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Connected and Automated Vehicles in the Making: The Socio-Technical Construction of Future “Drivers”

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Vernetzte und automatisierte Fahrzeuge, gesellschaftliche Perspektive, Nutzer:innenanforderungen, sozio-technische Perspektive, Transformation

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Vernetzte und automatisierte Fahrzeuge in der Entstehung: Die sozio-technische Konstruktion zukünftiger "Fahrer:innen"

In der Wissenschaft wurden vernetzte und automatisierte Fahrzeuge (Connected and Automated Vehicles, CAVs) bisher vor allem hinsichtlich technischer Fragen untersucht, die mit ihrer Entwicklung einhergehen sowie auf die vielversprechenden Auswirkungen, sobald diese Technologie eingesetzt werden kann. CAVs werden als Antwort auf aktuelle gesellschaftliche Herausforderungen wie die Verkehrsüberlastung in den Städten oder Umweltprobleme der Automobilität angesehen. In dem Versuch, die gesellschaftliche Dimension in den Diskurs einzubeziehen, konzentriert sich der vorliegende Bericht auf eine zentrale Frage: Welche Art von CAVs wollen wir als Gesellschaft haben? Unter Verwendung theoretischer Perspektiven aus der politischen Theorie, den Wissenschafts- und Technologiestudien, der psychologischen Mensch-Computer-Interaktion und Akzeptanzstudien argumentieren wir, dass die Automatisierung im Wesentlichen ein Prozess des soziotechnischen Austauschs und nicht nur eine Frage der technischen Umsetzung ist. Die Übersetzung des manuellen Fahrens in eine algorithmische Logik (d.h. die Automatisierung) impliziert eine Neukonfiguration des sozialen Geflechts des Verkehrs - was in der derzeitigen Governance von CAVs nicht erfasst wird. Um dieses neue Forschungsfeld zu erkunden, verwenden wir analytisch-deduktive Methoden auf der Grundlage vorhandener Literatur, Interviews und Fokusgruppen mit relevanten Akteursgruppen (Hersteller, Regierung und Öffentlichkeit). Um dieses neue Forschungsfeld zu beschreiben, schlagen wir zwei analytische Perspektiven vor, die die sozio-technischen Dimensionen des Verkehrs explizit machen: den Betriebsmodus von Fahrzeugen und das Organisationsprinzip des Verkehrs. Anhand dieser Konzepte definieren wir, wie sich CAVs etablieren können und welche Konsequenzen sich daraus ergeben können.

Der vorliegende Bericht zeigt vor allem, dass die derzeitigen Konzepte für CAVs zu sehr auf technische Fragen ausgerichtet sind, anstatt gesellschaftliche Perspektiven in die Entwicklung einzubeziehen. Wir betonen die Notwendigkeit, die gesellschaftliche Perspektive in dieser Entwicklung zu stärken.

Zweitens kann die Anwendung eines solchen soziotechnischen Ansatzes bei der Entwicklung von CAVs die erwarteten Ergebnisse mit den potenziellen Folgen in Einklang bringen, insbesondere solange die Vision noch nicht in greifbare Systeme, einen Betriebsmodus, umgesetzt worden ist. Wir schlagen vor, die Entwicklung der zukünftigen "Treiber" auf die gesellschaftlichen Ziele von CAVs auszurichten. Das bedeutet eine konkrete Diskussion über die Entwicklung eines Betriebsmodus und konsistenter Betriebsprinzipien von CAVs mit wissenschaftlichen Ansätzen.

Die dritte Schlussfolgerung, die wir präsentieren, ist, dass potenzielle Konflikte über den Wert der Automobilität im Gegensatz zu neu entstehenden automatisierten Anwendungen entstehen können, da Homogenisierung (Voraussetzung für jede Form von CAVs) und heterogene Strategien (aktuelle Governance) in starken Gegensatz zueinander stehen. Die Automobilität, wie wir sie heute kennen, wird sich grundlegend verändern. Nicht nur technische Aspekte, sondern auch das gesellschaftliche Verständnis. Sichtbar wird dies am Grad der Verschränkung vom heutigen Auto und CAVs der Zukunft, der zeigt, dass die (gefühlte) Freiheit der Automobilität mit der Vernetzung und Automatisierung von Fahrzeugen keinen Bestand mehr haben kann.

Der letzte Aspekt, den wir ansprechen, ist, dass zu erwarten ist, dass sich CAVs in unterschiedlichen Formen über kulturelle oder politische Grenzen und soziale Gruppen hinweg stabilisieren. Darauf aufbauende Studien sollten einen besonderen Schwerpunkt auf die persönlichen und gesellschaftlichen Anforderungen an CAVs legen. Darüber hinaus muss die künftige Forschung diese interdisziplinäre Erkundung eines neuen Forschungsfeldes mit spezifischen Untersuchungen bereichern.

Connected and automated vehicles, societal perspective, user requirements, socio-technical perspective, transformation

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Connected and Automated Vehicles in the Making: The Socio-Technical Construction of Future "Drivers"

Connected and automated vehicles (CAVs) have enjoyed much attention from scholars on the technical issues that accompany their development and the promising effects once this technology is deployed. CAVs are positioned as the answer to contemporary societal challenges such as urban congestion or environmental concerns of automobility. In an attempt to incorporate social dimensions into the discourse, this report gravitates around one central question: what kind of CAVs do we want to have as a society? By employing theoretical perspectives from political theory, science and technology studies, psychological human-computer interaction and acceptance studies, we make the case that automation is fundamentally a process of socio-technical exchange rather than a matter of technical implementation. The act of translating manual driving into algorithmic logic (i.e. automation) implies a reconfiguration of the social weave of transportation - which is not captured in current governance of CAVs. To explore this new research field, we use analytical-deductive methods on existing literature, interviews and focus groups with relevant actor groups (manufacturers, government and publics). To unravel this new research field, we propose and employ two analytical perspectives that render the socio-technical dimensions of transportation explicit: the operating modus of vehicles and the organizing principle of transportation. By employing these concepts, we define the ways in which CAVs can stabilize and the consequences that may arise. The present report shows, first of all, that current conceptions of CAVs are too focused on technical issues rather than incorporating societal perspectives into the development. We emphasize the need to strengthen the societal perspective in this development.

Secondly, that employing such a socio-technical approach on CAV development can streamline the expected results with potential outcomes, especially as long as the vision has not yet materialized into tangible systems, an operating modus. We propose to direct the development of the future "drivers", towards the societal goals of CAVs. That means a concrete discussion about the development of an operating modus and consistent operating principles of CAVs with scientific approaches. The third conclusion that we present is that potential conflicts may arise as to the value of automobility in contrast to emerging automated applications, as homogenization (requirement for any form of CAVs) and heterogeneous strategies (current governance) lie in stark contrast. The automobility, as we know it today, will change fundamentally. Not only technical aspects, but also the societal understanding. This gets visible with the degree of encrustation of the car of today and CAVs of the future, which shows that the (perceived) freedom of automobility can not endure with the connection and automation of vehicles. The last aspect that we touch on is that it can be expected that CAVs stabilize in different forms across cultural or political boundaries and social groups. Studies based on this should have a particular focus on personal versus societal demands on CAVs. Furthermore, future research needs to enrich this interdisciplinary exploration of a new research field, with specific investigation.

Connected and Automated Vehicles in the Making

The Socio-Technical Construction of Future "Drivers"

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List of Abbreviation

CAM	Connected and Autonomous Mobility
CAV	Connected and Autonomous Vehicles
DiVa	Project: Societal dialogue for connected and autonomous vehicles
ERTRAC	European Road Transport Research Advisory Council
EU	European Union
USA	United States of America
SCOT	Social Construction of Technology

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Management Summary

Connected and automated vehicles (CAVs) have enjoyed much attention from scholars on the technical issues that accompany their development and the promising effects once this technology is deployed. CAVs are positioned as the answer to contemporary societal challenges such as urban congestion or environmental concerns of automobility. In an attempt to incorporate social dimensions into the discourse, this report gravitates around one central question: what kind of CAVs do we want to have as a society? By employing theoretical perspectives from political theory, science and technology studies, psychological human-computer interaction and acceptance studies, we make the case that automation is fundamentally a process of socio-technical exchange rather than a matter of technical implementation. The act of translating manual driving into algorithmic logic (i.e. automation) implies a reconfiguration of the social weave of transportation - which is not captured in current governance of CAVs. To explore this new research field, we use analytical-deductive methods on existing literature, interviews and focus groups with relevant actor groups (manufacturers, government and publics). To unravel this new research field, we propose and employ two analytical perspectives that render the socio-technical dimensions of transportation explicit: the operating modus of vehicles and the organising principle of transportation. By employing these concepts, we define the ways in which CAVs can stabilise and the consequences that may arise. The present report shows, first of all, that current conceptions of CAVs are too focused on technical issues rather than incorporating societal perspectives into the development. We emphasize the need to strengthen the societal perspective in this development.
Secondly, that employing such a socio-technical approach on CAV development can streamline the expected results with potential outcomes, especially as long as the vision has not yet materialised into tangible systems, an operating modus. We propose to direct the development of the future "drivers", towards the societal goals of CAVs. That means a concrete discussion about the development of an operating modus and consistent operating principles of CAVs with scientific approaches. The third conclusion that we present is that potential conflicts may arise as to the value of automobility in contrast to emerging automated applications, as homogenisation (requirement for any form of CAVs) and heterogeneous strategies (current governance) lie in stark contrast. The automobility, as we know it today, will change fundamentally. Not only technical aspects, but also the societal understanding. This gets visible with the degree of encrustration of the car of today and CAVs of the future, which shows that the (pervceived) freedom of automobility can not endure with the connection and automation of vehicles. The last aspect that we touch on is that it can be expected that CAVs stabilise in different forms across cultural or political boundaries and social groups. Studies based on this should have a particular focus on personal versus societal demands on CAVs. Furthemore, future research needs to enrich this interdisciplinary exploration of a new research field, with specific investigation.

1. Introduction

Long-term social trends that, according to Borman et al. (2018), can be summarized in digitalization, environmental problems, urbanization and individualization, increasingly question the established mobility system. Therefore, there is a general pressure for action in the mobility sector, especially on the car. On the one hand the car does not seem compatible with these trends and on the other hand it is the most widely used means of transport in many societies. Against this background, one can undoubtedly state that automobility is in a fundamental process of change. The change process concerns a) the conversion from the internal combustion engine to electric vehicles, b) new market practices through mobility as a service (MaaS) and platform economic business models, and c) the automation of driving. In the present paper we want to focus on the last process: the automation of driving.

When engaging with the research field of connected and automated vehicles (CAVs) two basic observations can be made: firstly, scholarship concerned with the development of CAVs highly gravitates around technical issues and is highly motivated by instrumental understandings of technology. Finding the answer to societal problems are mere technical challenges that are needed to be overcome. Secondly, potential effects once this technology is deployed, paint a primarily optimistic picture. This picture justifies the unconditional backing from both governmental bodies and the automotive industry by positioning CAVs as the answer to contemporary societal problems. This is consistent with the Declaration of Amsterdam of 2016, a document that serves as a manifesto of CAV-development, signed by all EU member states. The declaration creates an axiom, namely that for improving traffic flow and making transport safer, cleaner and easier, CAVs offer excellent opportunities. Other positives such as social inclusion, improved mobility services in rural areas and cities, the development of mobility as a service, flexibility in door-to-door mobility, and lower travel costs are expected. And the Declaration of Amsterdam emphasizes the economic benefits for the European economy as well as effects on the topics of shared economy, decarbonization of transport and the transition to a zero-emission society as well as the circular economy. That means, right now CAVs are communicated as an important part of the solution for the prevailing great challenges of mobility such as urbanization, sustainability, digitalization and individualization of transport demand and a development that is only followed by positives (see Borman et al. 2018). But is it really that easy?

We state *no*, as the fulfillment of the optimistic vision of CAVs is highly tied to decisions about their development in the first place. To exemplify this, a simple thought-experiment suffices: CAVs that operate under the mantra “freedom for drivers” will elicit different effects than CAVs that follow an “energy efficiency” strategy. The former materialises in a fast driving sport-mode and maybe an easier-to-throttle gas pedal, and the latter energy-efficient deceleration and acceleration patterns. Beyond that, also the human behaviour “behind the wheel” and its strategies have to be considered. For example, one can drive aggressively or defensively, considerately or selfishly, sporty or dignified – with each strategy having an effect on others’ strategies and consequently on overall traffic flow, energy consumption and other direct and indirect effects. Translating human driving into CAVs, meaning a logic or rather a machine, is thus not a purely technical, algorithmic, process. Much rather, it is a translation that inherently carries normative decisions that are inscribed into the design of CAVs. Fundamentally, it is the design of the artificial character “behind-the-wheel” – or rather, “in the car” - which is open and in need of deliberation.

