# Vision or Threat—Awareness for Dual-Use in the Development of Autonomous Driving

Sebastian Schwartz, Laura Gianna Guntrum, and Christian Reuter

***Abstract*—In the digital age, the vision of autonomous vehicles (AVs) is vibrant. Research is being conducted worldwide to integrate AVs into our everyday lives in the future, spending considerable amounts of money in the development process. Actors from both engineering as well as social sciences are involved in this research, with technical disciplines strongly dominating. In addition to perceived progress of numerous newly developed technologies such as AVs, challenges should also be referred to. According to research analysis, the transferability of autonomous cars to the military sphere seems to be frequently forgotten or ignored (dual-use). Since not much research has been conducted in Germany on the potential deployment of autonomous driving development steps into military domains, 25 semistructured interviews with developers and researchers and actors involved in the field, were conducted in 2020. This article identifies that the majority of respondents interviewed were aware of general existing dual-use debates; however, few had reflected about dual-use issues regarding a possible transfer of their own development processes in the context of autonomous driving to military applications, intensively. One reason is the small-scale nature of research, another is the complexity of the field, which enables the engineer's alienation from their responsibility for the artefacts' use. Moreover, it has become clear that hardly any conversations among colleagues occur about possible misuse and that no standardized policy guidelines exist, which provide information about possible risk. To raise dual-use awareness, scientific contributions, risk education, and interdisciplinary discussions are essential.**

***Index Terms*—Autonomous driving, awareness raising, dual-use, risk education.**

## I. Introduction

In RECENT years, machine autonomy has increasingly found its way into civilian and military contexts [1]. Autonomous systems (ASs) can be found in many application areas and domains (air, space, water, etc.), which include, for example, logistics, hazardous environments, maintenance tasks, security or observation [2], [3]. Generally, the technology field of autonomy lies in the nucleus of civilian and military research, leading to ethical considerations [4]. According to Bissell *et al*. [5], research on automation is mainly taking place in engineering and most current research papers come from engineering or computer science [6]. Only three of the top 20 fields of study appear to be nontechnical in nature. Kyriakidis *et al*. [7] claimed a divergence between industrial and academic research and development (R&D). Since ASs are hybrids of software, hardware, and mechanical parts [8], an engineering research paradigm prevails. Within the consumer sector, the vision of autonomous driving is consequently vibrant. The technology enabling autonomous driving is not a monolithic technology, but rather a conglomerate of different scientific fields [9], [10]. Hereby, the "IT [Information Technology] and automotive industries [...] are major players in advancing autonomy" [11, p. 339]. In the automotive sector, classic mechatronic development is associated with advanced software. The generally established vehicle automation levels range from 0 to 5. Different levels of automation are distinguished. Level zero means manual operation of the car, while level five means that the car always makes its own decisions in all areas. At level 4, on the other hand, the driver is still required to be able to take over the wheel again. It is important to mention that despite the positive promises made by manufacturers, a fully autonomous vehicle (AV) (L5) cannot be used in everyday operation in the near future and expectations should be adjusted accordingly [12].

In general, it is important to note that technology presents opportunities and risks alike. This dualism is best demonstrated by many technological developments being used for both civilian and military applications. According to Altmann *et al*. [13], many technical innovations have been used for the development of weapons and warfare, such as the radar or later in the 20th century, the atomic bomb, to provide two prominent examples. Nowadays, there are still numerous research areas where a close interaction between technology, civil, and military research can be identified. According to Forge's [14, p. 117] definition, "an item (knowledge, technology, artefact) is dual-use if there is a (sufficiently high) risk that it can be used to design or produce a weapon, or if there is a (sufficiently great) threat that it can be used in an improvised weapon, where in neither case is the development of weapons the intended or primary purpose. The judgements about risk and threat are contextual." AVs and the underlying technologies and development knowledge meet those criteria: Besides civilian use, AVs can either be misused [15] or can be integrated into armed forces [16], [17]. Since autonomous

Manuscript received 24 March 2022; revised 30 May 2022; accepted 2 June 2022. Date of publication 13 June 2022; date of current version 23 September 2022. This work was supported in part by the German Federal Ministry for Education and Research (BMBF) in the Regional Research Center "Transformations of Political Violence" (TraCe) under Grant 01UG2203E, and in part by the German Federal Ministry of Education and Research and the Hessian Ministry of Higher Education, Research, Science and the Arts within their joint support of the National Research Center for Applied Cybersecurity ATHENE. *(Corresponding author: Laura Gianna Guntrum.)*

The authors are with the Science and Technology for Peace and Security, Technical University of Darmstadt, 64289 Darmstadt, Germany (e-mail: guntrum@peasec.tu-darmstadt.de).

Digital Object Identifier 10.1109/TTS.2022.3182310

technologies are largely of a dual-use nature [11], AVs are just another manifestation in the realm of autonomy.

Increasing technical development, especially in artificial intelligence (AI) and advanced mechatronic systems, will lead to an increased spread of ASs and AVs alike [18]. The academic discussion in the field of tension between the ethics of AI and autonomy, lethal autonomous weapon systems, proliferation, and respective arms control is vibrant [19]–[24]. Hereby, unmanned aerial vehicles are much more prominent in the debate [15]. Although these systems are of eminent importance, they are not in the scope of this article. Due to the rapid improvement of ASs, the military has a genuine interest to implement civil R&D into its own products or solutions [11]. Therefore, in the military, civil progress is followed with great interest [25]. To the general trend toward increasing autonomy, spill-over effects (e.g., off-the-shell technologies or civil-military job fluctuation) are used to reduce high development costs and to integrate know-how into military programs [26], [27]. [25]. To the general trend toward increasing autonomy, spill-over effects (e.g., off-the-shell technologies or civil-military job fluctuation) are used to reduce high development costs and to integrate know-how into military programs [26], [27].

