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Autonomous driving is a popular subject of discussion in today's media and, occasionally, a highly emotional one. Proclamations of success from car makers, system partners, and companies whose business models stem from other fields continue to fuel the debate. As late as 2011, as the “Autonomous Driving—Villa Ladenburg” project (which enabled the present volume to be published) was still being defined, we could not foresee how central the topic would be in public discourse at the project's end three years later.

In line with the objectives of the Daimler and Benz Foundation, the project aims to stimulate discussion on a technical topic of great social significance. It would be immodest and objectively false to credit growing discussion to this project when, at the same time, several leading global firms are using their research and public relations teams to position themselves in this forward-looking technological field. Nonetheless, the project influenced the public discourse decisively at various points, even if the connection was not immediately recognizable.

Indisputably, the Daimler and Benz Foundation has shown excellent and timely instincts in launching this project. Precisely because autonomous driving is currently receiving so much attention, the present volume's publishers deem it a good time to present as complete an overview of the topic as possible. For this discussion, researchers from various disciplines have taken up the task of sharing their viewpoints on autonomous driving with the interested public. This has brought many relevant issues into the debate.

As researchers, this has taken us into unfamiliar territory. We are addressing a specialist audience, potential stakeholders and the interested public in equal measure. Of course, this book cannot satisfy every desire. For further reading, then, please consult the prior articles of the project team in the journals and conference proceedings of their

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respective specialist fields. The Foundation also plans publications to accompany this volume that will summarize this book's key findings and put them in everyday language.

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## 1.1 What Is Autonomous Driving?

Even a quick glance at the current public debate on autonomous driving shows that there is no universal consensus on terminology. In order to bring about a certain convergence in how the terms of autonomous driving are understood among those involved in the project, some definitions were selected in a highly subjective fashion at the beginning of this project. These definitions were illustrated with use cases described in-depth (see Chap. 2). These definitions are described in all of their subjectivity here.

For decades, word plays on the word “automobile” have been rife among pioneers in the field of autonomous driving [1]. When the car was invented, the formulation of “automobile,” combining the Greek *autòs* (“self, personal, independent”) and the Latin *mobilis* (“mobile”) [2] stressed the “self-mobile.” The overriding emotion was joy that the driver was mobile without the aid of horses. What this term failed to acknowledge, however, was that the lack of horses meant that the vehicle had also lost a certain form of autonomy [1]. Through training and dressage, carriage horses had learned for themselves (self = Greek *autos*, see above) to stay within the bounds of simple laws (Greek *nómos*: “human order, laws made by people”). In this sense, horse and carriage had thus both achieved a certain autonomy.

In the transition from horse carriages to automobiles, important obstacle-avoidance skills were lost, as undoubtedly was the occasional ability to undertake “autonomous missions.” Many a time would horses have brought a carriage home safely even if the driver was no longer completely fit for the journey. They would have at least have conveyed the vehicle in a “safe state,” eating their fill of grass on the wayside. The autonomous automobile aims to recover its lost autonomy and indeed go far beyond its historic form.

A special perception of Kant's concept of autonomy, as formulated by Feil, came to be of importance in understanding “autonomous driving” within the project: autonomy as “self-determination within a superordinate (moral) law” [3]. In the case of autonomous vehicles, man lays down the moral law by programming the vehicle's behavior. The vehicle must continually make decisions about how to behave in traffic in a manner consistent with the rules and constraints with which it was programmed.

It has to be said that the reaction of experts from diverse disciplines ranged and ranges from complete rejection of this definition to carefully considered approval. Independent of this, however, it is possible, by reference to the concept of autonomy interpreted and understood in these Kantian terms, to point out the direct linkage between technological development and ethical considerations.

The importance of this definition for engineers comes through clearly in my discussions with students. Confronted with this definition, engineering students in Braunschweig and Munich have in the last ten years come to understand that the development of autonomous driving requires them to not only research and develop technology but also to implement “moral laws” with utmost consistency. How does an autonomous vehicle behave in a dilemma situation, when at least one road user will inevitably be injured in an accident? This discussion is explored in greater depth in this book by Patrick Lin and Chris Gerdes (see Chaps. 4 and 5).

To bring engineers and lawyers into agreement, various degrees of assistance and automation were defined in a working group drawn from the German Federal Highway Research Institute (BASt) [4]. The highest defined degree of automation was named “Full Automation”: The fully automated vehicle drives by itself without human supervision. Should system performance degrade, the vehicle is autonomously “restored to the system state of minimal risk.” From a technical point of view, the greatest challenge lies in the complete absence of a human supervisor who knows the system limits, recognizes system faults and, where needed, switches the vehicle into a safe state. Fully automated vehicles must monitor their own state autonomously, spot potential system faults and performance degradations, and then—with a threatened drop in performance—initialize and execute the transition to a safe state. Clearly, the safe state takes on a central role in the definition. What does a safe state consist of, however, when a fully automated vehicle is moving on the highway at 65 miles per hour (or even faster in Germany)?