Research on CAVs to date primarily focuses on, firstly, the effects of introducing CAVs in our current transport system and on different user groups, and, secondly, the investigation of very specific traffic situation in our current transport system. About the first focus, academic work that investigates the effects of the introduction of CAVs, was for example done by Milakis and van Arem in 2017. According to the authors, scholarship on CAVs can be categorised into three parts: direct effects, which include aspects such as reduced capacity, better resource consumption, lower emissions and decreased rate of accidents. These, according to the authors, amplify correlating to the degree of technology adoption and implementation. Second order effects, which include reduced vehicle ownership and sharing, more location choices and land use due to accessibility and land use, and transport infrastructure. And finally, catalytic effects, which trickle down on aspects of energy consumption, air pollution, safety, social equity, economy, and public health (Milakis and van Arem 2017). About the second focus, literature reveals that right now the discourse focuses on “selected parameters” of traffic situations, inspected through the lens of different computational models and in interaction with specific user groups. These however only look at particular aspects of automation “in isolation” linked to their specific operation such as platooning, changing lanes on highways, traffic jams, strategies of traffic management etc. (e.g. Alghuson et al. 2019, Diakaki et al. 2015, McConky and Rungta 2019). That means, whilst there is research done on isolated micro-situations (see e.g. Amirgholy et al. 2019, Guo et al. 2019, Guanetti et al. 2018), qualitative estimations of secondary rebound effects (see e.g. Anderson et al. 2014, Wadud et al. 2016, Milakis et al 2017, Fraedrich et al. 2019), planning and policy requirements (see e.g. Matyas and Kamargianni 2018, Bahamonde Birke et al. 2018, Hopkins and Schwanen 2018, Skeete 2018), there is little discussion about robotaxis or other forms of CAVs from a wider, systemic point of view, with which the complexity of this topic can be systematized and described. That these aspects are only one little part can be underlined by the Theory of Social Construction of Technology (Pinch and Bijker, 1987). In short, this theory assumes that technology is brought to life and constructed by an underlying web of social interactions and connections. Technology, in the sense of its technical artefacts and isolated, specific operations, has no meaning; but is embedded in a social context. Hence, social construction of technology always understands any technological context as a socio-technical constellation, where the success of a technology is not the explanation in itself. To our knowledge, this systemic perspective, including the social web around CAVs is largely unexplored and there is a lack of appropriate research.

There is a variety of options for how CAVs and the future transportation system can be designed: Is traffic control in the urban environment centralized dirigiste? Will there be a difference between robotaxis by public actors (today's public transport operators) and private companies (Mobility as a Service)? Who will be given priority in traffic flow and under what conditions? Who will be granted which individual decisions and individual driving strategies? How must individual vehicle behavior be programmed in order to achieve, for example, ecological and/or social and/or economic goals? These are all examples of questions, among many others, that demand answers and decisions in the construction of CAVs. To manage this process responsibly - i.e., in a way that takes such contradictions into account before technological developments produce ill-considered consequences - collaborative planning - introducing an agenda - helps align the development and design of CAVs with expectations of the technology.

This follows that navigating the design of CAVs is a high-stake political process, which requires anchor points that allow for the consideration of normative questions in the discourse between techno-optimistic political actors, manufacturers driven by economic interests and the needs of the public. In order to formulate such an agenda, this new field of research must first be explored, sounded out, and defined. This is the aim of the present paper and leads us to our research question: What kind of CAVs do we want to have on our streets and as a society, a) showing which behavior, b) implying which impact and c) how can we negotiate their behaviour while the technology is “in-the-making”?

2. Methodology

After defining our research question, we, firstly, reviewed existing literature gravitating around (technical) studies concerned with CAVs and science and technology studies. What we found were on the one hand socio-technical theories (e.g. digitalization is coming) and on the other hand Human Machine Interaction research dealing with very specific traffic situations with CAVs (e.g. turning off with a CAV in a specific traffic situation). What is lacking is the part in the middle of these two fields: the realization of CAVs, meaning, the translation of the human driving strategies into CAVs. From our literature review we saw that, to our knowledge, this research field was neither theorized nor conceptualized until now. So far, the conflict was neglected that, on the one hand, people already have individual driving strategies (e.g. sporty, safe, green, …) and corresponding expectations, how a CAV should drive. On the other hand, CAVs should serve certain promises (e.g. making cars greener, safer, more social, …) that may not be attainable, depending on the chosen strategy for CAVs. Both aspects will influence the selection of the strategy or strategies of CAVs and lead to different effects (e.g. greener, safer, more social cars), depending on which will be chosen. We assume, there can be no maximum of strategies (perfect individuality) with a maximum achievement of goals (see Figure 1).

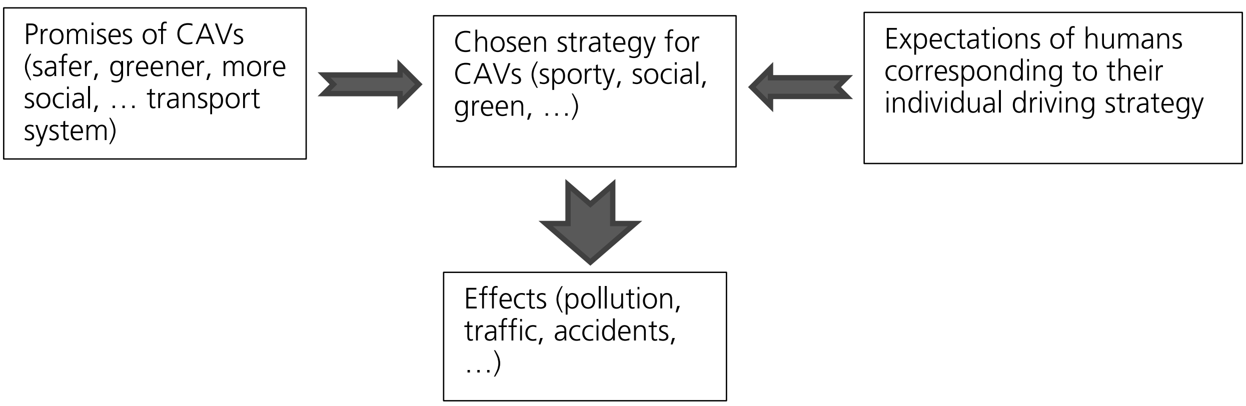

Figure 1. The influence of promises, and expectation about CAVs on the chosen driving strategy of CAVs and its different effects.

After this finding we, secondly, started to describe this research gap. We analyzed other transport systems to identify anchor points of the new research field. In some cases, we could apply theories (e.g. game theory, social construction of technology) to explain the identified anchor points.

To support this empirically, thirdly, data from interviews with representatives of different actor groups and a focus group was included. These come from a larger research project of the German Aerospace Centre called DiVA that was conducted on behalf of the German Federal Ministry of Transport and Digital Infrastructure. The aim of this project was to enable a dialogue between different publics and stakeholders with manufacturers and governing bodies about CAVs, rendering this project very close to the discussion that is led in this report (see Lenz et al. 2020). We derived and conceptualize two analytical tools aiming to create a methodological basis for shaping this new research field. The goal of this empirical work was to determine the current regime and how future scenarios have to be formulated.

To realize this we, lastly, wrote a use-case. With this, we showed the relevance of this research field and the current gap between theory and realization of CAVs.

In the present paper, these four parts result in a discussion of a new research field, gathering around the design of CAVs, meaning the translation of the human into CAVs, measurements that should be taken to achieve as many as possible of the promised goals of CAVs, and effects that can be expected, depending on the chosen realization.

3. The social-technical construction of transportation systems

Transport systems show structural and hierarchical "system horizons" defined by the technical infrastructure on which they are built. This can be a superficial differentiation, such as "road" or "rail", or on a deeper level "trucks" and "automobiles" for the road system and "locomotive" or "subway" for the "rail". Transport systems are thus divided into subsystems that hierarchically form a supersystem. The question that results is: what are the differences between these systems? For example, what are the differences between subsystems and how can we delineate the boundaries? If we inspect the subsystems motorcycle and automobile in relation to the supersystem road, both follow the same set of laws, both show similar license requirements etc. – yet, one system requires the driver to wear a helmet, the other requires a seatbelt. Of course, inspecting them with such detail, there are limitless differences that can be listed. However, what can we learn from these differences upon inspection? We want to argue that the dynamics between sub- and supersystems are fertile ground for mining for indicators that delineate the boundaries of operating modi. Furthermore, we want to extend the argument. Adding a geographical dimension to this analysis, we can observe different operating modi across cultures. If we look at American and Asian cities, we already see fundamental differences in the two operating modi of the same vehicle: in places where the motorcycle is a dominant vehicle in the overall transport landscape, an entirely different traffic culture develops as opposed to automobile-heavy urban landscapes. Extending our view beyond the supersystem "road", we see that entirely different operating modi are established for transportation systems that do not share the same infrastructure, as it is with rail-based systems or in aviation. It surfaces that operating modi are characterised by rules that evoke social order in the hierarchical technical structure (subsystem, supersystem) in which they are situated in. In order to notice the differences that indicate this thinking, a helping question can be brought to mind when inspecting these different everyday-situations of transportation: what generates order and how does it differ between these forms of transportation?

Turning to literature that specifically asks these kind of questions, e.g. large technological systems (Hughes 1987), social construction of technology (Pinch and Bijker 1987), or socio-technical systems / regimes (Berger and Luckmann 1966, Rip and Kamp 1998, Geels 2002), we can highlight the surrounding aspects that, together, are part of the larger network of the operating modus: the technical artefacts (existing infrastructure for instance), political regulation, scientific advancements, industrial possibilities or cultural currents of users. On the one hand, they are all acting independently within the boundaries of their own networks, but do show, on the other hand, relational connections that do have to be considered. Turning to electromobility for instance, we can observe how this new technology comes with fundamentally different features than those that already-established technology provides: the range, process of "refuelling", costs, value chains, policy etc. Such, possibly some overlapping, aspects are subject to change if CAVs are to take to the roads. Notably however, it is important to distinguish the operating modus from the socio-technical system (regime): A technological regime is the material and non-material environment, the artefacts and processes that make for a technology to become performable. The operating modus however is delimited through the interactions with the regime: the sets of rules, the inscribed possibilities that are delineated by material artefacts ("lanes" implying spatial for driving), the structures that are constructed to generate order in an otherwise messy, entangled accumulation of artefacts and entities. Finally, the operating modus manifests in the behaviour of participants – both human (drivers) and non-human (CAVs). As such, the operating modus is be situated on the interface with the socio-technical regime in which it is embedded; made visible by reflecting on the interactions. To empirically support this differentiation and make for understanding as to the themes, different aspects of the socio-technical regime of "automobility" were constructed in a joint workshop and supported by expert interviews. The resulting dimensions with descriptions for each can be seen in appendix 1 of this document. It is helpful to ask oneself, when inspecting these aspects, what constructs are built that generate order between all these aspects. This is what we call the operating modus.

To further approximate our definition of the operating modus of vehicles, we want to elaborate on what is meant by the word "rules" in a socio-technical understanding of transportation. We want to emphasize the multiplicity of the term as the fundamental definition of itself. That is, rules can be of legislative nature set by authorities, statically communicated through signs (e.g. stop signs, parking areas), collectively emerging (e.g. driving slower in heavy rain, slightly over-speeding socially accepted), individually decided (e.g. distance that subjectively feels safe, calling while driving) or inscribed into technical artefacts (e.g. markers on roads or kerbs imply certain behavioural rights and wrongs). There are of course further details, for example how rules emerge, the consequences they carry, etc. We can say that transportation abides and is framed by a multitude of rules that elicit order. To further conceptualise this thinking, it is important to emphasise that rules adhere to two aspects (in this context): I. they are attached to processes and have to serve functions, and II. they inherently are subject to decisions that imply a weighing of possibilities.

I. Processes and functions: These are actions that are necessary for participation and interaction in traffic (including e.g. licenses, overtaking, minimum distances etc.). which can be, more or less, standardized. To specify, for "overtaking an automobile" there is a semi-standardized succession of actions, that is: indicate – shoulder check left side – change lane – indicate – shoulder check right side – change lane. And, a law described in section 5 paragraph 1 of the German road traffic regulations that requires cars to only overtake on the left side on the Autobahn. Standardised are also characteristics of the indicator itself (frequency, colour, etc.). Not standardized however is the speed with which overtaking can take place or the distance to approaching, overtaking cars on the left lane when changing lanes. This illustrates the differences and thus the need for stricter clearance, as CAVs will, with a high degree of certainty, need to have these processes and functions fully standardized as part of their operating modi.