Generally, the dual-use potential of ASs on the ground is considered a high risk in academic discourse [28]. Yet, despite the relative urgency, the connection between dual-use and civil ASs R&D has not been prominently discussed, especially with a focus on AVs. This may be related to the fact that AV-research tends to investigate "ethical complexities related to an individual vehicle" [29, p. 384], like the German Ethics Code for Automated and Connected Driving [30], rather than "the ethical responsibilities of the designers of self-driving cars" [31, p. 67]. To date, few documents have addressed dual-use aspects regarding AVs and what areas of civilian research could potentially be used for the military research in the aforementioned area. The majority of people involved seem to have little awareness and the possible transferability of one's own research into military-relevant content might be an abstract idea. To gain precise insights and knowledge of stakeholders involved, we conducted 25 interviews with developers and researchers based in Germany ($n = 24$) and the United States ($n = 1$) between July 6, 2020 and December 4, 2020. By the time of the consultation, 24 interviewees claimed to live in Germany and one German respondent in the U.S. Of the 24 respondents residing in Germany, one respondent reported coming from abroad. The other 23 interviewees and the one respondent living in the U.S. reported being from Germany. The German automotive industry as one of the most important industries in the country and the associated research landscape [32] represent an excellent research sample. The German automotive industry as one of the most important industries in the country and the associated research landscape [32] represent an excellent research sample.

In the following, we will highlight existing research gaps and derive our research questions (RQs). Additionally, relevant related literature will be presented, including important contributions from research on autonomous driving, awareness, dual-use, and dual-use awareness in the field of AVs. Then, our methodological approach will be introduced and findings of our analysis will be exemplified and evaluated. Building on this, results will be discussed, implications pointed out, and limitations of the study considered.

## II. Research Gaps and Questions

Our empirical study ties in with previous research addressing dual-use issues. As a considerable amount of research is already being conducted on dual-use issues with regard to biological science, nuclear technology, and chemistry [25], [33]–[36], this study contributes to the field in terms of AVs. Since Germany has been planning on taking a pioneering role in the field of autonomous driving and has thus been heavily investing in R&D, we deem it important to investigate whether potential risks are also considered in this rapid development. Research on autonomous driving is very fragmented in general, making it difficult to maintain an overview. Based on the interviews we conducted, we identified a wide range of the areas involved.

Currently, very few documents on dual-use in the sector of autonomous driving are (publicly) available in Germany (gap 1). In addition to this gap, no research has been conducted in Germany on whether stakeholders involved in the area are aware of dual-use potentials and whether compliance and guideline papers help to create and/or increase dual-use awareness among employees in the AVs sector (gap 2). We therefore investigated a possible relationship between these issues. Furthermore, we recognized a current lack of studies on the increased likelihood of interdisciplinary teams to discuss dual-use risks in this sector (gap 3).

Inspired by these research gaps, we aim to answer the following RQs.

*RQ1:* To what extent do German employees, involved in the development process in the context of autonomous driving, possess a dual-use awareness?

*RQ2:* What measures are known to the interviewees that are being taken in Germany to address potential dual-use risks in the area of autonomous driving?

## III. Related Work

In the next section, we will present the aspects of autonomous driving, dual-use, and existing literature about awareness regarding dual-use issues in the area of AVs.

### A. Autonomous Driving

R&D of autonomous driving technologies takes place in various technical and social disciplines [18]. This ecosystem contains various and heterogenous actors, which do not necessarily exchange knowledge [8]. In general, complex "systems leverage on several technologies that are not necessarily specific to a given sector" [37, p. 2]. Hereby, machine autonomy advances are primarily driven by AI, robotics, and control theory [26]—as subdisciplines of engineering and computer science. Regarding connected and automated vehicles (CAVs), Elliott *et al.* [38, p. 110] claimed that there are "five areas that lie in the heart of CAV research: inter-CAV communications, security and privacy, intersection navigation control,

collision avoidance, and pedestrian detection." In comparison, Liu *et al*. [39] distinguished autonomous driving technologies into three main components: first, algorithms, which include sensing, perception, and decision-making. Second, client systems, incorporating the operating system, hardware platform, and third the cloud platform, which involves high-definition maps, deep-learning, simulation, and data storage. Overall, the research field is fragmented due to the various and broad disciplines involved. Therefore, the progress in the research field occurs simultaneously within various disciplines, which can result in little understanding of the entire AS by the various actors involved.

In academic discourse, it is generally assumed that technologies with dual-use potential, i.e., with the inherent possibility of using them for both civilian and military purposes, are becoming increasingly important [28]. The military use of semi-AVs is already a reality, as seen recently in Gaza [40], which is a clear indicator that autonomous driving can be considered dual-use. Compared to the undisputed relevance of autonomous driving, the relationship between civil AS R&D and dual-use has rarely been discussed, especially with regard to autonomous vehicles [41]. The same applies to dual-use risks in the field of computer science and, by extension, software development [42], [43], which is a key resource in the field of autonomous driving [26]. Compared to other dual-use goods, such as biological goods, the manifested effects of software are often not clearly identifiable, as the results may not necessarily be physically visible [44]. Software-based technologies are genuine dual-use as they are "incorporated into both peaceful civilian application and military weapon systems" [45, p. 1]. Even if the research was conducted for a defined, specific purpose or to develop a new technology, the developed technology may be used contrary to the originally intended objective or purpose [46].

Concerning ethical considerations on automated and connected driving, it is evident that reports e.g., by the German Federal Ministry for Digital and Transport mostly focus on ethical concerns regarding road safety. Ethical concerns with regard to the development of certain technologies, which play an important role for autonomous driving, seem to be scarcely present [47].

