("debug 2 :");
//Serial.print(motorActualAngle);
//Serial.print(" , ");
//Serial.print(motorSetAngle);
//Serial.print(" , ");
MotorDown();

if (motorSetAngle >= 145){digitalWrite(moveMotorUp, LOW); digitalWrite(moveMotorDown,
LOW);}

//else if (motorSetAngle <= 35){digitalWrite(moveMotorUp, LOW); digitalWrite(moveMotorDown,
LOW);}

else if (motorActualAngle < oldAngle - 30){

```

```

  digitalWrite(moveMotorDown, LOW);
}

else{

  switchMotorMode();
}

break;

case 21: //urgent - no switch (attention needed, no driving mode switch)
tone(piezos,1000);
delay(10);
noTone(piezos);
break;

case 22: //urgert - move up
servoUnlock();
tone(piezos, 200);
tone(piezos, 1000);
noTone(piezos);
MotorUp();
motorActualAngle = analogRead(actualAnglePot)/3.4;
motorSetAngle = analogRead(setAnglePot)/3.4;
//if (setAngle >= 155){digitalWrite(moveMotorUp, LOW); digitalWrite(moveMotorDown, LOW);}
/*else*/ if (setAngle <= 35){digitalWrite(moveMotorUp, LOW); digitalWrite(moveMotorDown,
LOW);}

else if (motorActualAngle > oldAngle + 70){

  digitalWrite(moveMotorUp, LOW);
  digitalWrite(moveMotorUp, LOW);
}

else{

  switchMotorMode();
}

```

```

break;

case 23: //urgent - movedown  servoUnlock();
tone(piezos, 200);
tone(piezos, 1000);
noTone(piezos);
motorActualAngle = analogRead(actualAnglePot)/3.4;
motorSetAngle = analogRead(setAnglePot)/3.4;
MotorDown();
if (setAngle >= 155){digitalWrite(moveMotorUp, LOW); digitalWrite(moveMotorDown, LOW);}
//else if (setAngle <= 35){digitalWrite(moveMotorUp, LOW); digitalWrite(moveMotorDown,
LOW);}
else if (motorActualAngle < oldAngle - 70){
digitalWrite(moveMotorDown, LOW);
digitalWrite(moveMotorUp, LOW);
}
else{
switchMotorMode();
}
break;

case 100:
digitalWrite(moveMotorUp, LOW);
digitalWrite(moveMotorDown, LOW);
servoLock();
tone(piezos, 1000);
noTone(piezos);

}
}

```

```

void ledCaseVoid(){
switch(ledCaseVariable){ //change the lit LED lights
case 0: //driving is not available, there is an ERROR
digitalWrite (led_whitesP,LOW);
digitalWrite (led_whitesR,LOW);
digitalWrite (led_whitesN,LOW);
digitalWrite (led_whitesM,LOW);
digitalWrite (led_park, LOW);
digitalWrite (led_reverse, LOW);
digitalWrite (led_neutral, LOW);
digitalWrite (led_white_assisted, LOW);
digitalWrite (led_white_handsfree, LOW);
digitalWrite (led_color_manual, LOW);
digitalWrite (led_color_assisted, LOW);
digitalWrite (led_color_handsfree, LOW);
break;

case 1://car in park -> up to manual available
digitalWrite (led_whitesP,LOW);
digitalWrite (led_whitesR,HIGH);
digitalWrite (led_whitesN,HIGH);
digitalWrite (led_whitesM,HIGH);
digitalWrite (led_park, HIGH);
digitalWrite (led_reverse, LOW);
digitalWrite (led_neutral, LOW);
digitalWrite (led_white_assisted, LOW);
digitalWrite (led_white_handsfree, LOW);
digitalWrite (led_color_manual, LOW);
digitalWrite (led_color_assisted, LOW);
digitalWrite (led_color_handsfree, LOW);

```

```

break;

case 2://car in reverse -> up to manual available
digitalWrite (led_whitesP,HIGH);
digitalWrite (led_whitesR,LOW);
digitalWrite (led_whitesN,HIGH);
digitalWrite (led_whitesM,HIGH);
digitalWrite (led_park, LOW);
digitalWrite (led_reverse, HIGH);
digitalWrite (led_neutral, LOW);
digitalWrite (led_white_assisted, LOW);
digitalWrite (led_white_handsfree, LOW);
digitalWrite (led_color_manual, LOW);
digitalWrite (led_color_assisted, LOW);
digitalWrite (led_color_handsfree, LOW);
break;

```