II. Decisions: Processes and functions of transportation are subject to decisions. For example, when to start the succession of actions for overtaking a car. Decisions are thus an elemental aspect of the degree of freedom that processes and functions are attached to, which can happen in a centralized or decentralized fashion. Let us turn to dynamic traffic management for an example of decentralization of decisions. Let us imagine a maximum allowed velocity of 80km/h on an urban highway. However, as it is peak hours, an increased density of traffic occurs that is indicating an emerging congestion. In this situation, one centralised system could calculate a new optimal velocity that, in combination with a prohibition to overtake other vehicles, could potentially avoid congestion. To communicate this, dynamically changing signs alongside the highway are placed. Nonetheless, even though the change in governing rules was decided centrally, manual drivers could still exceed the maximum velocity, acting counter-productively towards avoiding a congestion, as a decentralised freedom of "execution" exists (manual driving). With CAVs however, such dynamic recommended maximum velocities could be transmitted electronically and binding the automobiles to the governing rules without the freedom to exceed the velocity.

These rules, whether officially pronounced as in policies or informally agreed upon between social actors, material in the form of signs or implicit as in heavy snowfall, form the framework in which we find what we describe as the operating modus of vehicles. To be exact, they delineate the space that behaviour occupies. This means that by changing the framework, behaviour changes as well. Even though different vehicles may share the same technical infrastructure, they operate differently, which surfaced in the web of rules of operation that they abide. Inherently, such rules lead to the stripping away of ways to behave. Their nature is to limit action in order to organise an otherwise messy process: transportation. And the operating modus of vehicles, which the next chapter will introduce, allows to do exactly that – decontextualise the messiness of transportation into the instances of socio-material ordering of things.

3.1. Operating Modus of Vehicles

Why is it important to be aware of these differences? Why does the operating modus matter? This perspective allows the question: how willing are we to give up on our individual freedom for the collective good? And puts society in first place of this controversial question, independent of the scenario of CAVs, whether a hybrid transportation reality (manual and automated) or a fully automated scenarios that are being deliberated (robo-taxis). It is implied that automation would likely strip away the notions of individuality and independence and freedom attached to the (manual) automobile today, as centralized or decentralized decision-making would mean either the restriction of individual behavioural freedom (individual behaviour), or a homogeneity of vehicles (conditional behaviour). When vehicles operate almost entirely under standardised functions and processes, it can be described as a systematic dependence. To the contrary, when very little standardisation and a high amount of decentralised decision making prevails, it results in low systematic dependence. This attribute thus increases the rigidness, the encrustation, of the operating modus. Simultaneously, the degree of optimisation increases, as the nature of standards is to prevent misbehaviour, inefficiencies or vulnerabilities, developed and incorporated into the operating modus over time. We want to define this phenomenon as the 'encrustation' of operating modi: the level of systematic dependence between the standardisation of functions and processes, and the centralisation of decisions.

If we relate this back to the example of dynamic traffic management that was introduced earlier, we could arguably say that the effect of such dynamic traffic management with the goal to avoid congestion would increase, if one could force the users to abide the rules, simultaneously creating a (more) symbiotic operating modus. On the other hand, the non-existence of such a system and the non-existence of any regulatory framework would imply inconsistent modus of operation. What we can deduct from the encrustation of the operating modus is a matrix that illustrates the possible symbiotic and inconsistent operating modi (see Figure 2).

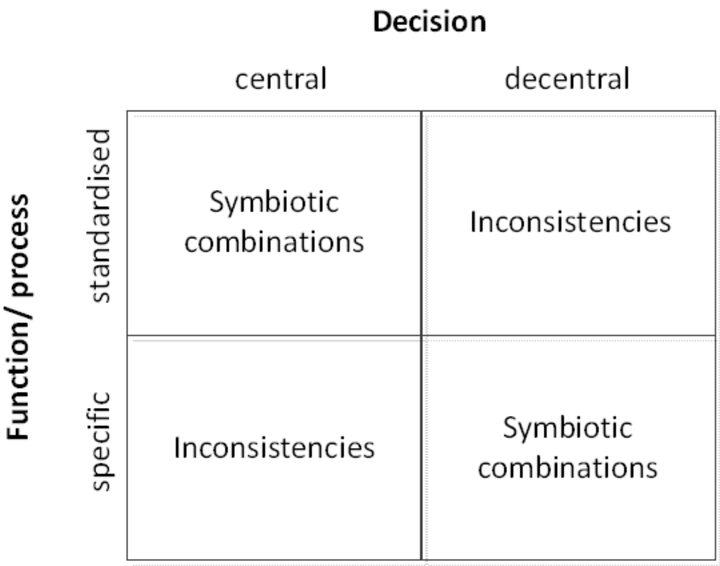

Figure 2. Matrix for symbiotic or inconsistent operating modi

The importance of encrustation is attributed to the fact that it partly defines the margins in which future designs of operating modi can emerge (for a more detailed explanation of lock-in effects and systemic dependencies see Sydow et al., 2005 or Christensen and Rosenbloom, 1995). Simultaneously however, encrustation implies a process of development. That is, because from an evolutionary perspective, inventions are, as of their emergence, exposed to and ascribed with rules that regulate their use, whether they are explicit (overtaking procedure) or implicit (designs that have certain ways of handling inscribed). What this results in is a body of rules, as part of the operating modus, that expands across its developmental path. According to Christensen and Rosenbloom (1995), this produces a construct that hardly allows for modification or "backwards" developments. To situate their findings, the authors propose a "nested hierarchical architecture" of products that produce dependencies on horizontal and vertical value chains. This describes how an element of a system is situated in dependency to other elements etc., that, together, form the overall architecture (system) as such. The point here is that with increasing size of such an architecture, it becomes more rigid, as dependencies increase. Indeed, trains are a good example for this: whilst, presumably because of already existing rail-infrastructure and therefore a more closed and predictable system, trains should theoretically be easier to introduce to autonomous technologies. The change of its operating modus is in reality more difficult, as high degrees of encrustation has driven the train into a rigid position that shows a higher resistance to change than e.g., the automobile. What encrustation thus highlights are questions of "breaking" stabilised systems and the opening of black-boxes, the facts and artefacts that are being taken for granted: What would need to change, if CAVs would take for the streets? These analytical moves impiels to argue against a techno-optimistic strategy, as it allows us to highlight that it is not only the technical implementation of any alternative technology. Rather, it would imply shifting the body of rules (implicit and explicit) that govern the roads towards a new status quo that offers the space necessary for its new operating modus; or the design of an everyday behaviour in traffic that can be described as desirable.

These components form the basis of what we understand as operating modus: The operating modus manifests the collective, individual or conditional behaviour of participants in traffic, based on and defined by (1) the standardisation of functions and attached processes for (vehicle) operability and (2) the degree of centralisation of decision-making within the tangible horizon of the socio-technical system (see Figure 3). The illustration depicts two axes, standardisation of functions and processes and centralisation of decision-making, which emerge from, are dependent of and entangled with the dimensions of the socio-technical system it is surrounded by. The two dimensions are the variables that determine, as argued, the encrustation of the operating modus. To underline the examples given, we depicted their position in this illustration. Following the two dimensions, we see that the airplane has the highest level of dependency to functions and processes, as well as the most centralised system of decision-making, whilst the train and the automobile show a lower degree of encrustation.

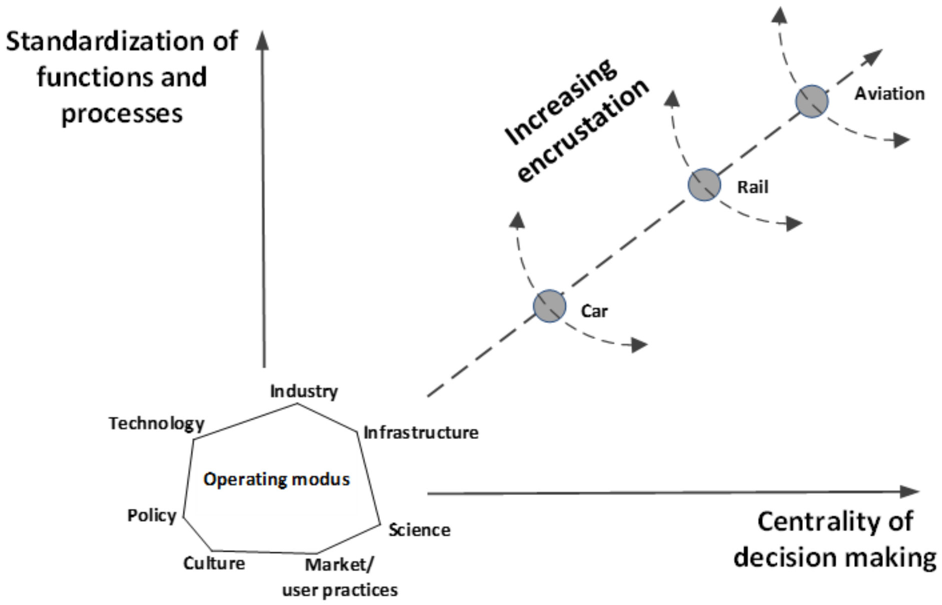

Figure 3. Conceptualisation of the operating modus of vehicles

Integrating this concept as the framework which dictates behaviour may invoke notions of psychological studying of behaviour in traffic. This is not the case, but would be the next step. In this first step, we want to show how the socio-technical context in which traffic happens implicitly (when to take-over) and explicitly (red traffic light) defines behaviour; to show how attached "the car" or "the train" is to its respective networks that ensure, order and legitimise its operation. The psychological consideration and investigation of dependencies would be the next logical step. The current perspective shows how the technical features of a car alone, and thus the attempt to understand traffic by only taking these into consideration, do not justify the embedded social web for understanding and concluding the "right" and "wrong" ways of developing CAVs. What is particularly interesting in the context of CAVs is that framing behavioural principles of traffic as the operating modus, we disjoint the notion of behaviour as an inherently human attribute, as it shifts the focus to behaviour of vehicles and the reasoning behind it: whether this comes from a human brain or artificial logic programmed into a vehicle then becomes a mere pre-condition.

3.2. Discussion of the findings with the literature

So far, we have argued that (1) the operating modus defines the behaviour in traffic, (2) wich is dependent on the level of centralisation/ decentralisation of decision-making and the standardisation of attached functions/ processes, which (3) together define the degree of encrustation.

What this allows us to conclude is that developing CAVs is a highly inter-aligned process, because it is not a traffic model that inspects phenomena in isolation, but a lens through which one can dissect different aspects of transportation and inquire about their relations to one another (see Diakaki et al. 2015, Amirgholy et al. 2019, Alghuson et al. 2019, McConky and Rungta 2019, Guo et al. 2019 Dresner und Stone 2008, Guanetti et al. 2018). The technical models introduced earlier are known to be reducing the complexity of reality (Latour 1999). One might be right in saying that we have already formulated robo-cars in our models (of course with a lower complex environment than reality is). However, do we have the template for automated vehicles and do the simulations justify the public investment into automation to solve the challenges congestion, safer, cleaner and easier transport? Car-following models or other prominent artificial logics can be formulated with a differing number of parameters attached to the simulation of the longitudinal and transversal behaviour of drivers after all. This results in phenomena that are part of drivers' behaviour that are not covered by the simulations. To exemplify this, we can think of collectively emerging behaviours (e.g. accident gawking) or psychologically emerging behavioural differences (e.g. aggressive vs. defensive driving). What does the operating modus position itself against this problematisation? What is it, that it allows us to inspect? How is it different from traffic simulations, and what do these differences imply?

As we have shown, developing CAVs means (in part or fully) to substitute human action by computation in the context of driving a vehicle. What needs to be put into focus, for which the operating modus again works well as an analytical move, is the fact that a stabilisation of (for example) car-following models as the dominant logic-to-be in CAVs simultaneously implies previously stated, non-accounted-for phenomena in traffic would not be possible anymore. Whilst this determination of behaviour might be beneficial (ethical considerations of accident gawking for instance), there is a potential that "taking away" the choice to either drive defensively or aggressively may lead to resistance by users (what may lead to overruling). The challenge that emerges is one of deciding for which aspects of the already-established operating modus of manual driving to translate into automated processes and which to leave for the users. This consideration shows increasing importance and increasing complexity with advancing automation. Nonetheless, there are fields that already tackle such questions: technology acceptance studies or human-computer interaction could offer insights to these questions that are part of the differentiation between the operating modus and traffic simulations.