### *B. Dual-Use and Dual-Use Awareness*

As explained above, we speak of dual-use when an item may be used for the production and development of a weapon or dangerous substances, which stands in contrast to its primary or intended use [14]. The state of literature illustrates that dual-use is mainly discussed in natural sciences, ranging from nuclear to life sciences and chemical research, to information technology [35], [42], [48]. Even though dual-use is not primarily discussed in computer science [35], a growing awareness of the issue in the academic field and the involved actors can be observed. Even though dual-use is not primarily discussed in computer science [35], a growing awareness of the issue in the academic field and the involved actors can be observed [11]. Particularly in the 2000s, debates on dual-use focused on research on diseases such as the human transmissive bird flu virus, as the results could be misused [49]. Nowadays, the term dual-use has become an increasingly familiar term in technical research that pertains to a technology that can be used for both civilian and military purposes. It "refers to materials, hardware, and knowledge that have peaceful applications but could also be exploited for the illicit production" [25] of weaponry or military applications. According to Kavouras and Charitidis [33], the "flow of information" between civic and military sphere has changed. While until the 1960s, knowledge flowed from military to civic research, this trend has since reversed. In general, some emerging dual-use technologies like UAVs, AI or surveillance tools are increasingly accessible for nonstate actors all over the globe, scattered and influenced by multiple disciplines. Due to the increasing complexity of this issue, "classic" strategies such as export control are no longer sufficient. Furthermore, researchers face a dual-use dilemma, as data disclosure is more frequently requested, despite the high risk of potential misuse.

Generally, it seems that education on dual-use is scarce and that it is difficult to formulate responsibilities since even policymakers lack insight into all the details. Some studies highlight that existing initiatives, such as dual-use guidelines for EU funding, constitute an initial step to control certain research, but still leave many questions and problems unresolved [49]. Since to date, no unified dual-use guidelines exist, legal proposals can merely be followed and a significant amount of ownership is required [33]. In life sciences and bio security, where dual-use issues are an important factor, (risk) education is considered an essential component when responding to existing challenges [50].

Since our study deals with AVs and dual-use, we briefly introduce related work in this field. As already mentioned, ASs combine different knowledge of heterogeneous systems, as they are a mixture of various technologies (e.g., AI, mechatronics), different sector fields (e.g., aviation and automotive), and can therefore be identified as potential dual-use items [45]. Pitas [51] stated that "drones and AVs are multipurpose ASs with civilian, police and military applications, thus their prototype design include components that may be built for dual use purposes." Given the large number of different application areas and involved actors in AS, the consideration of ethical issues proves challenging [24], [52], [53]. Despite a long history of dual-use technologies [14], not much research has been conducted on dual-use aspects of AVs—either in science or industry. The research available mainly focuses on logistical aspects of military operations and potential roles for ASs when integrated into the forces [54]. A case study from the U.S. [55] shows that most ethical debates focus on situation awareness and decision making for autonomous driving during difficult traffic situations (trolley problem). Besides safety issues, questions regarding cybersecurity [56] and social dilemma, e.g., conflicts between collective and personal interests, are debated. Martinho *et al*. [55] identified and ranked 21 topics based on their assessment of ethical issues relating to autonomous driving. Dual-use and military were ranked 16th, following amongst others, safety, cybersecurity, public awareness, and privacy. Most narratives discussed concerning AVs are "pragmatic and oriented toward technical solutions" [55, pp. 6

and 7]. According to Pitas [51], numerous technical measures exist that can be considered during development to minimize potential risks. Similar to other dual-use items, no consistent legislation seems to exist addressing measures to prevent improper use of AS.

Considering the RQ related to dual-use awareness, we briefly introduce the concept of awareness. Generally speaking, there is no universally valid definition of awareness due to its diverse application in numerous fields [57]. Especially, in psychology and philosophy, research on awareness and awareness raising is conducted. Analyzing awareness from a cognitive psychological perspective, it may be understood as a state of processing internal and external environmental influences [58]. According to Velmans [57, p. 3], "a person, or other entity, is conscious if they experiencing something." Once experiences have been accumulated, they are memorized as information and may be used in specific situations to guide actions [57].

## IV. Methodology

In the following section, we will elaborate on the case selection, the process of data collection, and their analysis.

### A. Case Selection

As we mentioned above, there is only very limited research on dual-use in relation to autonomous driving. In our specific case, we focus on Germany—a country which currently possesses over 50% of the world's patents for autonomous driving [59] and which is one of the top three producing countries for passenger cars [60]. In May 2021, the German Federal Council (*Bundesrat*) adopted an act on autonomous driving, enabling regular service of AVs on German roads by 2022. This act represents a milestone for the country, as it will be the first country in the world to allow level 4 autonomous motor vehicles to operate on short distances in numerous deployment scenarios. In order to quickly achieve this aim, the German government plans to promote R&D, evolving Germany into a pioneer in matters of autonomous driving. The overall aim is to create a more "diverse, safe, environmentally friendly, and user-oriented" mobility and to develop rules that are practicable for multiple countries [32].

### B. Data Collection

Overall, the research subject requires an empirical qualitative research design, since qualitative expert interviews offer the possibility to get deeper insights into the interviewees' working processes. Instead of statistical representativeness, the qualitative research design relies on the findings of significant correlations derived from a small number of cases and, therefore, permits a clearer description of the experts' lived experiences (Bogner *et al.* 2009). Thanks to several expert interviews ($N = 25$, see the Appendix, Table I; $x_{\max} = 72$ Min., $x_{\min} = 23$ Min, $\bar{X} = 42$ Min) with mostly German developers and scientists ($n = 24$) in the field of autonomous driving, the existing precarious data situation on the topic can be partly filled with practice-oriented information from Germany. Given the fact that we collect personal data, we followed guidelines set by the university's internal ethics committee and assured that the transmitted data was pseudonymized and stored securely.

We identified the interview partners through personal contacts, recommendations (snowball sampling) [61], as well as through in-depth Internet research (e.g., companies, recent studies, and media coverage). Eligible participants were selected based on either their expertise related to our RQ or their involvement in science and industry, covering a wide range of possible individuals involved in the field of autonomous driving [62]. As Appendix Table I illustrates, the interviewees work in very different areas and leadership positions. A technical background is not a defining requirement for somebody to be referred to as an expert, rather dealing with, for example, ethical, administrative, and interdisciplinary topics related to autonomous driving, were identified as suitable prerequisites for our survey. A request containing a research description was sent via e-mail in most cases. Of those solicited ($N = 72$), relatively few agreed to be interviewed ($n = 25$), while a large number either did not respond to our request or declined to participate. The interviews were conducted via the data-secure and General Data Protection Regulation (GDPR) compliant communication software Jitsi Meet.