Ohl [7] pointedly concluded that the prototypes for autonomous vehicles demonstrated on public roads by research institutes, vehicle manufacturers, and IT companies in recent decades have only been partially automated in terms of the BASt definition. Safety drivers have supervised the automated vehicles; a production-ready safety concept for fully automated vehicles has yet to materialize. While there have been successful trips in which the safety driver has not had to intervene, to this day we lack evidence of the feasibility of journeys on public roads with fully automated vehicles.

Despite the concerns of some experts mentioned above, autonomous vehicles in the present volume are characterized by their “self-determination within a superordinate (moral) law” laid down by humans (Kant, as found in [3], see above). They are fully automated vehicles in terms of the BASt definitions [4].

For reasons of space, it has been decided for this book to forego a narrative history and a documentation of the state of research and the technology. Regarding autonomous road vehicles, Matthaei et al. [5] have summarized the current state of the art. In Chap. 3, Fabian Kröger gives an arresting historical overview of autonomous driving as a visionary concept, or as science fiction, chiefly within image-based media.

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## 1.2 Autonomous Driving—Drivers Behind the Research

Research into fully automated vehicles [4] used to be, and still is, driven by a host of reasons. Only the most common are given in this section.

Even though the number of accident deaths in Germany drops nearly annually, the estimated worldwide number is occasion enough for a further increase in transport-system safety. According to the WHO, 1.24 million people worldwide died in road accidents in 2010 [8]. In Chap. 17, Thomas Winkle examines the conditions under which the accident-prevention impact of automated vehicles can be forecast prior to their being launched on the market.

How much a driver or potential user requires assistance is at the heart of any particular vehicle system. Is he or she confronted with an activity that is tiring and kills off any pleasure in driving (stop-and-go traffic, long stretches on highways)? Or is he or she temporarily unfit to drive, for instance under the influence of medication, too tired or simply too inattentive for active driving? Is there a need for assistance because of diminished faculties due to illness or old age, or diseased muscles or bones? In these cases, a car's autonomous capability to drive opens up new opportunities for individual mobility.

Fully automated driving [4] offers the greatest potential for optimizing traffic flow. By far the most well-known European program of vehicle automation of the last century has already indicated this objective: “**Programme for a European traffic with highest efficiency and unprecedented safety**” (1987–1994), or “Prometheus” for short [6]. More recent projects have demonstrated technical solutions specially designed to increase traffic flow. In Chaps. 15, 16, and 19, the authors occupy themselves with autonomous vehicles' potential for improved traffic flow and new vehicle usage concepts.

The significance of the capability to drive autonomously for commercial vehicles merits special attention. Heike Flämig examines what potentialities arise for autonomous vehicles in the area of freight transport (see Chap. 18).

The potential that autonomous vehicles' rollout holds for a far-reaching reshaping of the transport system—indeed the city itself—has not yet been heavily researched. The authors of this book's “Mobility” and “Acceptance” sections illustrate how multilayered the changes made possible by introducing autonomous vehicles could be. These potential changes can drive, but also inhibit, such an introduction.

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## 1.3 The Layout of this Book

Immediately following this introduction, the use cases which contributed to the authors' common understanding of autonomous driving, and which should do the same for readers (see above), are elucidated. This is followed by six sections, each overseen by editors with specialist knowledge, from whose pens also stem the short introductions preceding each section.

Fabian Kröger opens the first section on the topic of “Human and Machine” with a summary of how autonomous road vehicles have been viewed in public, mostly in the media, since work started on vehicle automation almost one hundred years ago. Chris Gerdes and Patrick Lin address how autonomous driving is to be assessed under ethical considerations, and whether autonomous vehicles can behave ethically. Berthold Färber and Ingo Wolf discuss questions of human and machine coexistence.

The “Mobility” section examines how mobility may be altered by the introduction of autonomous vehicles, both generally and in specific aspects. To this end, Miranda Schreurs and Sibyl Steuwer give an overview of the political framework. Barbara Lenz and Eva Fraedrich examine the potential for new mobility concepts that may result from autonomous driving. Sven Beiker outlines various deployment scenarios for fully automated vehicles [4]; he also discusses an actual case of them in use. Dirk Heinrichs looks at the ramifications and questions for urban development that may arise from autonomous driving. Hermann Winner and Walther Wachenfeld take up the question of what impact autonomous driving may have on the vehicle concept itself. Rita Cyganski looks into the issue of how autonomous vehicles may change demand for mobility and how this can be represented in models for transport planning.