Another consideration is that different operating modi produce different results in traffic simulations. As we already established, there is a considerable amount of studies that produce knowledge about CAVs based on traffic simulations, concluding into statements that claim better traffic flows, inclusion, or higher quality of life in cities (for a detailed analysis see Milakis et al. 2017). However, these knowledge claims are not comparable, as they are built on models that (may) differ ontologically already. Hence, they are not based on the same operating modus, which is yet of speculative nature, and thus produce different results. If we would, for instance, reduce the minimum distances between vehicles or reduce the imperfection parameters in (car-following-) models to zero, such simulations (without an indication as to which operating modus they succumb to), cannot recommend any strategies for the planning or design of CAVs. To be very clear: this is not to discredit the knowledge that is gained through such experiments and modelling but rather to try and contextualise the knowledge produced. For example, it might be concluded from an experiment homogenous vehicle behaviour can increase road capacity. What is however missing is the information as to which operating modus this homogenous behaviour translates. To formulate a practical question: how does one get to homogenised vehicle behaviour? Standard cars with standard behaviour (a car-following model for all)? Central and rigid traffic management?

To summarise this line of argumentation, we can say that research in this arena is lacking a reference point, in this case the operating modus, against which different aspects can be weighed or tested. This is important to realise, as discourse about CAVs in different forms of public life largely focus on the positive effects that are, to an extent, based on such simulations, manifesting CAVs as a "natural" solution to contemporary mobility challenges. This in turn justifies the use of political or economic resources, whilst de facto the reference point has not yet been discussed nor declared. Although the finding that lower distance and homogenous vehicle behaviour have positive impact on road capacity is correct in the simulated environment, we must further translate this knowledge into the operating modus. From that perspective, it would mean that homogeneous vehicle behaviour would be necessary for such positive effects of automation. Efforts that suggest fixing the freedom of driving in the design of automated vehicles are thus insufficient. The increasing number of critical voices have to resist and correct such results that, out of context, may produce false impressions. In fact, potential drawbacks of CAVs concerning the goals are subjects to an increasing number of publications (see e.g. Anderson et al. 2014, Wadud et al. 2016, Milakis et al 2017, van den Berg und Verhoek 2016, Nielsen and Haustein 2018, Moriarty und Wang 2018 Fraedrich et al. 2019, Makridis et al., 2018; Perraki et al., 2018). Again, these thoughts do not point to any reduction of complexity in simulation models or to any claim to increase the complexity of simulation models. These thoughts rather point to the need to align upstream knowledge and downstream goals in the design of CAVs.

3.3. Operating modus of CAVs in practice

We have made the argument that the operating modus has following elements (1) functions and processes as well as the centralisation, and decentralisation of decisions, (2) encrustation: the systematic dependence between standardisation and degree of decentralisation and centralisation, and (3) dimensions of manifestation: it is constitutive of and by social and psychological, technological, infrastructural, political, scientific aspects, as well as user cultures, interindividual differences, industry, markets and other, practically infinite numbers of influences.

With these conceptual definitions in mind, we would now like to focus attention to questions that concern the establishment of an operating modus of CAVs in the first place. We do this in order to highlight the complexity of the introduction of CAVs and build a case that, at its core, has two arguments: 1) that current structures and practices in transportation are not necessarily compatible, and 2) that it therefore needs reflection on how to govern a liminal state of joint (manual and automated) transportation landscapes. We do this by being as practical as this discussion allows. In order to identify the functions and processes that the currently existing operating modus encompasses, an ideation session was organised (see Table 1). We want to note however that these serve only the exemplification of the complexity that inherently comes with the construction of operating modi. These (and many more) aspects of the operating modus would, in the case of a transition into an operating modus of CAVs, need to be reconsidered and adjusted towards the target system (more about the target system in chapter three).

Table 1. Aspects of operating modi (exemplified)

Individual Domain	
Route determinism	Time of departure, location of departure, location of arrival, route
Vehicle behaviour determinism	Velocity, distance between vehicles, acceleration, transgressions
On-demand determinism	Manoeuvrability, alternative routing, degree of aggressiveness
Collective Domain	
Informal rules of interaction	Priority, velocity, vehicle distance, threatening (considerably reducing distance)
Group dynamics	Submission, tailgating, leading, cooperation, competition
Communication	Indicating, flashing, gestures, screaming, educating
Conditioning	
Transportation environment	Traffic flow, vehicle diversity, weather, infrastructure of lanes, construction, insurance

Formal rules	Velocity, parking, priorities, routing, highways, one-way streets
Execution	Traffic management systems, local political dynamics, traffic signs (dynamic / static, intelligent / procedural)
Control	Surveillance systems, radars, police, social control, collection of data
Influences	See aspects from socio-technical system description in the appendix

These aspects are parts of different operating modi for different vehicles and can be at play in a given time and different traffic situations. To illustrate how deeply interwoven the operating modus is and how it contributes to resolving many of the arising issues. Game theory describes the branch of mathematics that models effects of strategies across actors. There, decisions are dependent on not only the deciding entity, but also on others' behaviour. Each decider is conscious about this interdependency and is aware that others are aware as well. This interdependence of decisions can thus lead to conflicts of interests and problems of coordination. Game theory provides a scaffold to dissect such instances of decision-making by tracing the possible strategies that can be employed (Holler et al. 1991, Rieck 2013, Rothfuß et al. 2020). There is an abundance of situations in traffic in which drivers influence each other until a decision is made. As such, each participant is considered an egoistically-motivated player. If all players are reluctant to change their strategy, they stabilise in a nash equilibrium. This nash equilibrium however does not always correspond with the optimal option for all players (individual optimisation). If an optimum exists which does not setback any player but favours at least one player, a so-called pareto-optimum stabilises. Every day and unconsciously, traffic participants follow strategies and make an abundance of decisions. For example, they cooperate by sending signals or by experience. To illustrate the consequences for traffic, and automated traffic in particular, we want to introduce a case below.

Let us consider the following situation on a highway (assuming that we are located in Germany): we are driving on the right lane and approximate a truck that is considerably slower, which is why we would like to overtake it. However, on the left lane, where it is allowed to surpass the truck according to German regulations, there is another driver already, slightly behind our position, with a moderately higher velocity than ourselves. Thus, we cannot simply change lanes as we would need to give the other driver priority, with the result of considerable breaking to not collide with the truck. This situation presents us with, to use the vocabulary from game theory, following moves and theoretical payoffs:

- Both break: both loose speed and the situation remains unchanged
- We break, the other accelerates: the situation would be resolved, as we give priority to her or she forces us to break, and change lanes afterwards, the other however would win
- We accelerate, the other breaks: the situation would be resolved, as the other one gives us priority or we force her to break, and we change lanes befor her, we win, the other loses
- Both accelerate: after both invested energy to accelerate, the situation remains unchanged

We can assume that accelerating is the dominant strategy to follow and that it furthermore is the only strategy with which the drivers could win this game. This leads us to expect that both choose this strategy and accelerate. Also, when repeating this game (as both notice that the other driver is accelerating, there is a re-calculation of acceleration or breaking), the dominant strategy would be the only one to win. Theoretically, this means that an accident is unavoidable. In reality of today, this situation is being resolved by employing one of four forms of cooperation:

- Cooperation 1: Both drivers evaluate the situation as such, that the driver on the right faces the obstacle, which is why the driver on the right should break.

- Cooperation 2: One driver decides to drive defensively. This assumes that this decision has to be communicated to and understood by the other driver.
- Cooperation 3: The model of the car (e.g. premium muscle car) implicitly communicates a strategy (that may even signal the other driver to break).
- Cooperation 4: The safety of both of the drivers and the vehicles is to be protected, which results in breaking and carefully solving the situation (latest after the second round).

Let us play this game with CAVs. Generally, we can assume that acceleration is the dominant strategy. Following the first logical analysis from before, acceleration is what the producers of the vehicle (of the operating modus to be exact), would choose to program. This is already where the translation into logic finds its first obstacle: this strategy would provoke accidents. This implies that both operating modi must be following defensive strategies. This however would also lead to both vehicles breaking, therefore not resolving the situation at hand. Without cooperation, both vehicles would, in that case, break until standing still. From this thought experiment, we can already conclude: the vehicles must cooperate (just as the human drivers). How would then the cooperation looks like with which operating modus at hand if we take the four outcomes from before into account?

- If cooperation 1 would generally be inscribed into the operating modus, it would lead to not being able to surpass the truck in dense traffic. The passengers would automatically be the losers in the daily games of traffic, which is why no automobile maker would decide to impose this logic onto its clients.
- Cooperation 2 could be translated by randomising the decision. If, however, defensive driving would be the fundamental logic-to-be-followed as introduced earlier, it would lead to the passengers always losing. This strategy would also automatically lead to a standstill, if it were fundamental to the logic.
- Cooperation 3 would be excluded, as CAVs would not be influenced by social factors that would, for instance, discriminate between premium cars and more "standard" models. Nonetheless, one could, with machine learning techniques, understand the "typical" behaviours of other CAVs (or human-driven vehicles left) computationally.
- Cooperation 4 would also lead to a constant losing of the passengers, thus also not attractive for either them or the manufacturers.

This simple situation exemplifies our motivation of understanding transportation as a socio-technical construct. In the light of CAVs, we are now collectively responsible for determining what strategies, what moves, the non-human drivers will adhere to, and prioritise over, another. We have elaborated how the operating modus delineates the behavioural possibilities in any given situation, inscribed through implicit and explicit rules. The question to ask now is what underlies these rules, especially considering CAVs, that determine what behaviour vehicles engage with. The findings of this analysis reveal that the development of CAVs is not a linear, technical process; but inherently socially dynamic and somehow unpredictable. The practices of today's road transport show a deep entanglement between the social and the technical, therefore affecting the horizons of what can, what ought and what must with regards to developing CAVs. In order to give a framework to think about this, we introduced the concept of the operating modus, which was followed by different elements and analytical moves that this concept allows for. It delineates the web that creates some orientation on the roads, rails and air. In order to return to the initial question that we posed of **what 'algorithmic drivers' are socially desirable**, we need to ask ourselves how such an operating modus comes to life in the first place. What are the underlying currents that make for order and what shapes these in the beginning? To both answer these questions and further delineate this research arena that we are opening, we want to introduce a second concept that we call the **organising principle of transportation**, which essentially describes which principles operating modi follow and therefore demarcate the transportation landscape.

4. Taking another step back: societal principles of rules

Our discussion so far gravitated around the operating modus of vehicles. Whilst this concept suits well to dissect how individual vehicles operate in their environments and are operated (by either humans or not). This perspective does not incorporate the driving force of an operating modus, the fundament on which an operating modus builds. Questions that allow for understanding why the operating modus of a car is different in the United States than in Germany or even different from Germany to Austria. Understanding the driving force behind an operating modus enables constructive change of it. This chapter will focus on this exact concept: the organising principle.

Let us focus on this "driving force" through an example, a specific aspect of the operating modus of both motorcycles and automobiles in Germany: the speed limit on highways – or to be exact, the nonexistence of speed limits on certain highway stretches. In the operating modus of these vehicles, highways have in many places (not all) no standardisation of the function "speed" – not in snowy or rainy conditions, nor in dense traffic. The decision-making (how fast am I driving) happens decentralised, meaning that driver can decide for themselves the appropriate velocity. This decision is manifested in a range of aspects, e.g. legislation that gives the regulatory framework for unlimited speeding, premium cars that are technically able to perform on high velocities, but also the infrastructure, the highway itself. The technical details of the "German Autobahn" reveal that it is built for high velocities: curve radi are based on Euler's spirals, curved roads are tilted to allow for both high velocities in curves and rain drainage, and specialised asphalt dampens the noise created from the fast-rotating tires. The material "being" of the highway, the legislation around it and the industry that produces vehicles that allow for the exploitation of maximum velocity are thus all part of creating the (or part of the) operating modus that in Germany is an almost unique worldwide. But how, then, did Germany get to a situation, where one can drive 200 km/h or more without driving the risk of being fined for speeding? On the one hand, the operating modus that this aspect is part of adheres to an organising principle of freedom and independence for drivers that social, political and cultural currents gave rise to in the 1950s and 1960s, when the automobile was politically appropriated as a bearer of hope and prosperity after the misery of the first and second world war in Germany (see Canzler 1996, Rinn 2008, Sachs 1990, Grieger 2019). On the other hand, if we look to the United States, where the car also carries notions of freedom and independence, we see that speed is highly regulated and controlled. Explaining these differences is possible by looking at these "driving forces" and how they are being translated into the operating modus – and these "driving forces" are what we label the organising principles. We define the organising principle of transportation as the underlying normative framework, the tenet, that constitutes the foundation that determines how operating modi of vehicles are constructed, stabilised through the creation of facts and artefacts through negotiation of power and interests across actor (groups). A fundamental aspect is that it describes societal currents spanning actors and actor groups, interests, dependencies, power and peripheral networks. What we do not mean is an elite group of "decision makers". Rather, a societal construction of operating modi based on societal normativity. This is accompanied by the fact that different societal structures influence the organising principles embedded in them. We could hypothesise that if there would be broad consensus about decentralised decision-making of appropriate velocities on the streets, there would be a way in the US-American democracy to incorporate a "speed-is-free-to-choose" strategy into the current operating modus of vehicles. The same applies to Germany: there surely could be restrictions on German highways if there would be societal momentum and consensus towards it, showing again that the organising principle of each society (or actor groups) shapes the operating modi that stabilise.