According to the theoretical sampling, it was important to reach a broad range of people with expertise on the analyzed phenomenon (predefined criteria) without having to determine a concrete sample size in advance. The sampling was appropriate when we had enough information in order to understand the phenomenon to be studied (data saturation) [61]. For the interviewers, it remains difficult to assess whether respondents only disclose information that correspond to their work position or, if they answered freely without any restrictions and concerns, even though all interviews were pseudonymized. Prior to the interviews, all respondents signed a consent form.

Once we identified the interviewees, a semistructured questionnaire was developed on the basis of existing theoretical approaches [63] in the area of autonomous driving and dual-use and aspects we were particularly interested in concerning our RQ. The guideline was divided into four thematic issues (subject-specific background, technology complex "autonomous driving," general awareness of dual-use issues, and dual-use challenges regarding autonomous driving), containing 20 open questions (see the Appendix, Table II). Since we derived and defined the questions ourselves, a personal bias cannot be entirely avoided. We tried to incorporate our own positioning as little as possible in order to minimize normative believes which we certainly hold as peace and conflict researchers. The semistructured questionnaire was cross-read by two additional researchers in order to reduce a potential own bias and to provide multiperspectivity.

At the time of the interviews, 24 of the respondents lived in Germany and one person in the United States of America. Out of the 24 people living in Germany, one respondent emphasized that they were not born in Germany but had lived in the country for several years. The remaining participants reported being born and socialized in Germany. Most of the interviewees hold an engineering degree either in their bachelor's or

master's, including mechanical ($n = 6$) or electrical engineering ($n = 4$) or in computer science ($n = 5$), with 13 having a doctoral degree. At the time of the survey, the respondents were engaged in 14 different working areas, ranging from AI to environmental perception to the cloud architecture or ethics. Regarding the interview partners, it is relevant to highlight that we only interviewed two women, as we could hardly find women working in the subject area. From the beginning, we paid particular attention on finding female interview partners, although this proved to be difficult. The snowball process also failed to help us identify additional female interviewees, implying that the interviewees themselves experienced difficulty in naming female colleagues in the field. Having explicitly contacted various institutions working in this field and searched the Internet for women in practice and research, we contacted four with no response. As a result, a clear gender imbalance in the distribution can be observed. Besides the difficulty in finding sufficiently representative interviewees and the limitations posed by recruitment, Section VI-B outlines other challenges.

### C. Data Analysis

After the interviews were conducted, they were transcribed and manually coded by two authors. Concerning the interdisciplinarity of the authors, we hold the interdisciplinary approach of consensus coding [64] convenient for working with data at the intersection of natural sciences and ethical issues. Due to our operationalization, i.e., the creation of category systems, forms an important part of the methodological procedure, we consider the qualitative content analysis by Mayring [65] as the adequate tool of analysis for our survey. We developed the coding abductively, relying on the existing literature in the field and information derived from the collected empiric data. Important findings regarding our RQ were clustered in over-, main-, and subcategories (see the Appendix, Table III), providing a clear overview of the various subtopics. The categories and codes were defined by the authors and briefly explained in a jointly developed codebook. The two runs of consensus coding revealed a total of 1971 codes. To obtain a simplified representation of the category systems and the codes, the software program MAXQDA (Analytics Pro 2020) was used. In general, during both data collection and analysis, we tried to reflect on own limitations and not to include personal normative perceptions.

The richness of the coding scheme indicates that a large number of valuable insights were drawn from the interviews. In light of the limited space of this article, it is not possible to discuss all of the results here. While this article focuses on dual-use awareness and possible measures in case of dual-use, a separate article will address identified potential dual-use technologies in the field of autonomous driving and how civilian R&D on autonomous driving in Germany may be transferred to the military sphere.

## V. Findings

In the following, different perspectives of German experts working in the field of autonomous driving on personal and general dual-use awareness in the development of AVs are presented (RQ1). Furthermore, we analyze whether, and if so, which measures exist to date in Germany that assess possible dual-use issues in the field of autonomous driving (RQ2).

### A. Dual-Use Awareness in the Context of Autonomous Driving

*General Dual-Use Awareness:* During the interviews, we raised the hypothesis that civilian technology can be used for military purposes. On this basis, we explicitly asked, if their personal research can be (mis)used for other purposes, e.g., the military, and how this plays a role in their daily work. When we posed the question relating to the dual-use potential in one's own work environment, one interviewee inquired what exactly we understood by dual-use (I20: 103).[1] Almost all interviewees had heard of the term before, but not all knew which aspects were included in it. It was pointed out that it is difficult to assess what can be considered as dual-use, as nearly everything can possibly be misused (I13: 65). Another question raised regarding dual-use was whether it is inherently bad (I22: 72).

Fifteen of the interviewees stated that they had already thought about dual-use in general. Nevertheless, it was mentioned that overall, the topic is discussed very little in their immediate vicinity (I11: 40) and that few people seem to be sensitized with the issue (I11: 71). One possible reason why dual-use with respect to the transfer to military does not seem to be discussed much in Germany nowadays, e.g., in comparison to the United States, is that only few Germans are directly connected to the military. In the United States, many people work for the military and it appears to be more accepted by society than in Germany (I14: 68). Even though only two of the respondents explicitly mentioned that they had served in the German army for one year, it is very likely that more of the respondents had served in the military, as completing either civilian or military service was mandatory in Germany until 2011 (Jones 2010). Out of the 15 who reported being aware of dual-use issues, seven stated that they had given little to no consideration to it in their personal field of work (I12: 66), as they did not see a direct link to the military or proliferation risks for harmful or unethical use (I22: 74): "I have already thought about dual-use, but not related to my own work. Of course, about the whole topic and the automation in the military field. I wouldn't say I've meditated or philosophized about it for a long time" (I18: 69). In response to the question of potential transferability between the civilian and military sector, various areas such as software (I9: 39), radar technology (I5: 35), image processing (I10: 46), infrared cameras (I4: 36), localization algorithm (I13: 59), AI, and face recognition (I3: 42) were mentioned. The concrete identification of components illustrates that many interview partners, when questioned, were able to identify where a transferability between the two sectors may occur.