```

case 3://car in neutral -> up to manual available
digitalWrite (led_whitesP,HIGH);
digitalWrite (led_whitesR,HIGH);
digitalWrite (led_whitesN,LOW);
digitalWrite (led_whitesM,HIGH);
digitalWrite (led_park, LOW);
digitalWrite (led_reverse, LOW);
digitalWrite (led_neutral, HIGH);
digitalWrite (led_white_assisted, LOW);
digitalWrite (led_white_handsfree, LOW);
digitalWrite (led_color_manual, LOW);
digitalWrite (led_color_assisted, LOW);
digitalWrite (led_color_handsfree, LOW);
break;

```

```

case 4://car in manual -> up to manual available
digitalWrite (led_whitesP,HIGH);
digitalWrite (led_whitesR,HIGH);
digitalWrite (led_whitesN,HIGH);
digitalWrite (led_whitesM,LOW);
digitalWrite (led_park, LOW);
digitalWrite (led_reverse, LOW);
digitalWrite (led_neutral, LOW);
digitalWrite (led_white_assisted, LOW);
digitalWrite (led_white_handsfree, LOW);
digitalWrite (led_color_manual, HIGH);
digitalWrite (led_color_assisted, LOW);
digitalWrite (led_color_handsfree, LOW);
break;

```

```

case 5://car in park -> up to assisted available
digitalWrite (led_whitesP,LOW);
digitalWrite (led_whitesR,HIGH);
digitalWrite (led_whitesN,HIGH);
digitalWrite (led_whitesM,HIGH);
digitalWrite (led_park, HIGH);
digitalWrite (led_reverse, LOW);
digitalWrite (led_neutral, LOW);
digitalWrite (led_white_assisted, HIGH);
digitalWrite (led_white_handsfree, LOW);
digitalWrite (led_color_manual, LOW);
digitalWrite (led_color_assisted, LOW);
digitalWrite (led_color_handsfree, LOW);
break;

```



```
case 6://car in reverse -> up to assisted available
digitalWrite (led_whitesP,HIGH);
digitalWrite (led_whitesR,LOW);
digitalWrite (led_whitesN,HIGH);
digitalWrite (led_whitesM,HIGH);
digitalWrite (led_park, LOW);
digitalWrite (led_reverse, HIGH);
digitalWrite (led_neutral, LOW);
digitalWrite (led_white_assisted, HIGH);
digitalWrite (led_white_handsfree, LOW);
digitalWrite (led_color_manual, LOW);
digitalWrite (led_color_assisted, LOW);
digitalWrite (led_color_handsfree, LOW);
break;
```

```
case 7://car in neutral -> up to assisted available
digitalWrite (led_whitesP,HIGH);
digitalWrite (led_whitesR,HIGH);
digitalWrite (led_whitesN,LOW);
digitalWrite (led_whitesM,HIGH);
digitalWrite (led_park, LOW);
digitalWrite (led_reverse, LOW);
digitalWrite (led_neutral, HIGH);
digitalWrite (led_white_assisted, HIGH);
digitalWrite (led_white_handsfree, LOW);
digitalWrite (led_color_manual, LOW);
digitalWrite (led_color_assisted, LOW);
digitalWrite (led_color_handsfree, LOW);
break;
```

```
case 8://car in manual -> up to assisted available
```

```
digitalWrite (led_whitesP,HIGH);
digitalWrite (led_whitesR,HIGH);
digitalWrite (led_whitesN,HIGH);
digitalWrite (led_whitesM,HIGH);
digitalWrite (led_park, LOW);
digitalWrite (led_reverse, LOW);
digitalWrite (led_neutral, LOW);
digitalWrite (led_white_assisted, HIGH);
digitalWrite (led_white_handsfree, LOW);
digitalWrite (led_color_manual, HIGH);
digitalWrite (led_color_assisted, LOW);
digitalWrite (led_color_handsfree, LOW);
break;
```

```
case 9://car in assisted -> up to assisted available
digitalWrite (led_whitesP,HIGH);
digitalWrite (led_whitesR,HIGH);
digitalWrite (led_whitesN,HIGH);
digitalWrite (led_whitesM,HIGH);
digitalWrite (led_park, LOW);
digitalWrite (led_reverse, LOW);
digitalWrite (led_neutral, LOW);
digitalWrite (led_white_assisted, LOW);
digitalWrite (led_white_handsfree, LOW);
digitalWrite (led_color_manual, LOW);
digitalWrite (led_color_assisted, HIGH);
digitalWrite (led_color_handsfree, LOW);
break;
```