Let us apply this concept to the automation of vehicles. "Defining" an organising principle produces questions like: do we want Robotaxis to drive without speed restrictions? Should these vehicles follow a strategy of exploiting this rule and purposely drive as fast as possible at all times (or in which conditions not?)? Would you enter, or buy, such a vehicle that adheres to such an operating modus? Or to even think this further: should CAVs adhere to an operating modus that minimises its ecological footprint the best it can, or one which operating modus is catering to individual benefit? Should the automobile in Germany stay a symbol for independence and freedom or should it become a functional machine that allows for covering mobility needs? Should the operating modus impede the user's mobility to achieve higher goals like less congestion or reduced CO2 emissions? Depending on the answers to these (little of many) questions, the operating modus would turn out one or the other way. Or to further point out the importance of this observation: depending on how society answers these questions, the technical characteristics change with regards to maintaining the operating modus consistent to the underlying goals (e.g. how fast cars may drive). Simultaneously, it is to be presumed that different regions or countries find, for themselves, different answers to these questions – and frankly there are no answers at the moment that highlight questions of how to govern the process of developing CAVs. Indeed, this has not received the attention that it deserves – and navigating these questions is delicate. Especially, because it seems as if we need to conceptualise an operating modus from the bottom up for the first time ever since the beginnings of the automobile.

4.1. Organising Principle(s) of transportation

The organising principle emerges from societal currents, which is supported by diverse actors who partake in the shaping of the operating modus. It is important to not understand the following paragraphs as the mechanisms that are underlying these developments (there is much literature on that in social, and political science as well as in technology studies). Rather, it is about systematically showing characteristics that can be observed in the creation of operating modi of CAVs.

4.1.1. Facilitating Negotiations of Change

Organising principles collate social currents into a normative framework that demarcates the rights and wrongs – especially in technological contexts. In that regard, we can also talk about a relating word. That is, acceptance; an organising principle is a commonly accepted framework of technical developments and employment of technology. This does not mean that every actor subscribes to this framework or design it that way. Rather, it means that no societal currents are big enough to lead to a change of an already-existing organising principle. Nonetheless, a particularly important aspect of an organising principle however is that it is changing. It is not a constant, absolute and immutable framework, but changes considerably across time. For example, in the last decades the organising principles of safety (artefacts in the operating modus include the seat belt and the obligatory wearing of these) and ecological sustainability (technical focus on emission-efficiency, now electric vehicles) gained more attention. Simultaneously, a tenacity of already-existing organising principles has to be recognised – a societal memory for the already-established that is being black-boxed and not questioned. In psychology a comparable phenomenon is known as status quo bias, a distortion of perception, which leads to people not wanting to change already-settled situations (Döring and Aigner-Walder, 2017). Socio-technically, we can speak of a path dependency (Sydow et al. 2008), that describes how the established becomes narrowed, intensified but not necessarily fundamentally rethought.

In order to highlight this phenomenon of the organising principle, we want to turn to our example with the speed limit on the German highways. With rising concerns about the environment and safety in the 1970s this organising principle got questioned. This aspect of the operating modus of vehicles that are part of highway-traffic is fertile ground for social controversies and political discourse about the rights and wrongs of the organising principles that govern the roads. In early 2020, another political discourse came up in Germany that demanded the capping of highway velocity to 130 km/h for more road safety and environmental concerns. In an interview, the transport minister replied to these demands: "Everything has been said. Everyone knows that I am a supporter of the established recommended velocity of 130km/h (which is not binding in Germany). There is a decision by the German Federal Parliament. The representatives decided, with an overwhelming majority, against the capping. Scientific research has shown that the average speed on German highways is 117km/h. We don't need more metal signs. We need intelligent, digital traffic control that shows the driver the recommended speed limits." (Apfel & Weber 2020). In other words, a majority of the representatives decided for the retention of the existing operating modus. It also shows that an attempt was made to add ecological and safety aspects to the existing organising principle (that would determine the operating modi of vehicles on the highways). Finally, it illustrates that once facts have been stabilised and artefacts produced, they not only are hard to reverse, but produce new contexts that represent these new orders, further stabilising the governing organising principles.

Hence, not only human actors (citizens, politicians, lobbyists, users and non-users) exert influence on the stabilisation or destabilisation of organising principles, but also pre-existing organising principles encoded in the material structure of the operating modi of vehicles (infrastructure, etc.) pre-empt possibilities of what can and what cannot. Eventually, such organising principles and the resulting operating modi become cultural resources: just like the non-existence of a speed limit is part of an automobile culture that is closely connotated with notions of freedom and independence. Not by chance does the interview that was introduced above carry the normative title "Freedom of mobility without useless rules". Let us further exemplify with a similar process in the USA: in 1974, the maximum allowed velocity was reduced to 55 miles per hour (89 kilometres per hour) with the goal of saving fuel, as a result of the oil crisis in 1973. However, after the crisis was over, the speed limit was maintained in order to support traffic safety ("Drive 55 and stay alive!"), which was contested by many low-density population regions outside urban contexts. And given that states who did not adhere to the new policy would not get any further funds for developing their road infrastructure, almost none did oppose. Here, the power of the organising principle becomes apparent; if we look at how Germany handled the very same crisis. Germany did not impose a speed limit. This change in the context of the organising principle rather led to more energy efficient vehicles to be built – the act of driving was, however, left untouched. To the contrary in the USA, where the act of driving was regulated but the same vehicles were maintained throughout. This example shows how organising principles define the way that operating modi materialise – in a very societally-specific way. The organising principle reacts to cultural and social influences and transforms across time, and with it, the operating modi that are attached to it. However, it also shows what role the already-established plays in that context. Changes oppose the already-established: on the one hand does it take time to bring change into action and develop a societal relevance. On the other hand, the established has to be paid attention to, if the system architecture is not to be questioned.

Further than that, the organising principle shows that it functions on different levels it is scalable as to the subject that it is being employed for. For example, it can be employed to understand the fundamental developments, such as that automobility has implications of freedom and independence (in Germany, at least), surfacing in an operating modus where functions are hardly standardised and decisions happen decentralised as well. The organising principle however also manifests itself in the creation of artefacts as we can observe in the infrastructure (see the constructive details for high velocities on highways) or get used to understand something as material and specific as the designs of steering wheels that follow the very same organising principle (think of how a steering wheel that adheres to an organising principle of "ergonomics" would stabilise in shape and form versus a steering wheel that adheres to "aesthetics").

4.1.2. Negotiating Connected and Automated Vehicles

That details of today's operating modus of vehicles may change was sketched above. The assignment that we are now collectively facing however (in the context of CAVs) is that we are substituting the human through automated processes in the form of pre-determined choice architectures inscribed into algorithms. Artistically said, our assignment is to create the human anew: which one of the grand societal currents should the drivers subscribe to in traffic, how should the drivers react and interact? We expect answers to these questions are found embedded in different forms of societies. Some examples of possible tenets, may point:

- Economic tenet: if CAVs should be exploited for the individual benefit, it stands to reason to employ economic principles that are translated into the operating modus. This can result in the willingness to pay for specific actions in traffic, such as overtaking, velocity or mobility as such. How can both "drivers" with and without a willingness to pay be put into one and the same infrastructure? Which economic mechanism is guiding the interaction of vehicles (passengers)? This is less of a question of ethics after all (given that the considerations have to be deliberated beforehand), but rather about translating this aspect deeply into the operating modus.
- Social tenet: if a societal optimum should be at the heart of CAVs, it can be argued that a range of offers that would otherwise be there (see last bullet point) would not make it to market (priority in traffic that one can purchase for instance) and that some functions that speak against current market dynamics would be thinkable (for instance that all vehicles have to be accessible to immobile / physically handicapped people). Logically, it would imply that some individual benefits would be needed to be let go against the principle of social aspects.
- Ecological tenet: if CAVs should adhere to ecological principles, the vehicles should then be optimised towards environmental aspects, possibly having to rethink the data management, allowing for a more

centralised possibility in contrast to the economically-oriented organising principle. CAVs would thus drive as energy-efficient as possible, possibly reducing individual's advantages, for instance driving with a set velocity "in flock" on highways to reduce acceleration/ deceleration effects. This would also imply a move against premium vehicles that are trimmed to be fast and loud.

These tenets do not necessarily exclude each other. Nonetheless, many of the aspects could not be put into place simultaneously. As such does the economic tenet hinder the social tenet if it were purely monetarily constituted. Along the same line, an ecological tenet is at odds with the economic one if there is a desire to own fast vehicles, and is also at odds with a social tenet if there were no highly priced vehicles anymore. Finally, this is one of the strengths that we discussed above: the organising principle allows to negotiate the weights of these tenets towards each other. What starts to become visible is that the development of CAVs is much less of a technical question as it is portrayed in many cases. Rather, a question of the normativities that are ought to be inscribed into how CAVs operate. Indeed, we can and should expect different organising principles across societies and macro-trends which already now become visible: in the USA, where individualism is highly prominent across national cultural standpoints, Europe, which follows a tendency of social market economy, or China, where goals of the state are prioritised. All three regions will possibly develop CAVs under three different organising principles, where the first tenet might be pointed as "all about the individual", the second as "all about society" and the last as "all about the state". This will inevitably result in different operating modi with different consequences and different socio-economic feedbacks on CAVs.

The last aspect in the discussion around the organising principle(s) that we would like to touch on is what actually happens if organising principle(s) are considered in the development of CAVs. Which implicit considerations does it render explicit? We argue that there are two ways of employing it: firstly, the reflective, and secondly the active use of organising principles. The former is a deductive approach to reflect upon already-stabilised designs, while the latter renders the implicit explicit in processes of designs-in-the-making. Firstly, the reflective use of organising principles is about the disentanglement of already-existing designs (artefacts, e.g. products, objects, and facts, e.g. processes, services). It is a "backtracking" of the organising principles that are inscribed into the design of things, a deconstruction through questioning and a reconstruction through acceptance simultaneously. Inherent to this process of disentanglement is the challenging of assumptions that are silently inscribed into everyday things. One famous example from the field of science and technology studies is the enrolment of a speedbump into the design of a street. It enforces a "drive slow" program, forcing every driver to adhere to the governing speed restrictions (Rosenberger 2017)). Indeed, the organising principle of "enforcement of speed restriction" is very explicit in this object – with alternatives spanning from signs that indicate the maximum allowed speed to police patrolling. Thus, the reflective use of organising principles allows to rehearse the thinking that led to the materialisation of an artefact or fact, often revealing how (socially, economically, politically) entangled technologies are and therefore how important the process of designing these is. Secondly, the active use of organising principles is about the deliberate employment of the concept as a space for negotiations during design processes with multiple actors. The function that it assumes in these situations is that of transparency and acceptance: it allows actors to formulate a common understanding of the frameworks that each individually deems necessary. As such, the organising principle represents an anchor around which a discussion, a negotiation can evolve. It creates the space necessary for actors to agree about the principles that the thing-to-be-designed radiates. In Milakis and Müller (2021) the importance of the societal dimension of CAV and a specific research agenda are elaborated.

With this conceptualisation of the organising principle in mind, let us inquire about the organising principles related to CAVs. To do so, we will look at three different actor groups and dissect the organising principles that the empirical material surfaces, which is followed by reflections about how consistent these organising principles are that currently shape the CAV-to-be-designed in all its aspects and an identification of the challenges that lie ahead when thinking about the two concepts that we introduced in the first place.