While most of the respondents expressed a critical view of possible cooperation between the military and civil research,

[1]The abbreviation "*I*" stands for interviewee and the respective number indicates the paragraph of the respective transcript.

one person seemed positively disposed toward cooperation: "We are very happy that we can also use things militarily" (I9: 37). Regarding military cooperation, most interviewees emphasized that it strongly depends on the area of application—whether for offensive or defensive applications (I9: 39) or for (transport) logistics in the military itself (I24: 92). I22 (72) alluded that they were very glad not having to deal with dual-use issues often and not being authorized to make decisions about possible cooperation, because they were not comfortable deciding in such difficult cases. They reported being glad about other people currently being in charge of the decisions. This statement demonstrates the tendency in complex and difficult situations to abandon decision-making processes without further in-depth consideration.

Regarding possible misuse, 11 interview partners stated that they consider the autonomous car itself as a potential weapon. It could deliberately run over people (I8: 54) or carry dangerous (chemical) cargo (I20: 127). This illustrates the dual-use potential of AVs as a transport or carrier system for other weapons. Since we mainly conducted interviews with technicians, we could not clearly ascertain whether there is a difference in awareness between technical and social science backgrounds.

*Dual-Use Awareness in Own Work Environment:* Interviewee 6 (35) underlined that the technologies they were working on would be addressed by other researchers, if they themselves failed. They did not see any problem in their own research: "There is nothing, i.e., no technology, that would not come to light and could not be used for armament, if I refrained doing it." The question of whether something comes to light or not also plays a role in the opensource debate. Two-thirds of the respondents reported that they frequently use opensource databases, i.e., in route planning and mapping (I19: 50), as they saw great potential in a shared open community (I13:51). However, it is less pushed than pulled. Among other things, one reason is that secret and company-internal information are not allowed to be disclosed (I20: 99). One interviewee pointed out that pushing is not allowed due to a potential dual-use risk (I9: 33).

Others seemed very aware of the possibility of dual-use in their own field of work. "I'm aware that of course everything we do in computer science always has dual-use aspects. You only have to look at all the scientific work in the field of image processing and who financed it" (I10: 47). It was exemplarily stated that symposiums, e.g., about radar, were financed by German defense companies. People from the automotive industry were also invited (I5: 35). Ten people were aware that their research could be, and was already being, transferred to the military at least to some extent: "I'm pretty sure that almost everything we do, can be utilized. We design environment perception algorithms that can be used in many ways. They can not only be applied in vehicles, but also for many other purposes, no matter whether it is person classification or tracking over time" (I14: 55). Technologies for road vehicles can be quickly refined for off-road vehicles and would therefore likewise serve well for military operations (I6: 39). Interviewee 17 (50) emphasized that "the overall field of autonomous driving is of course something that is of great importance in the military sector." In addition, it was stated that the origins of automated driving clearly go back to military activities (I7: 49). In response to the question of how autonomous driving and the military are related, the DARPA Urban Challenge was often mentioned ($n = 10$). This illustrates again how closely autonomous driving and the military are linked (I19: 66).

When asked how they would act in the case of potential dual-use risk in their own work environment, numerous options for action were named. Some stressed the need to distinguish how it is used militarily, as not everything in the military is deemed bad and potentially dangerous (I21: 95). The reactions varied between informing colleagues and people about dual-use risk (I12: 68), publishing about it (I20: 109), contacting supervisors (I25: 63), and possibly rejecting projects in which the topic is dealt with (I21: 94). Another interviewee indicated that they would proceed with the project despite a possible risk, especially if it was publicly funded and, thus, legal and ethical assistance would be provided (I23: 75).

Another interesting aspect to note is that some respondents seemed to feel constrained in their own work by the constant need to take dual-use aspects into account. It seems a greater effort to consider certain aspects, to follow rules and to coordinate with more people (I11: 71). Particularly, in the academic sphere, strict rules and restrictions by the university can contradict academic freedom (I10: 52). One interviewee underlined that although they personally reject the development of armament, they disagree that a university commission should be in charge of deciding whether research on military equipment should be allowed or not, as it is not per se illegal (I6: 37). However, some of the interviewees who work in the university sector underlined that most universities are principally against collaborating with the military (I20: 101). Exceptions include the *Bundeswehr* universities, which are closely linked to the military (I9: 39). According to interviewee 9 (43), research on autonomous weapon systems was already being discussed in selected universities in order to react in a possible urgent situation, to assist the Federal Foreign Office and to work in the field of dual-use prevention. It seems ubiquitous, that "there are fantastic opportunities at universities and institutions that get funding from the military. As a researcher and as a career person, you need to make that decision" (I8: 43).

*Complexity and Diversity of Involved Areas:* A highly important aspect that was often mentioned by the interviewees is that for many, the transfer of their own research to the military seemed very abstract and remote (I17: 46). One explanation is the small-scale nature of tasks and research in a complex system related to autonomous driving (I19: 14): "At the end, you are only a very small part of the big picture" (I25: 27). Due to the enormous number of involved disciplines, it seems partly elusive for some developers and researchers to imagine potential consequences of their own development and how parts are being used (I25: 53). In the following figure (see Fig. 1), we illustrate mentioned components within the field of autonomous driving to underpin the diversity of fields.