```
case 10://car in park -> up to handsfree available
digitalWrite (led_whitesP,LOW);
```

```

digitalWrite (led_whitesR,HIGH);
digitalWrite (led_whitesN,HIGH);
digitalWrite (led_whitesM,HIGH);
digitalWrite (led_park, HIGH);
digitalWrite (led_reverse, LOW);
digitalWrite (led_neutral, LOW);
digitalWrite (led_white_assisted, HIGH);
digitalWrite (led_white_handsfree, HIGH);
digitalWrite (led_color_manual, LOW);
digitalWrite (led_color_assisted, LOW);
digitalWrite (led_color_handsfree, LOW);
break;

case 11://car in reverse -> up to handsfree available
digitalWrite (led_whitesP,HIGH);
digitalWrite (led_whitesR,LOW);
digitalWrite (led_whitesN,HIGH);
digitalWrite (led_whitesM,HIGH);
digitalWrite (led_park, LOW);
digitalWrite (led_reverse, HIGH);
digitalWrite (led_neutral, LOW);
digitalWrite (led_white_assisted, HIGH);
digitalWrite (led_white_handsfree, HIGH);
digitalWrite (led_color_manual, LOW);
digitalWrite (led_color_assisted, LOW);
digitalWrite (led_color_handsfree, LOW);
break;

case 12://car in neutral -> up to handsfree available
digitalWrite (led_whitesP,HIGH);
digitalWrite (led_whitesR,HIGH);

```

```

digitalWrite (led_whitesN,LOW);
digitalWrite (led_whitesM,HIGH);
digitalWrite (led_park, LOW);
digitalWrite (led_reverse, LOW);
digitalWrite (led_neutral, HIGH);
digitalWrite (led_white_assisted, HIGH);
digitalWrite (led_white_handsfree, HIGH);
digitalWrite (led_color_manual, LOW);
digitalWrite (led_color_assisted, LOW);
digitalWrite (led_color_handsfree, LOW);
break;

case 13://car in manual -> up to handsfree available
digitalWrite (led_whitesP,HIGH);
digitalWrite (led_whitesR,HIGH);
digitalWrite (led_whitesN,HIGH);
digitalWrite (led_whitesM,HIGH);
digitalWrite (led_park, LOW);
digitalWrite (led_reverse, LOW);
digitalWrite (led_neutral, LOW);
digitalWrite (led_white_assisted, HIGH);
digitalWrite (led_white_handsfree, HIGH);
digitalWrite (led_color_manual, HIGH);
digitalWrite (led_color_assisted, LOW);
digitalWrite (led_color_handsfree, LOW);
break;

case 14://car in assisted -> up to handsfree available
digitalWrite (led_whitesP,HIGH);
digitalWrite (led_whitesR,HIGH);
digitalWrite (led_whitesN,HIGH);

```

```
digitalWrite (led_whitesM,HIGH);
digitalWrite (led_park, LOW);
digitalWrite (led_reverse, LOW);
digitalWrite (led_neutral, LOW);
digitalWrite (led_white_assisted, LOW);
digitalWrite (led_white_handsfree, HIGH);
digitalWrite (led_color_manual, LOW);
digitalWrite (led_color_assisted, HIGH);
digitalWrite (led_color_handsfree, LOW);
break;
```

```
/*case 15://car in assisted -> only automation available
```

```
digitalWrite (led_whitesP,LOW);
digitalWrite (led_whitesR,LOW);
digitalWrite (led_whitesN,LOW);
digitalWrite (led_whitesM,LOW);
digitalWrite (led_park, LOW);
digitalWrite (led_reverse, LOW);
digitalWrite (led_neutral, LOW);
digitalWrite (led_white_assisted, LOW);
digitalWrite (led_white_handsfree, HIGH);
digitalWrite (led_color_manual, LOW);
digitalWrite (led_color_assisted, LOW);
digitalWrite (led_color_handsfree, HIGH);
break;*/
```

```
case 15://car in handsfree -> up to handsfree available
```

```
digitalWrite (led_whitesP,HIGH);
digitalWrite (led_whitesR,HIGH);
digitalWrite (led_whitesN,HIGH);
digitalWrite (led_whitesM,HIGH);
```