4.2. Organising principles across actor groups

This chapter aims at presenting empirical material and discuss different aspects of organising the development process across the groups of actors that were mentioned previously: the policy makers, the manufacturers, and the users. The empirical material for this analysis partly derives from an earlier project, DiVA, that is part of the portfolio of the German Aerospace Centre and can be classified by groups of actors: as such the policy-making, the state-side, will be analysed, as already done partly, from both policy documents and strategy documents that discuss CAVs or the topic as such (Lenz et al. 2020). The industry, the manufacturers, will be discussed on the basis of interviews that were held. The users' perspective derives from both in-depth interviews and two focus groups that were organised as part of DiVA. From this material we will dissect the organising principles for these three actor groups, which is followed by a presentation of material from a workshop on translating implied organisational principles to aspects of operating modi. We do this in two forms: first, in a "raw" format – a table that outlines different aspects across a stereotypical journey. Later, we take (some, not all) of these aspects and present them in a narrated format, a story of a journey in a possible future CAV-reality.

4.2.1. The organizing principle as for policy-makers (state)

In order to describe how policy-makers approach the technology, we will look at formulations of the visions that accompany automated driving in the European Union. The basis will be strategy documents that stem from policy-actors. As Schreurs and Steuwer discussed in 2016, regulatory debates may influence public perception and vice versa – practically co-constituting each other, which again amplifies the importance of understanding the framing of such technology. The European Commission and the European Road Transport Research Advisory Council (ERTRAC) published a number of documents to mine for such indices. The European Commission for instance proclaims a number of positive effects of automation. For example the following quote about the aspects safety, efficiency and user friendliness: "The development and large-scale deployment of Connected and Automated Mobility (CAM) provides a unique opportunity to make our mobility system safer, cleaner, more efficient and more user-friendly. Their development is being linked to concerns about industrial competitiveness, sustainable development, resource efficiency, safety, and assistance for the elderly and others who might otherwise not be able to drive a car." (European Commission 2018). Notably, industrial competitiveness is regarded as a chance that emerges from this technology with the goal of strengthening a European industry and establishing a technological prime position, following these economic goals (Schreurs and Steuwer 2016). An underlying motivation for this economic positioning of this technology was identified by the same authors, where CAVs are looked at as a key to "overcoming the economic crisis in general and the crisis of the European automotive industry in particular" (2016). Another aspect is that of sustainability and resource-efficiency, both corresponding to ecological dimensions of CAV's vision (even though by definition, sustainability also reflects economic and social dimensions): "also the CARS2020 action plan establishes a strong link between competitiveness and clean and green vehicles." (Schreurs and Steuwer 2016, p. 154). Goals that address inclusion (assistance for elderly and others who might otherwise not be able to drive a car) and safety are mainly oriented against social goals. These visions are also reflected in the Strategic Research Agenda of ERTRAC. Also there, inclusion, safety and energy-efficiency are prominent aspects. Further, ERTRAC elaborates by congestion and urban mobility as themes that can be addressed through CAVs. Automated vehicles are seen as a positive move towards social challenges: "Connected automated driving is the opportunity to address several important societal challenges of road transport: safety, energy efficiency, congestion, urban accessibility and social inclusion, in-line with the 2050 vision outlined in the ERTRAC Strategic Research Agenda. It is important to have systems approach of what the deployment of connected automated driving can bring. Both new technologies and new services enabled by connected automated driving have great potential to contribute to the societal challenges. New automated solutions for shared mobility and public transport could have very positive impacts on our future urban and inter-urban environments, making the system more accessible for elderly and people with disabilities. New automated logistics solutions will contribute to meeting the increased goods transport demands, improving resource utilization and environmental impact." (ERTRAC Working Group 2019). To summarise, we can say that European policy-making follows ecological, social and economic visions with the development of CAVs (see Table 2.). However, a considerable focus lies on the economic dimension, especially in the form of strengthening industry and its competitiveness through the development of such technologies. The focus thereby lies in the making of a European single market (Schreurs and Steuwer 2016).

Table 2. Key themes of organizing principles across policymakers (state)

Dimension	Aspects from literature	Source
Social	• Inclusion • Safety • Sustainable development	European Commission 2018
Ecological	• Sustainable development • Resource efficiency	European Commission 2018
Economic	• Industrial competitiveness	European Commission 2018

4.2.2. The organizing principle as for manufacturers (industry)

As opposed to the policy-making side, the manufacturers' vision of CAVs and their deployment are based on in-depth interviews that were made in the scope of DiVA – a project about CAVs that is part of the portfolio of the German Aerospace Centre's Institute for Transport Research (see Lenz et al. 2020). Interestingly, the aspects that were mentioned do not necessarily, as we have also seen before, give an account of the effects. Rather, they discuss, to a large degree, different aspects of the operating modus of CAVs that spark reflections on the underlying (organisational) principles that they follow. For instance, it was mentioned that there should generally be an equal right to the priority in traffic and be decided by the legislative and technical limitations that CAVs face. Manufacturers should not be able to determine these aspects. Rather, the governing logic should be based on the given context, such as the velocity or distance to other vehicles in a specific situation. These should delineate the cooperative decisions and thus determine the behaviour of priority. These social aspects are reflected well when confronted with the possibility of paying for priority, which is largely rejected as a governing principle, as it would endanger equality given that it would be beneficial for drivers with a better economic status. Interestingly, it is imaginable for manufacturers to establish a system that connects price with route distribution in the light of optimising traffic flow in a fully automated transport system, as slower routes would need to be used as well. There, depending on road occupancy, the prices could vary. As such, raising fees on faster routes could be a way to increase the attractiveness for slower routes, according to the manufacturers. This would lead to organising traffic flow by social anchor points, whilst economic instruments are being used to control the regulation. Simultaneously, this would also include ecological aspects, as aligning for a system optimum would make for homogenisation of traffic and thus support fuel-efficient transportation. Another take on CAVs and the creation of a system optimum is that the automobile assumes characteristics of public transportation in a sense that one enters the vehicle but does not, beyond that, assert any influence on the process of driving as such. A centralised body, in this scenario, is at the core of controlling the vehicles in a system.

Another aspect that was touched upon was safety. There, automation portrays opportunities in the increasing safety; also, in mixed road landscape between manual and CAVs. For example, it could be systematised when and when not drivers could focus on aspects other than driving. Hence, on routes where the likelihood that drivers would need to assume an active role (in partly automated realities), infotainment systems could be switched off for instance. That such aspects of safety are important to manufacturers is also visible by inspecting the way interiors of automated vehicles adapt. Depending on different situations of (part) automation, the arrangement of seats could be modified. These aspects of ensuring safety while driving supports social aspects, on the one hand (because they decrease fatalities and rates of accidents), but also show economic and ecological dimensions – these are connected to creation of system optima in traffic flow that would follow a mantra of "energy efficiency by homogenisation", on the other hand. That manufacturers are strictly tied to principles of supply and demand surfaces when conversing about economic aspects of CAV (production), where distinction from competition by for example technical features or interior design of the vehicle aim at catering to different groups of customers. This surfaces in discussions about different modes of driving. In the conversations, an eco-mode and sport-mode was mentioned, where the driver could toggle between faster and dynamic driving and conservative and energy-efficient driving. Ironically, this stands in stark contrast to the previously mentioned mantra of homogenisation, as different modi could contribute to a disbalance and thus the failing to achieve a system optimum. Nonetheless, dynamic driving does not necessarily lead to a reduction of travel time. Rather, it mostly influences the subjective perception of being faster. This is why for manufacturers, it is plausible for having all vehicles on a specific section of a route drive equally dynamic/ conservative. Especially as it is expected that non-driving related activities will become more important (as CAVs would not require constant attention), the style of driving may become secondary. If a section however allows for higher velocity, the general velocity of traffic could be increased, leading to a travel time reduction for all participants. To summarise, there is a basic idea of homogenising traffic, while keeping vehicles heterogeneous to cater to different user groups. Nonetheless, how it might play out is still of speculative nature. With regards to organising principle, manufacturers do show a stabilised vision of homogenised traffic (ecological and social dimension), but are strictly tied to today's production principles. This moves the focus to legislation, as in effect, the design of CAVs will be tied to regulation, but within the regulatory framework, designs will possibly deviate from another for competitiveness. The following table summarises the key themes.

Table 3. Key themes of organizing principles across manufacturers (industry)

Dimension	Aspects	Source
Social	• Increasing comfort for passengers	European Commission 2018
Ecological	• Resource efficiency (homogenisation)	European Commission 2018
Economic	• Heterogeneity for competitiveness	European Commission 2018

4.2.3. The organizing principle as for users (public)

This section builds from empirical data obtained from three focus groups with six participants each and five in-depth interviews (see Table 4.). Socio-demographically, the participants come from a wide range of backgrounds and live in German cities. What is important to notice in this section is that the users' relationship with CAVs (and their development) does not come from expert cultures. As such, especially with regards to their organising principle, it often reflects the conditions with which users would use CAVs in the first place, which provides an in-road for discussing the underlying principles.

On the one hand, a major concern that is decisive in whether or not the participants would drive (with) CAVs is safety. They show a clear need for a high system resilience, for if parts of the CAV would fail to function properly, safe driving should still be guaranteed. Hence, acceptance for CAVs is a major concern before even engaging with this technology. The behaviour of the vehicle on the other hand is another concern that was dominant in the discussions. There, participants wish for CAVs to be as close to their experience with non-automated vehicles as possible. That means that the driving style of the users on manual vehicles should be basically replicated as close as possible. Interestingly, this would imply theoretically the positive effects that highly motivate the development of CAVs could not be attained, as practically there would be no difference between "now" and "then". Ironically however, most of the participants would hope for a considerable homogenisation of collective driving behaviour that would also prohibit constant taking over and tailgating. Traffic flow should be consistent and the driving experience relaxed, which would speak for an organising principle that underscores ecological aspects such as reduction of emissions through homogeneity. Simultaneously, it reinforces the social dimension as it democratises transportation as to everybody adhering to the same conditions, thus not posing any disadvantage to anybody. However, a contradictory position was voiced as well, where individual transportation is looked at as more important, shifting focus towards reduction of travel time and reduction of (monetary) costs. This radiates with the earlier mentioned possibility of paying-for-priority that was articulated by the manufacturers, which would be one “solution” to a reduction of travel time in an otherwise homogenised transport system. However, some participants voiced concern that this would endanger democratic principles and proposed a potentially fairer solution, such as that each participant gets the same number of overtaking-allowances per time or route module. This could incorporate a social aspect into a rather economically-oriented organising principle.

Table 4. Key themes of organizing principles across users (public)

Dimension	Aspects	Source
Social	• Equal rights for participants of traffic • Priority-per-unit • Safety	European Commission 2018
Ecological	• Resource efficiency (homogenisation)	European Commission 2018
Economic	• Buying priority (contested)	European Commission 2018

5. A Case of Operating Modus and Organizing Principle in Action

This section of the report is aimed at providing a tangible, yet speculative glance into how an operating modus of CAVs may develop in relation to current observations as to deliberations gravitating the organising principle. This takes the form of a table that outlines different aspects of the operating modus across phases of a journey and a case that puts these considerations into a narrative form. To construct this, we will naturally need to define some assumptions that frame the basic situation. The job of this section is thus bifold: on the one hand, it is aimed at providing a tangible “story” that readers of this document can relate to and “situate” their understanding of the operating modus and organising principle thus far. On the other hand, it aims at provoking deliberation and reflection as to how organising principles may or may not be translated into operating modi. The data that builds the foundation of the case was collated in a joint workshop of the research team, where, in an inductive method, different aspects of operating modi were ideated. To come up with these aspects, each phase of an archetypical journey was brainstormed individually, followed by a swapping of post-its, where these were captured. Each idea of each team member then was complemented and “thought further” by each other member of the team. These “further considerations” can be found in the table below (see Table 5.). The table thus outlines the outcomes of this ideation session, which is followed by a case that, in a non-academic style, describes the story of a protagonist who completes one journey. This is done to put the aspects of the table into perspective and communicate the tacit knowledge that the researchers have and might take for granted.