As Fig. 1 illustrates, numerous areas are involved in the development of AVs. On the one hand, rather technical parts

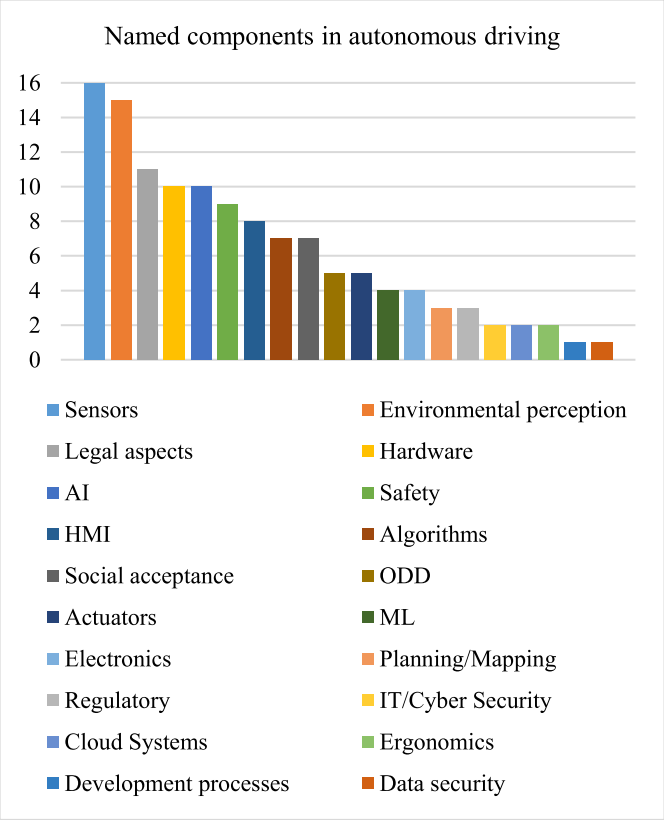


Fig. 1. Visual representation of named components in the field of autonomous driving. *x*-axis: Named components in autonomous driving; *y*-axis: Frequency of occurrence of named components in the field of autonomous driving. Abbreviations: HMI: Human Machine Interaction; ODD: Operational design domain; and ML: Machine learning. Source: Own research.

which are important for the vehicle itself, on the other hand administrative, legal, and ethical aspects necessary for the implementation. It seems difficult to fully understand the complexity due to the high number of different components—especially, if they deviate from one's own expertise.

### *B. Guidelines and Discussions in Order to Establish Dual-Use Awareness*

To investigate whether measures contribute to awareness of dual-use challenges, we asked if any and which measures or ethics councils exist and whether they potentially have an impact on own dual-use awareness (RQ2).

*Measures Relating to Dual-Use Issues:* Certainly, many employees, especially scientific researchers, need to submit project applications in order to receive financial funding. Interviewee 11 (44) stated that they had never encountered a section in a project application form indicating that a potential dual-use risk might exist in relation to the proposed research. This implies that it is rather rare that demands from funding ministries or institutions exist to explicitly reflect on potential dual-use risk in the development of parts for AVs. It seems more often the case that solely internal regulations of the company or university should be fulfilled. Those are often related to the existing laws, standards, and regulations (I18: 88). The German Federal Ministry of Transport, for example, founded its own ethics committee regarding autonomous driving. It debates ethical issues and formulates guidelines in this sector (I23: 7). If and to what extend dual-use risks are being debated in the committee, was unknown to anyone. According to the majority of respondents, the committee will only permit AVs in daily life, once their driving behavior is safer than that of humans (I11: 74). This point was critically questioned by some due to insufficient verifiability (I11: 34).

Regarding compliance, slightly more than half of the interviewees ($n = 14$) stated that they have internal compliance guidelines. Compliance might include staff training (I25: 23), external consultancy (I24: 59), and the possibility of addressing contact persons (I16: 57). Conversely, ten respondents either reported not knowing whether their own employer had introduced compliance policies ($n = 9$) or not having any ($n = 1$). Interviewee 17 (48) insisted that the process of introducing compliance policies was in progress at the time of the interview. This reveals that almost half of the employees seem to be unaware of the existing compliance guidelines and that considerable potential for improvement exists.

*Exchange About Possible Dual-Use Risks:* Solely, two people emphasized that within their team a strong and valuable debate culture about potentially critical topics such as dual-use exists (I24: 59, I16: 57). Only a few more ($n = 7$) exchanged information on dual-use with their colleagues. The intensity varies greatly from once a year (I6: 33) to regularly (I18: 77). Others noted that no conversations about possible dual-use potential had taken place: "Whether there are talks about dual-use... rather not. I don't think that's an issue for us" (I1: 43). Since the exchange between colleagues seems very low overall, we could not find clear evidence of whether discussions about dual-use would be considered as helpful and stimulate critical reflection.

Interviewee 23 (7), working on ethical issues, reported about their interdisciplinary workshops to raise awareness on various topics in the field of autonomous driving. Interdisciplinarity in general appears to be important for many but has still not been implemented in many projects and teams. The field seems to be dominated by (mostly male) engineers (I22: 38, 92). However, exchange, also with project partners, is considered essential to complement individual work steps and developments (I1: 25).

In summary, the existence of guidelines does not seem to have an impact on the awareness of the interviewees. This may be due to the fact that they seem little addressed and discussed at work, despite implementation. It rather seems to be a personal attitude to critically scrutinize developments on dual-use potential and less related to institutional requirements.

## VI. Discussion

Focusing on the relation between dual-use and autonomous driving, we were first interested if dual-use awareness exists amongst individuals involved in the field of autonomous driving (RQ1). Second, we were keen to investigate whether measures exist, addressing dual-use questions regarding autonomous driving (RQ2). In this section, key findings are summarized and implications identified. Furthermore, some limitations are outlined.

### A. Dual-Use Awareness: Expandable Area

Focusing on dual-use awareness in the development process of AVs, we were originally interested in whether German researchers and developers in this field are aware of dual-use potential in their own field of work and, therefore, the impact of their technologies to society. We were astonished that more than half of the interviewees indicated that they were aware of the existence of dual-use issues, although the research on dual-use regarding autonomous driving is hardly existent [55]. Mentioned areas were, for example, AI, radar, image processing, and infrared cameras. Despite the knowledge, respondents did not appear to apply this awareness to their own work. One of the main reasons is that the transfer to the military seems to be quite abstract for some, making it difficult to envision a connection between the company's own research and the use of malicious systems by military actors [25]. In general, it shall be noted again that in contrast to some other countries, such as the U.S., few Germans are directly associated with the military. Given the low level of direct linkage and a number of restrictions (e.g., affecting the cooperation between military and research institutions), it seems difficult to imagine potential transfers between the two sectors. As the cooperation between the military and the civic sector seem to vary greatly among countries, it seems important to conduct country-specific analyses and to make context-specific presumptions. As the cooperation between the military and the civic sector seem to vary greatly among countries, it seems important to conduct country-specific analyses and to make context-specific presumptions.