```
digitalWrite (led_park, LOW);
digitalWrite (led_reverse, LOW);
digitalWrite (led_neutral, LOW);
digitalWrite (led_white_assisted, HIGH);
digitalWrite (led_white_handsfree, LOW);
digitalWrite (led_color_manual, LOW);
digitalWrite (led_color_assisted, LOW);
digitalWrite (led_color_handsfree, HIGH);
break;
```

```
/*case 17://enforced automated driving
```

```
digitalWrite (led_whitesP,LOW);
digitalWrite (led_whitesR,LOW);
digitalWrite (led_whitesN,LOW);
digitalWrite (led_whitesM,LOW);
digitalWrite (led_park, LOW);
digitalWrite (led_reverse, LOW);
digitalWrite (led_neutral, LOW);
digitalWrite (led_white_assisted, LOW);
digitalWrite (led_white_handsfree, LOW);
digitalWrite (led_color_manual, LOW);
digitalWrite (led_color_assisted, LOW);
digitalWrite (led_color_handsfree, HIGH);
break; */
```

```
case 100: //MRM
```

```
digitalWrite (led_whitesP,HIGH);
digitalWrite (led_whitesR,HIGH);
digitalWrite (led_whitesN,HIGH);
digitalWrite (led_whitesM,HIGH);
```

```

digitalWrite (led_park, HIGH);
digitalWrite (led_reverse, HIGH);
digitalWrite (led_neutral, HIGH);
digitalWrite (led_white_assisted, HIGH);
digitalWrite (led_white_handsfree, HIGH);
digitalWrite (led_color_manual, HIGH);
digitalWrite (led_color_assisted, HIGH);
digitalWrite (led_color_handsfree, HIGH);
}
}

```

```

void printString(){
//Serial.print(" , from here string:");
//Serial.print(" ");
Serial.print(steering);
Serial.print(",");
Serial.print(gas);
Serial.print(",");
Serial.print(brake);
Serial.print(",");
Serial.print(ledCaseVariable);
Serial.print(",");
Serial.print(reverse);
Serial.print(" ,");
Serial.print(currentMode);

```

```

//Serial.print(" , Usermovement = ");
//Serial.print(movementTo);
//Serial.print(" , manualmovement =");

```

```

//Serial.print(manualMovement);
//Serial.print(" , currentMode = ");
//Serial.print(currentMode);
//Serial.print(" , automationHandleMovement = ");
//Serial.print(movementHandle);
//Serial.print(" ,");
//Serial.print(" , Actual Angle = ");
//Serial.print(actualAngle);
//Serial.print(" , Set Angle = ");
//Serial.print(" ,");
//Serial.print(setAngle);
//Serial.print(" , urgency = ");
//Serial.print(",");
//Serial.print(urgency);
//Serial.print(" , availableModes = ");
//Serial.print(availableModes);
//Serial.print(" , motorCaseVariable = ");
//Serial.print(" ,");
//Serial.print(motorCaseVariable);
//Serial.print(" ,");
//Serial.print(oldAngle);
//Serial.print(" , movementHandle = ");
//Serial.println(movementHandle);

}

```


Unity Code:

Script 1 – Speedchecker

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using UnityEngine.UI;

public class SpeedChecker : MonoBehaviour
{
    //object waar je de snelheid van meet
    public Rigidbody carObject;
    public float speed;
    //object waar je de tekst van wilt veranderen
    public Text textObject;
    // Start is called before the first frame update
    void Start()
    {

    }

    // Update is called once per frame
    void Update()
    {
        speed = carObject.velocity.magnitude * 4.5f;
        textObject.text = (int)speed + " Km/h";
    }
}
```