Table 5. Ideation session: aspects of operating modi across stages of a journey

BEFORE	**PLANNING JOURNEY**	Anything-bookable or adjustable: aggressivity vs. passiveness; routes, etc. - risks are being weighted out by insurance companies
	ENTERING THE VEHICLE	Seats that automatically adjust ergonomically based on a saved physical profile
		Emotionality of driving (e.g. aggressive driving style) does not exist. Does then the status symbol "car" and the emotional behaviour in traffic get substituted? How does our driver feel after entering the car?
		Seats can be modified as to their directionality.
	BEFORE DRIVING	Infotainment system activates after successfully completing the planning of a journey: logging onto Netflix etc.; meeting postponed automatically, because the route is becoming congested
		Before any journey, the car needs to scan for newest updates (and possibly download and install them).
		Centralised optimization of route and determination; also rejection of route options or departure times; what are the criteria for prioritisation?
DURING	**DEPARTURE**	We substitute drivers with "intelligence" – do we also program emotionality? We program the taxi driver – depending on your mood, the CAV calms, etc.
		Driving style adjusts to the characteristics of the passengers to drive as energy-efficient as possible: size, weight etc. become calculated into "best possible" acceleration rate, velocity, etc.
		Optimized algorithm: centralized signals; collectively slower for upcoming traffic light, centralized departure acceleration rates etc.
	JOURNEY	Lane for manual cars, lane for CAVs, lane for public transport.
		CAVs inherently defensive in risk-situations. Manual drivers shoving themselves into lanes, knowing that CAVs will "let them pass" anyway.
		Collective and centralized decision-making.
		Seamlessness in route calculation (individual): if there is a train to catch in good time, the car drives slower, so that the passenger won't need to wait too long.
		Driving style depending on contextual information from the immediate situation.
		(Un)fairness: social equality as to the monetary dimension of CAV-based transportation; today already: a BMW gets less damaged than a Skoda, is that fair?
		What if I need to go to the hospital? Is there an "emergency button"? How can you regulate this button? Would all other CAVs automatically make way for you?; A centralized system where the emergency-centre gets the notification and prepares everything for your arrival (briefing to hospital staff etc.).
		How large is the percentage of people who do agree with one driving style only?; Actually the perceived value of driving decreases, similar to manual vs automatic gearboxes in manual vehicles.

		Decreasing insurance fee, the more you drive in ECO-mode; do insurances exist even in such a reality?
		Already car-owning people get premium offers.
		"But if I cannot drive with 200km/h on the highway, CAVs won't be any faster?!"
		Lanes are classified in vehicle performance (against bottlenecks).
		Overtaking per route section or time slot.
		Cross-country roads can be driven "more freely" than highways. Highways are functional for collective locomotion.
		I am sitting in the car and want to work, but I get so sick, that I cannot concentrate.
		Vehicles are designed to do other things than driving in them. They are that boring that naturally people don't even raise the need to drive faster.
		Third-party-developers offer extra services and products for the CAV.
		Toggle between ECO and SPORT mode with corresponding driving styles; how does it work? Is there some kind of limitation as to minutes that you can book? Is ECO mode then especially cheap or expensive given that you save resources?
		Highways have a general speed limit of 140km/h. Also, there are lanes of deceleration / acceleration that span about one km to not interrupt "the flow".
		Passenger crossings are being deconstructed, because they pose a too risky situation to calculate for CAVs; crossings are not being deconstructed after all, because pedestrians now need to make a special gesture with their arms that resolved the issue with the sensors and cameras.
		Infotainment systems get interrupted in situations where "high attention" would be required for a driver (for security reasons) – similar to the infotainment systems in airplanes when the crew make announcements.
	APPROXIMATING DESTINATION	Vehicles with long journeys have priority as to the parking spaces that are being booked before arrival as in distance in relation to destination.
AFTER	**PARKING / STOPPING**	"Big" vehicles get assigned the better parking positions.
		Depending on age and mobility impairment, parking positions get assigned; screening at the doctor who transmits the "impairment score" to the system, allowing for parking close to destination.
		What do you do if you want to spontaneously take someone with you (hitching for example)?
		Parking spaces get assigned via betting wars on a yearly basis.
	CONCLUDING JOURNEY	Scanning fingerprint to conclude the booking and end the journey.
		Can you spontaneously and anywhere conclude a journey?

The basic structure of this case will be the following of a person across "one journey" by CAV. The story that is presented did not emerge by chance either. Specifically, the data that underlies the case has its basis in the empirical material presented above. From the interviews and focus groups with manufacturers, policymakers and users, as well the expert workshops organised as part of this project, key statements from these actors were extracted that served as "organising principles". Following that, a workshop that spanned the team of this project was organised that had the purpose of "translating" these preliminary organising principles into consistent aspects of an operating modus for CAVs. These were further categorised into "phases" of an archetypical journey to ensure a comprehensive depiction of this case. This case inherently comes with basic assumptions: First of all, given that CAVs can take any form (in terms of the vehicle, that is), one basic declaration for this case is to define CAVs as what could be understood an equivalent of the automobile today. This automated automobile then could have a range of "levels of automation". For the sake of this case, we want to focus on a reality where there are fully automated CAVs which do not require active driving task from any passenger. Equally important is to define when this case takes place. Whilst we do not want to and cannot formulate a year in the future, another assumption of this case is that the road landscape is defined by a hybridity of automated and manual vehicles – where they co-exist next to each other. To further specify, one persona was developed that served as the basis for constructing the story. This person is female, 28 years old, living in a high-density urban environment in a major German city.

A day in the life:
Every single day, hundreds of thousands of people move in her city. Day in, day out. Really, there is no time of day where no rumbling of the underground metro across wide, open crossings of the city's main streets – her veins – can be felt when waiting at the carefully systematised pick-up spots - special 'pick-up lanes' had to be built as well that allowed for these robotaxis to move out of flowing traffic and decelerate, that the city built some years ago. She remembers that in the beginning, many citizens protested against the extensive construction sites that were ubiquitous in the city – after all, research had shown that for CAVs, or robotaxis as people began to baptise them, to work, it was required for the city to construct these pick-up spots across every 400 metres in the cities' total road network of 3730 km. But not only these were the 'problem' in the protesters' eyes. Much of it came with the blocking of parking spaces, as special 'pick-up lanes' had to be built as well that allowed for these robotaxis to move out of flowing traffic and decelerate, precisely locating the waiting passenger at the pick-up spots. But that's over now. This huge constructing effort, she believes, paid off: mobility was, in a sense, democratised with these robotaxis. No matter what age (almost, as you need to be 14 years old at least in the booking system of the government), gender, mobility impairments or background you have, you can always get to wherever you want to go. Indeed, it had huge effects on public transport to a point where now, given that robotaxis are still more expensive "per kilometre", there is a debate about the actual inclusiveness, as some people still cannot afford it and are forced to use the older, public means of transport. And just as the metros keep driving, the fleet just keeps moving. Driving, charging, driving, charging – day in, day out. Of course, it cannot be neglected how weird it was at first for many people to voluntarily sit into a vehicle that basically is responsible for your life. The loss of control was not easy on many. Eventually however, people got used to it. After all, what is the alternative when there is no connection to public transport near your destination? Taxis are a thing of the past, these poor people all had to find new ways of making a living. They found jobs eventually – at least she hopes they did. The 18th birthday is also not the way it has been in the past. It was not long ago when you still needed an expensive license to be allowed to move from place to place by car. That's why it was a "milestone" present for parents to give to their children at the verge of adulthood. Pretty unjust for anybody who could not afford it. Now, a simple one-day workshop is necessary that costs "only" 150€ during a seminar in your local government's administrative offices, running over what you need to do when the robotaxis ever does behave undesirably or what to do if an accident happens is sufficient – after all, there are, still, the "savage" manual drivers on the roads, often older people who own the old driver's license and, she guesses, see driving not only as a function of going from A to B. Her friend, who has an eight-year-old schoolkid, actually sent her a picture of a very concerning letter that the teacher sent to all parents. There, the teacher explicitly asked the parents to talk with their children about the differences between manual cars and automatic cars. The reason being that one third of the kids, whose parents come to pick them up, drive "old", manual vehicles, which apparently became extremely "uncool", propelled by how CAV-subscriptions are being advertised especially. What is interesting

however, she finds, is that "back in the day", children focused on the car models and manufacturers, which made a car cool or not. Now, it is the strict divide between manual or automatic driving – which honestly, she finds very ironic, as the automatic cars look all the same anyway – at least the robotaxis. As she was thinking along, a notification popped up that informed her on her smartphone that a ride is now available, ready to be confirmed. It always works pretty fast, she thought, again wondering about how so much information is organised, left in awe. Much like the app that Uber had used (and still uses in other parts of the world), this one also asks you for your destination, then calculates the route followed by the different fares and estimated times of arrival. Generally, people who pay the higher fares arrive faster. That's why she learned to not snooze her alarm twice – it became a little expensive with the unpredictability of traffic. The notification also made her attention move back to her surroundings: the wide four-lane road next to her; one lane for robotaxis, one lane for private CAVs, one lane for public transport and one for heavy vehicles and manual cars; the old traffic lights, which were now reworked for the different lanes, allowing CAVs to pass through longer than manual cars for some "connectivity" reason that she never understood. Indeed, she liked that she has "lived through" the purely manual times of driving – the wild days! Where she could drive as fast as she wanted on some German highways, where you could just leave, without entering your route or enabled your GPS in the central system for tracking and "traffic flow" reasons. On the other hand, though, she likes it. After all, she thought, traffic is more energy efficient now, which she, a person with a sense for ecological focus, really appreciates. As she was thinking this, the robo-taxi she had ordered arrived, carefully indicating that it wants to stop, precisely halting perfectly parallel to the sidewalk. Upon arrival, the back-left door of the robo-taxi opened. Funny, she thought, why exactly is it that she needs to sit in the back, as if some kind of manner is appropriate to not insult the driver or adhere to principles of privacy. Still, everybody does it, which is why she complies. Then she remembered hearing that one manufacturer wanted to have the seats facing each other but failed, because it did not meet the safety requirements for CAVs. The irony though was that as to manual car standards, this would have been perfectly fine. She guessed that with "no drivers", regulations were much stricter – give the people what they need, right? After entering, she felt very comfortable straight away. Actually, she thought to herself, she prefers this manufacturer's robotaxis, because they have screens for the passengers that show the details of why the vehicle behaves why it behaves – pretty impressive, from how far a "machine" can recognise a traffic light and pre-empt its behaviour accordingly. That the screen shows this information has given her a stronger sense of security. She remembers her first ride with a robo-taxi: she was purely fixated on this screen, carefully observing so that the robo-taxi does not do anything unexpected. Of course, the range of entertainment options is given as well for those who are not necessarily interested in the "rear camera view". The car and the smartphone, or mobility app, exchange data even before the car is opened to enter. The data exchanged is about the driver's ID, credit score, and mood data. Mood data is a novel thing that allows the use of the passenger's physical and mental state, which the car reflects through appropriately adjusted ambient lighting, music, seat settings, and so on. After entering the cabin and automatically fastening the seat belt, the journey is basically ready to start, as the route itself was already predefined in the ordering of the robo-taxi. She thinks that they did this on purpose, so that the operating system already calculates and predicts a best possible route, adjusting the routes of others as the collective of simultaneous robo-taxi-journeys influences each other – smart, that's for sure, she thought. The way the robo-taxi accelerates felt very familiar. Not too careful, not overly aggressive. She thinks she would have accelerated equally strong if it were here controlling the vehicle. Luckily, she is one of those who can easily stare at a screen or read a book while driving. Others, and she heard from many, get dizzy and sick – forcing these poor people to do nothing at all, stare at the moving traffic around them all journey long. The ride feels really smooth. There are minor aspects that require her attention, which is why she read up on the latest news and answered some long-waiting messages. Only once did the robo-taxi ask her for her preference: because of increased traffic (always during rush hours, but she cannot avoid it unfortunately), a faster route became available. The choice that she then received was to either stay on the (slower) route she was on or pay extra to be redirected onto the other, faster, route. Other than that, the journey was pretty smooth. Except in one instance, where a manual driver shoved herself in front of the robo-taxi after presumably forgetting to change lanes prior to a right turn. The "problem" here is that robotaxis will always drive defensively to mitigate any damage. That's why it became a social rule among manual drivers to not generally do that – at least that is the case most times anyway; exceptions confirm the rule as we all know. The journey went on for another 15 minutes approximately. As the robo-taxi was arriving in the wider area of the city where she lives, the car gave her a sound-alarm to let *her know that she can get ready to pick up her things. Lucky, she thought. She prefers robotaxis over owning one, actually. Not only are they extremely expensive to buy as such, but maintaining them is a luxury as such! A friend of hers, he thought he'd buy one. Now he is always complaining and thinking about selling it again. What he hates the most he said is that he needs to pay a 25,00€ monthly fee on top of his monthly update subscription to get priority on the proximity of parking spaces in relation to his destination addresses. The more annoying thing then was that even with the fee, it does not always work, as some people apparently got fed up with parking "too far out", making many of these people book the extra service. The problem with that is however that it does not necessarily lead to more parking spaces – at least not those designated for automated vehicles – which in itself has become a public debate among the public and policymakers. What she finds nice though is that people who are physically impaired, due to age for example, get this priority for free. Thinking about her friend again, she is impressed as to what people are willing to pay for to not have to wait for these 10 minutes for ordering a robo-taxi – she could not afford it, that is for sure. When the robo-taxi did the final turn into the street of her destination, a one-lane one-way street, she already knew that her walk would be a little longer as she had hoped for. That is, because the street was full of parked cars, thus not giving the robo-taxi space to halt and end the journey. Indeed, the city already had plans of reconstructing her street to add a designated pick-up and drop-off lane, but it did not go through yet. As she lives in the outskirts, construction began just now, in the past 3 months. The problem is that her neighbourhood actively protests against the city's plans, because her neighbours are fighting for their parking spaces. Actually, she is one of very few in her street to use robotaxis actually. That's why she gets looked at in a very alien way sometimes when she enters or exits a robotaxi. In the end, her vehicle dropped her off 350m down the road. This was the way they were programmed. If there is no room to not block traffic, do not stop. Unfortunate for her, but good for overall traffic flow apparently. It stopped gently, asked for feedback in the form of "unhappy to happy" smileys and wished her a good day.*

Whilst this case did not incorporate all of the aspects from the table above, it renders a reality that delineats how organising principles can be translated into aspects of an operating modus for CAVs. As such, this text provides one example of how decisions about the organising principles that are being done today carry their echoes into the way that the operating modus of CAVs stabilises tomorrow.