In the “Traffic” section, Peter Wagner and Bernhard Friedrich forecast how autonomous vehicles may affect traffic. Thomas Winkle furthers the discussion on the potential safety benefits of assisted, partially, and fully automated vehicles [4]. Heike Flämig examines their particular significance for freight transport. Marco Pavone discusses the potential of “Mobility on Demand.”

The “Safety” section tackles basic questions of technical reliability in machine perception (Klaus Dietmayer), functional safety (Andreas Reschka, Walther Wachenfeld, Hermann Winner), and data integrity (Kai Rannenberg).

In the “Legal and Liability” section, Tom Gasser, Stephen Wu and Bryant Walker Smith examine the current legal systems and legal frameworks for autonomous driving in both Germany and the USA; Thomas Winkle recommends drawing from the experience of liability cases in the development process.

In the “Acceptance” section, Eva Fraedrich and Barbara Lenz explore questions of individual and societal acceptance of automated vehicles. Armin Grunwald investigates questions of society’s perception of risk in connection with autonomous driving. Eva Fraedrich and Barbara Lenz examine the relationship between today’s car-usage practices and attitudes to autonomous driving. David Woisetschläger discusses the economic consequences for the traditional car industry and new market players.

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## 1.4 Work in the Project

The working methods in the “Autonomous Driving—Villa Ladenburg” project have influenced the present book. They are thus briefly sketched out below for the sake of transparency. The “motor” of the project was the core team consisting of Chris Gerdes,

Barbara Lenz, Hermann Winner, and Markus Maurer. This was supported by the research work of Eva Fraedrich, Walter Wachenfeld, and Thomas Winkle, who receive our grateful thanks at this point. In the first of the project's two years—the project ran from October 2012 to September 2014 in total—over 200 questions relevant to autonomous driving were identified among the core team. These questions were the basis for project specification sheets that served as guidelines for this volume's authors. Three workshops were carried out to bring about a common understanding of autonomous driving among the participants in the project and share different perspectives from their various specialist disciplines. At one of the first workshops, in November 2013 in the Möhringen district of Stuttgart, the concept of the project and basic understanding of autonomous driving—established via the definitions discussed above and the use cases (see Chap. 2)—were introduced and explored.

At two further workshops in Monterey (February 2014) and Walting (March 2014), the authors presented and put forward for discussion their answers to the project specification sheets. It is thanks to the discipline, openness, and expertise of the authors that a comprehensive discussion on autonomous driving can be presented in this volume, addressing in equal measure the potential and the challenges to society on the path to mass production. In this sense, this book hopes to be a starting point for sustainable research and development of autonomous road vehicles. Special thanks are due to all the authors, who have involved themselves in this book project with focus, discipline and a willingness for interdisciplinary dialogue.

In the closing phase of this book's production, the authors were overseen by the editors of the individual sections, who took great pains to aid the convergence of the articles therein. Editing the sections was among the tasks of the core-team members. Special thanks go to Tom Gasser and Bernhard Friedrich, who each took on the editing of a section and brought necessary expertise that was not available on the core team. Even before it had drawn to a close, the project made a considerable impact on the specialist discussion on autonomous driving in Germany and the USA. One particularly positive outcome was that many participants in the project have taken part in round table discussions on “automated driving” at the initiative of the German Federal Ministry for Transport and Digital Infrastructure (BMVI) and its working groups since December 2013. Project findings thus flowed, and continue to flow, into the reports of the round table. The interest of experts and the public became clear in the response to the numerous talks, press interviews, and publications carried out in the context of the project. Over the duration of the project, considerable adjustments were made in the communications of leading vehicle manufacturers and tech companies relating to autonomous driving. It cannot be ruled out that the project has already left its first relevant marks here.

Even though the project itself employed a scientifically clear-cut definition of autonomous driving, some of its findings will be of direct practical relevance for highly automated vehicles and even driver assistance systems already in use in today's production road cars.

This book has only been possible thanks to the support of the Daimler and Benz Foundation, for which we are extremely grateful. “We” in this context means all the authors and editors of this book. We would also like to thank the Springer publishing house for a good working relationship and the high quality print edition. Particular thanks go to Thomas Winkle for supporting all translations and coordinating the English edition. Thanks to the Foundation’s support, this book is available electronically at no charge. Special thanks are due to various employees at Daimler AG for interesting discussions, but especially for the understanding that the researchers in this project were guided by scientifically motivated questions, independent of commercial interests.

My wholly personal thanks go to Barbara, Chris, and Hermann for their readiness to collaborate in the core team, intensive cooperation, openness in discussions, constant striving to bring in their own experience to further develop their own concepts, and their constant struggle to make a common contribution to the sustainable research and development of autonomous driving.

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