Script 2 – DetermineDisplayState

```
using System;
using System.Collections;
using System.Collections.Generic;
using UnityEngine;

public class DetermineDisplayState : MonoBehaviour
{
    public ArduinoCommunication arduinoScript;
    public List<GameObject> imageList;
    public int displayState;
    public List<GameObject> warningList;
    public int warningState = 0;

    // Start is called before the first frame update
    void Start()
    {
        displayState = 0;

        foreach (GameObject warning in warningList)
        {
            warning.SetActive(false);
        }
        UpdateState();
    }

    // Update is called once per frame
    void Update()
    {
        displayState = arduinoScript.displayState;
        if (Input.GetButtonDown("Fire1"))
        {
            Next();
        }

        if (Input.GetKeyDown(KeyCode.G))
        {
            warningState = 0;
            UpdateWarning();
        }
        if (Input.GetKeyDown(KeyCode.H))
        {
            warningState = 1;

            UpdateWarning();
        }
        if (Input.GetKeyDown(KeyCode.J))
        {
            warningState = 2;
            UpdateWarning();
        }
        if (Input.GetKeyDown(KeyCode.K))
        {
            warningState = 3;
            UpdateWarning();
        }
        if (Input.GetKeyDown(KeyCode.L))
        {
            warningState = 4;
            UpdateWarning();
        }
    }
}
```

```

    }

    MRMessage();
    ErrorMessage();
    UpdateState();
}

void UpdateState()
{
    foreach (GameObject imageObj in imageList)
    {
        imageObj.SetActive(false);
        imageList[displayState].SetActive(true);
    }
}

public void Next()
{
    displayState++;
    if (displayState >= imageList.Count) { displayState = 0; }
    // !! vanaf hier wel

    //update de state naar het nummer dat je wilt begint met 0
    UpdateState();
}

public void MRMessage()
{
    if (arduinoScript.displayState == 16)
    {
        warningState = 5;
        ActivateWarning(5);
    }
    else
    {
        DisableWarning(5);
    }
}

public void ErrorMessage()
{
    if(arduinoScript.displayState == 0)
    {
        warningState = 6;
        ActivateWarning(6);
    }
    else
    {
        DisableWarning(6);
    }
}

public void ActivateWarning(int i)
{

```

```

        warningList[i].SetActive(true);
    }

    public void DisableWarning(int i)
    {
        warningList[i].SetActive(false);
    }

    public void UpdateWarning()
    {
        //staat de warning aan?
        if (warningList[warningState].activeSelf)
        {
            //zet uit
            warningList[warningState].SetActive(false);
        }
        //ander zet aan
        else { warningList[warningState].SetActive(true); }
    }
}

```

Script 3 – ArduinoCommunications

```

using System;
using System.Linq;
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using System.IO.Ports;

public class ArduinoCommunication : MonoBehaviour
{
    SerialPort serial = new SerialPort("COM4", 9600);

    public string arduinoSerialString;
    public List<int> values = new List<int>();
    public int steeringWheelAngle;
    public int brakeValue;
    public int gasValue;
    public int automationSteering;
    public int automationGasBrake;
    public int displayState;
    public int reverse;

    // Update is called once per frame
    void Update()
    {
        //Debug.Log(arduinoSerialString);
        if (!serial.IsOpen)
            serial.Open();

        arduinoSerialString = serial.ReadLine();
        values = arduinoSerialString.Split(',').Select(int.Parse).ToList();
        steeringWheelAngle = (int)(values[0] * -0.58f);
        brakeValue = values[1];
        gasValue = values[2];
        if(gasValue < 10) { gasValue = 0; }
        displayState = values[3];
        Debug.Log(displayState);
        if (displayState == 100) { displayState = 16;} //this is the MRM code
        reverse = values[4];

        // transform.localEulerAngles = new Vector3(0, rotate, 0);
    }
}

```

Script 4 – CameraFollow

```

using System;
using System.Collections;
using System.Collections.Generic;
using UnityEngine;

public class CameraFollow : MonoBehaviour
{
    [SerializeField] private Vector3 offset;
    [SerializeField] private Transform target;
    [SerializeField] private float translateSpeed;
    [SerializeField] private float rotationSpeed;

    // Start is called before the first frame update
    void FixedUpdate()
    {
        HandleTranslation();
        HandleRotation();
    }

    private void HandleTranslation()
    {
        var targetPosition = target.TransformPoint(offset);
        transform.position = Vector3.Lerp(transform.position, targetPosition,
        translateSpeed * Time.deltaTime);
    }

    private void HandleRotation()
    {
        var direction = target.position - transform.position;
        var rotation = Quaternion.LookRotation(direction, Vector3.up);
        transform.rotation = Quaternion.Lerp(transform.rotation, rotation,
        rotationSpeed * Time.deltaTime);
    }
}