6. Conclusion

The present report is dedicated to the topic that through the connection and automation of driving, humans are replaced by machines. The literature about CAVs reveales two difficulties: firstly, scholarships about CAVs mainly gravitate around technological aspects, and secondly, the assumed effects, once CAVs are deployed, are primarily positive. The first aspect neglects the socio-technical nature of vehicles. The second aspect concerns that right now CAVs promise to make our transportation system for instance safer, cleaner, and easier, as well as more socially inclusive, flexible, and green. But is it really that easy? We state *no*, as the fulfillment of this optimistic vision of CAVs is highly tied to decisions about their development in the first place. The translation of the human driver into a machine (the CAV) dictates the effects of the CAV. We follow, there is a lacking research field about, on the one hand, the socio-technical construction of CAVs, and on the other hand, depending and potentially conflicting requirements of individuals on CAVs and promises of CAVs. This led us to our research question: As a society, what kind of CAVs do we want to have on our streets, a) showing which behavior, b) implying which impact and c) how can we negotiate their behaviour while this technology is "in-the-making"? Furthermore, the social construction of future "drivers" is a very important topic, yet it has not received explicit attention in the literature. Against this background, the present report aims to structure this research field, the social construction of future "drivers". This was achieved by introducing two central concepts, the operating modus, and the organising principle. The formulated use case demonstrates the application of the operating modus and the organising principle, and shows the advance to other visions of the future. The following important findings can be concluded from the work:

Firstly, what the automation of vehicles will be is still open. Existing concepts are currently too much driven (or limited) by technical possibilities and potential business models. Such approaches can be interpreted better as a starting solution and a narrative of the first developments. Inspecting the whole transportation system, we can see different operating modi, which are embedded in socio-technological regimes. But for

CAVs, too little or no attention has been paid to the potential of feedback from society. This concerns not only the resulting social use of the technology but also the consequences of the resulting use. Automation is currently treated as a promise: "It will get better!" But potential pitfalls are a) people believe they can retain much of today's automobility (freedom), b) the profit motive of a few is beneficial for everyone and c) it can be regulated afterwards when a problem is arising and urging. Operating modi are characterized by rules, which delineate behavior that occurs. An operating modus decontextualize the complexity of the transportation system by rules through instances of socio-technological order. This means, by changing an operating modus, the rules and the behavior changes as well. Right now, CAVs lack a reference point, an operating modus.

Secondly, to understand the driving force behind the operating modus, we introduced organizing principles. These are the underliying normative frameworks, determining how operating modi of vehicles are constructed, based on a societal construction process. When thinking about such a societal construction process one must also consider what tenets we want to follow in the construction process of CAVs. Different goals will lead to different organizing principles and operating modi of CAV. An economic, social or ecological tenet will produce different CAVs. The tenets do not necessarily exclude each other, but some are conflicting. The organizing principle allows to negotiate the weights of the different tenets towards each other.

Thirdly, there are formulated objectives to be achieved with automation. However, if one were to prior the organising principle and operating modus for objectives, the framework of the development of automated vehicles would become focussed. This narrowed development path is for good reason, because scientific methods can be used to determine effects and target contributions and thus also to evaluate solutions.

Fourthly, whether we will live in a hybrid (manual and automated), or fully automated future transport system, automation will likely strip away individuality and independence ofdriving. What leads to an additional important societal question: how willing are we to give up individual freedom for a collective good? Different transportation systems show different degrees of standardization (rail – high vs. car – low). The level of dependence between the standardization of function and processes, and centralization of decision we call the encrustration of the operating modus. “Taking away” the choice how to drive a car may lead to resistance by users. This produces the challenge to decide, which aspects of the already-established operating modus of cars to translate into CAVs, and which to leave for the users. Furthermore, we assume a social change of values towards the car and automobility for any concept of automation. In particular, the aspect of encrustation shows that the current (perceived) freedom of automobility will not be maintained with CAVs. This change in values, in whatever details it will manifest itself, needs scientific (and social) attention and focus in the discourse on the development of CAVs.

Fifthly, as we have shown it is to be expected that regional solutions of CAVs will emerge because of different answers to aforementioned issues. By regional solutions we mean organisational principles of CAVs focused by cultural areas, partly by national borders. This has enormous consequences for industrial policy from the macro level (e.g. how can German CAVs be sold in Asia in the future?) to the micro level (e.g. what incentives can manufacturers and their products still offer?). But, we may not have to go beyond boarders. It can be assumed that even different social groups may require different CAVs. Future research should focus on the requirements of different social groups on CAVs. Some research has already been done here, but way to litte. A special focus should lie on individual versus social/ collective requirements.

These conclusions are certainly not final or complete. However, they highlight the importance of the field of the social construction of future “drivers” for politics, society and industry. One of the strengths of this report is that it is situated in between a range of existing theoretical clusters: from fields of political theory to science and technology studies to psychological human-computer interaction and acceptance studies, this report touches on many aspects to underline different arguments made in this document. However, a specific inquiry from each of these fields would be beneficial to further understand the shades of this space, but also the wider discussion that these two concepts frame. After all, different aspect of either concept that we introduced can be found anywhere where a transportation system exists. But this report is no definitive answers to questions. This document should be understood as a way of surfacing a discussion that so far was submerged: the searching for and understanding of a technical fix to social problems, which leads us to the second part of the conclusion.

We hope that this report provokes critical thinking towards current practices of governance of CAVs and stimulates reflection in order to move away from a purely technical construction approach of CAVs and incorporate the social into the development of CAVs in the first place. This argument circles back to the very beginning, where we presented how simulating models are taken as a basis for policy-making or manufacturing of CAVs. And indeed, we are not saying that these simulations and models are not productive in what they do. They do certainly, and very accurately, highlight certain aspects of CAVs-in-practice. However, it should not be mistaken with an accurate depiction of a reality where CAVs took to the roads. Rather, simulations should be very consciously deployed as thin slices of CAVs-in-action and not as rich enough in "facts" that they can be regarded as the foundation for entire policy strategies by major governmental bodies. Simulations are susceptible to inconsistencies in how it actually plays out. We have seen in this document that transportation is not a purely technical matter and that issues that arise within transportation are not to be answered by providing a purely technical solution, as it does not account for the social, cultural and political dimension of transportation. It might be worth understanding, by use of the vocabulary introduced in this report, to what extents the currently posed targets (and simultaneously justification) of CAVs take such elements into account; as there indeed are many positive voices that support CAVs (how they are currently planned), yet little critical voices – and this runs the risk of prematurely concluding that CAVs are the answer to the problems that societies face in the present time. Conclusively, the organising principle and operating modus should be understood as a perspective-under-development to understand transportation – and all the matters it encompasses – from a point of view that exceeds the technical, bringing the often-overlooked aspects into the picture.

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Appendix

Technology		
	Vehicles	Car, truck, motorcycle, special vehicles
	Trailers	Caravans, load trailers, horse trailers
	Automotive engineering	Propulsion, material, sensor technology, tires, physics (thermodynamics, fluid mechanics etc.)
	Information technology	FAS, navigation, telephony/connectivity, convenience systems
	Traffic management	Phased traffic light, indicator detection, signs for regulation/information, traffic management center
	Road structure	Asphalt, marking, curb, width, number of lanes, substructure, superstructure, planning aspects (such as course, swivels, piers, planting, avenues/ trees)
	Traffic control	Access/ user permission, surveillance camera, induction loops, speed camera, policy control
Industry		
	Production value chain	OEMs, suppliers, logistics, advertising, automation engineering, dealer, financial industry
	Value chain maintenance	Road maintenance agencies, road construction companies, engineering offices, consultants, mobile car aid
	National input/output	Labor, R&D budget, tax-payer, fees-payer
	Strategies	Image, competition, collaboration, coopetition, mass producer, premium producer, pricing policy, vehicle segments, business cases, customizing, design, innovation cycles, lobbying, labor union
Infrastructure		
	Road infrastructure	Road types, elements (nodes, links, bridges, tunnels), street space (vehicles, cycling, pedestrian), transport organization (traffic light, signs, constructional separations, traffic routing), services (public and private parking space, snow, cleaning
	Service station infrastructure	Petrol pump, service buildings and services (pressure air, oil, washing rooms, vacuum cleaner), number and spatial density of service stations, car washing facilities, refueling by hand, price display, parking/break
	Electric infrastructure	Lighting, telematics, electric car charging, emergency telephones
	Water infrastructure	Water supply, drainage
	Car dealer	Brand specific, independent
	Car repair shop	Network, parts shipment system, mobile repair aid
Policy		
	Laws/directives	Traffic rules, safety maintenance, international agreements, norms/standards,
	Policy fields	Transport, environment, economy, research, safety and security, social affairs
	Planning	Urban planning/spatial planning/infrastructure network planning, traffic data, statistics, capacity provision
	Actors / Institutions	Ministries, associations/ lobbies, authorities, supervisory authorities (police, fire fighting, ambulance

	Market interventions	Fiscal policy (subvention, pricing), regulation, control, taxation
Science		
	Research facilities	Large-scale research institutions, universities, private R&D institutions, industrial R&D, Think tanks
	Publication/transparency	Journal ranking, peer-reviewed quality control, neutrality, lectures, conferences
	Projects/ collaboration	Dependence on third-party funding, patents, spin-offs, start-ups, data access, method development, professorship system and secondary occupations, method development
	Disciplines/perspective	Transport system dependent disciplines (e.g. combustion technology), research disciplines, approaches/ schools in disciplines
User preferences and market		
	Time-space preferences	Flexibility, route selection, value of time, congestion level
	Attitude and preferences	Rule conformity, convenience, safety and security, environment issues)
	Driving preferences	Safety distance, speed, acceleration
	Purchase preferences	Purchase cycle, vehicle choice, buy new/used vehicles
	Driving mode	Driving pleasure, gender issues, driving ability
	Socio-economic background	Incomes, marital status, gainful activity, age, vehicle ownership/ Car-Sharing, driver's license ownership, technology affinity, affinity for cars
Culture		
	Mobility education	Toys, brand loyalty, mobility routines, acceptance of negative consequences, externally characterized by mobility environment, conditioning to car characteristics (safety, freedom, house with own garage), driving schools
	Land use planning alignment	House outside cities, mega centers/outlets, car-friendly cities/ car-free areas, choice of location
	Functions	Enthusiasts/ scenes, status symbol, service stations as meeting places for young people, service stations as 24h shops
	Individual expression	Lifestyle, driving style, clothing/ merchandise, adulthood, traffic teaching, aggressions (pushing, gestures, jelling), peaceableness
	Collective expression	Brand image, news in radio / fixed part of news, film image/ product placement, Drive-in restaurants and cinemas, liberty/ freedom, internet forums)
	Rituals	Permanent personal belongings in the cabin, cocooning (e.g. own music and singing), frequently change of oil and tires, cleaning, polishing and waxing
Market		
	Markets types	New car market, used car market, re-imports (in Europe), exports, imports, scrap yard/recycling, stock market (oil, energy)
	Business models	Usage mode (exclusively, shared, pooling), fleets (renting, mobility as a service
	Financial concepts	Interest/credit, purchase, hire, leasing
	Obligations	Insurance, taxes, driving license, license plate
	Exclusion	Inability (mental, physical, age), loss of driver license because of misbehavior (mental and psychological tests for rehabilitation)
	Customer relation	By car dealership, Apps/platforms, major customer discounts
	Market rules	Lead market, international competition, patents, standards, norms. production planning, stock planning

	Market particularities	Natural monopolies of infrastructure, external costs, production of mobility services in advance is impossible
	Vehicle segments	SUV, coupe, sports car, van, family car, luxury car, old-timer