Principally, the studies revealed that dual-use and potential transfer from civilian development to military use is a little-discussed topic among colleagues. Concluding, it seems essential to place one's own small-scale R&D within the overarching topic. It is crucial that employers and research institutions identify interrelationships and provide discussion platforms and information in order to be able to identify potential risks. Thus, both employers and employees can take responsibility [33].

It is evident that many different disciplines are integrated in the field of autonomous driving [18]. As mainly technical professions dominate the work field [66], we could not determine whether, for example, people with a social science background might have different perceptions about dual-use. Overall, we observed that working practices are not yet organized in an interdisciplinary manner. It is important to take an interdisciplinary view on certain developments, since each discipline approaches existing challenges differently. So far, there seems to be no common understanding of interdisciplinarity within the different disciplines regarding the topic, which should be addressed.

Second, we posed the question (RQ2) if measures, policy papers or guidelines exist that address dual-use issues in the context of autonomous driving (see Section V-B). We found out that there are hardly any corporate guidelines and corporate policy papers available to employees in autonomous driving development. Furthermore, it became clear that official documents on autonomous driving seem to be barely known and that the majority does not address dual-use or other ethical questions beside (road) safety issues [55]. We therefore consider it an important step to introduce such discussion papers in wide parts [33] and propose to revise existing documents such as those of the German Federal Ministry for Digital and Transport in an interdisciplinary set up team. Generally, ethical considerations shall be broadened as well as technology assessment incorporated. New documents may also be implemented that shed more light on dual-use, risk education, a culture of shared responsibility [50], and address possible needs of people involved in the field of autonomous driving. Regular meetings and seminars with actors from practice and academia could be additionally helpful. Equally, they may serve as a platform to reflect on different terminologies as dual-use is understood differently across different disciplines. It should be openly and comprehensibly communicated who determines at which point research is considered critical. This could potentially minimize confusion and frustration among people involved. A jointly created questionnaire, containing dual-use aspects, might help to question personal development.

### B. Limitations

Certainly, qualitative studies pose some challenges—for example, being limited to a specific case or country. In our case, it is the sheer focus on German experts in the field of autonomous driving. Prospectively, it would be interesting to study more countries advanced in the development of AVs to analyze commonalities and differences. To be able to provide informative statements, the responses of the interviewees have been quantified. Beginning with the selection of interview partners, it cannot always be ensured that all relevant persons who might have provided new information were interviewed. Nonetheless, an excerpt of reality in a nonrepresentative manner is offered. We are aware that expertise is a debatable term and that people in high positions do not always have more expertise than other people in lower positions. With fewer women employed in the field of autonomous driving overall, we found less potential female interviewees. The same applies to nontechnical professions. Further studies may complement our sample including more women and employees from the nontechnical field. This might be possible through a differing focus, e.g., on other disciplines in the field. Moreover, the question remains whether women are employed in lower positions and are thus less visible. In general, within our study, we cannot provide a scientifically well-founded statement on whether attributes, such as gender, cultural background, and seniority have an influence on the perception of dual-use. Broader studies may close this existing research gap in the future.

In order to verify the interviewee's statements and to examine whether the same narratives about ethics and dual-use awareness exist in reports, business and technical reports should be analyzed, keeping in mind that they are difficult to access. Overall, the topic is quite controversial, why it is important to critically questions one's own role as a researcher. Especially, when dealing with sensitive topics it can happen that own viewpoints, e.g., by selecting certain questions, come into play. We are aware that certain normative beliefs cannot be fully erased and that we may perceive certain issues more critically than others given our academic background as

TABLE I
LIST OF INTERVIEW PARTNERS. SOURCE: OWN RESEARCH

| No. | Position | Organization | Subject area | Degree |
|---|---|---|---|---|
| #1 | Lead Autonomous Driving Projects | Start-up | Public transport | Master[2] |
| #2 | Senior Software Developer | Tier 1[3] | Camera technologies | PhD |
| #3 | Research associate | Technical University | Localization | Master |
| #4 | Senior group manager | Non-university research institution | Infrastructure and embedded systems | Diploma |
| #5 | Research associate | Technical University | Simulation, environmental perception | Master |
| #6 | Professor | Technical University | Sensor development | PhD |
| #7 | Senior developer | OEM | Automated Meta Driving | Master |
| #8 | CEO/Founder | Start-up | AI | PhD |
| #9 | Professor | Research institution | Human System Integration | PhD |
| #10 | Professor | Technical University | Computer Science | PhD |
| #11 | Team leader | Technical University | Cloud-architecture | Master |
| #12 | Senior Developer | OEM | Functional safety | PhD |
| #13 | Head of Department | Technical University | Safeguarding | Master |
| #14 | Senior Developer | Start-up | Safety | PhD |
| #15 | Professor/Head of Department | Non-university research institution | Driver assistance systems | PhD |
| #16 | Team leader | Tier 1 | Functional system development | Diploma |
| #17 | Professor | Technical University | HMI | PhD |
| #18 | Team leader | Tier 1 | Movement planning | Master |
| #19 | Team Leader | Start-up | Public transport | Bachelor |
| #20 | Employee | Technical University | Vehicle communication | Master |
| #21 | Employee | Tier 1 | Safety | PhD |
| #22 | Independent Scientist | University | AI | PhD |
| #23 | Research associate | University | Research ethics | PhD |
| #24 | Senior Manager | IT/Critical Infrastructure | Critical infrastructure | Master |
| #25 | Senior Manager | Tier 1 | HMI | PhD |