```

Script 5 – CarController

```

using System;
using System.Collections;
using System.Collections.Generic;
using UnityEngine;

public class CarController : MonoBehaviour
{
    public ArduinoCommunication arduinoScript;

    private float horizontalInput;
    private float verticalInput;
    private float steerAngle;
    private bool isBreaking;

    public WheelCollider frontLeftWheelCollider;
    public WheelCollider frontRightWheelCollider;
    public WheelCollider rearLeftWheelCollider;
    public WheelCollider rearRightWheelCollider;
    public Transform frontLeftWheelTransform;
    public Transform frontRightWheelTransform;
    public Transform rearLeftWheelTransform;
    public Transform rearRightWheelTransform;

    public float maxSteeringAngle = 30f;
    public float motorForce = 50f;
    public float brakeForce = 0f;

    private void FixedUpdate()
    {
        GetInput();
        HandleBreaking();
        HandleMotor();
        HandleSteering();
        UpdateWheels();
    }

    private void GetInput()
    {
        if(arduinoScript.displayState == 9 || arduinoScript.displayState == 14 ||
arduinoScript.displayState == 15)
        {
            if (arduinoScript.brakeValue < 10f && arduinoScript.gasValue < 10f)
            {
                horizontalInput = Input.GetAxis("Horizontal");
                verticalInput = Input.GetAxis("Vertical");
            }
            else
            {
                horizontalInput = arduinoScript.steeringWheelAngle / 100f;
                verticalInput = arduinoScript.gasValue / 100f;
            }
        }
        else if(arduinoScript.displayState == 12 || arduinoScript.displayState == 10
|| arduinoScript.displayState == 7 || arduinoScript.displayState == 5 ||
|| arduinoScript.displayState == 3 || arduinoScript.displayState == 1 ||
|| arduinoScript.displayState == 16)

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        {
            horizontalInput = Input.GetAxis("Horizontal");
            verticalInput = Input.GetAxis("Vertical");
        }
        else
        {
            horizontalInput = arduinoScript.steeringWheelAngle / 100f;
            verticalInput = arduinoScript.gasValue / 100f;
        }

        if(arduinoScript.reverse == 1)
        {
            verticalInput = verticalInput * -1;
        }
    }
    private void HandleBreaking()
    {
        if (arduinoScript.displayState == 9 || arduinoScript.displayState == 14 ||
arduinoScript.displayState == 15)
        {
            if (arduinoScript.brakeValue < 10f && arduinoScript.gasValue < 10f)
            {
                isBreaking = Input.GetKey(KeyCode.Space);
            }
            else
            {
                if (arduinoScript.brakeValue > 10f)
                {
                    isBreaking = true;
                }
                else
                {
                    isBreaking = false;
                }
            }
        }
        else if(arduinoScript.displayState == 12 || arduinoScript.displayState == 10
|| arduinoScript.displayState == 7 || arduinoScript.displayState == 5 ||
arduinoScript.displayState == 3 || arduinoScript.displayState == 1 ||
arduinoScript.displayState == 16)
        {
            isBreaking = Input.GetKey(KeyCode.Space);
        }
        else
        {
            if (arduinoScript.brakeValue > 10f)
            {
                isBreaking = true;
            }
            else
            {
                isBreaking = false;
            }
        }
    }
}

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private void HandleSteering()
{
    steerAngle = maxSteeringAngle * horizontalInput;
    frontLeftWheelCollider.steerAngle = steerAngle;
    frontRightWheelCollider.steerAngle = steerAngle;
}

private void HandleMotor()
{
    frontLeftWheelCollider.motorTorque = verticalInput * motorForce;
    frontRightWheelCollider.motorTorque = verticalInput * motorForce;

    brakeForce = isBreaking ? 3000f : 0f;
    frontLeftWheelCollider.brakeTorque = brakeForce * arduinoScript.brakeValue
/10;
    frontRightWheelCollider.brakeTorque = brakeForce * arduinoScript.brakeValue
/10;
    rearLeftWheelCollider.brakeTorque = brakeForce * arduinoScript.brakeValue /10;
    rearRightWheelCollider.brakeTorque = brakeForce * arduinoScript.brakeValue
/10;
}

private void UpdateWheels()
{
    UpdateWheelPos(frontLeftWheelCollider, frontLeftWheelTransform);
    UpdateWheelPos(frontRightWheelCollider, frontRightWheelTransform);
    UpdateWheelPos(rearLeftWheelCollider, rearLeftWheelTransform);
    UpdateWheelPos(rearRightWheelCollider, rearRightWheelTransform);
}

private void UpdateWheelPos(WheelCollider wheelCollider, Transform trans)
{
    Vector3 pos;
    Quaternion rot;
    wheelCollider.GetWorldPose(out pos, out rot);
    trans.rotation = rot;
    trans.position = pos;
}
}

```