TABLE II
SEMISTRUCTURED QUESTIONNAIRE. SOURCE: OWN RESEARCH

| | |
|---|---|
| 1. Professional background | 1) Please introduce yourself and briefly explain your professional activities.<br>2) What training did you undergo?<br>3) What fascinates you about the topic "autonomous driving"?<br>4) How regularly do you exchange information with other departments/research institutes that also work or research in the field of "autonomous driving"? |
| 2. Location in the autonomous driving technology complex | 5) If you think of the overall systemic development in the area of "autonomous driving": Which components or fields of research do you think there are?<br>6) Where would you locate yourself individually in the topic "autonomous driving"?<br>7) Does this location correspond to your current professional position?<br>8) How important is the interdisciplinary exchange on the topic of "autonomous driving" between the different departments/research disciplines?<br>9) How mature do you consider the technology to be with regard to autonomous driving? When do you consider a widespread application in terms of series production to be realistic?<br>10) When you think of all the technology needed to develop L5 vehicles: Which area of technology do you see as crucial for realization? |
| 3. General awareness of dual-use issues | 11) There is currently little public discussion about dual-use challenges. How do you see the situation? Why is there little discussion about it?<br>12) Does the Open Source idea or practice play a role in your professional life?<br>13) Civilian technology can always be used militarily. Does this idea play a role in your daily work? If so: How does this consideration influence you in your daily work?<br>14) How would you act if you were aware of a concrete dual-use risk in your work area?<br>15) Has your employer implemented processes such as compliance guidelines or a hardship committee for potentially abusive technologies or similar? Are there discussions between colleagues on these topics? |
| 4. Dual-Use problems in the field of autonomous driving | 16) Do you believe that the technology area you are working on could potentially be used in military applications? If so, which technology areas do you mean specifically? If no: What are the reasons you assume that this is not the case?<br>17) If you are thinking of the overall system "autonomous vehicle": Where do you see the highest potential for misuse (e.g. AI applications, sensor packages, etc.) |
| | 18) Which technology areas of autonomous driving are in your opinion best transferable to the military?<br>19) How fast in terms of years would it take in your opinion to adapt the technology of autonomous driving as a whole to military needs? |
| 5. Open questions | 20) After we have gone through the list of questions: Are there any open points or important aspects on your side that have not been addressed? |

technical peace and conflict researchers. Therefore, it is necessary to consider that social reality is always a subject result of interpretative and interactive processes [67]. For a critical and transparent reflection of the study design and the relationship between scientist, subjectivity, and the interview partners, a detailed documentation of the methodological approach has been made.

## VII. CONCLUSION

We believe that dual-use should be more often considered in technical disciplines, such as computer science, because it does not seem to be something that the majority of people are concerned with—especially, in their own field of work—as the respondents indicated. This is partly due to the

TABLE III
CODING SCHEME. SOURCE: OWN RESEARCH

| Level 1 (super-categories) | Level 2 (main-categories) | Level 3 (sub-categories) |
|---|---|---|
| Personal information/ background | Anonymity | Asked again about anonymity |
| | Gender bias | |
| | Highest degree (education) | Professor, PhD, Master/diploma, Bachelor |
| | Education | Mathematics, industrial engineer, physics, electronics, social science, mechanical engineering, computer science, automotive engineering |
| | Education/ specialization | ADAS, HCI, Autonomous driving, AI |
| | Employment relationship | Research group leader, research assistant, (Junior)Professor, private sector (Tier 1, OEM, subject matter expert, project leader, senior manager) |
| | Career | Industry and academia, private sector/industry only, academic, private sector to academia, academia to private sector |
| | Outlook/ open aspects | |
| | Use of open source | Not allowed to push, important, not (really) relevant, push and pull, pull but not (yet) push |
| | Own localization in (research) field | HMI, ethical/social questions, navigation, system engineering, computer science, functional security, development processes, perception |
| | Current profession corresponds to own localization | Yes, no, not relevant, volunteering |
| | (Personal) challenges | Communication, standardization, problem definition, technical development, ethical/legal questions, different traffic domains, cyber security, pure assumptions, interdisciplinary exchange, testing/safety, high costs, social acceptance, tension concerning academic freedom |
| | Frequency of exchange between departments | Not at all, little, frequently/at least 1x month, at least 1x week, daily, a lot |
| | Current projects | With industry and universities, with industry partners only, with other universities |
| Dual-use | Own limitations regarding dual-use topic | |
| | Exchange about dual-use topics | With colleagues, not with colleagues, difficult, interdisciplinary, mainly with technological chairs, mainly in own company, with other institutions, important, necessary to unite knowledge |
| | Potential of abuse/misuse | Surveillance, not intended way of operation, data security, cyber war/cyber security, hacking, AI, Algorithms, environment perception, misuse of the vehicle itself |
| | Link to military | |
| | General dual-use awareness | Not important, aware but seems to be limiting for own research, no information from firm/institution, few people have it, conscious but does not seem to be important, low consciousness, conscious |
| | Dual-use awareness in daily life | Plays a role, no/little influence, hardly, discussion among colleagues |
| | Thinking that own research can be used for military | Civilian technologies come from military, not part in the project proposal, only on a personal level, not important/has not thought about it, no/not aware, yes/aware |
| | Guidelines | Ethic commission |
| | Compliance guidelines | Contact points, exist, in process, not known, do not exist |
| | Reaction if dual-use risk would exist | Encourage discussion, depending on development/topic, address topic/issue to supervisor/contact person, contact point not known, not accept project/do not work in this project, not yet thought about it |
| Autonomous driving | Questioning term of autonomous driving | |
| | Personal fascination | Improving safety, interdisciplinary exchange, ethical questions, technology of the future, unexplored area, gain in comfort, new possibilities, programming, having more leisure time, possibilities of influence, improving situation for disadvantaged/disabled people, technical challenge |
| | Scope of duties | Ethics, HMI, automated driving, OEM, AI, NATO, ergonomics, IT security, process integration, consulting, functional security, cloud architecture, connected driving |
| | Components of research field | Material science, business model, infrastructure/urban planning, simulation, social science, computer science, engineering, data fusion, object-identification, localization, mapping, ethical/legal questions, machine-learning, algorithms, regulatory, electronics, safety, IT security, development processes, ODD, data security, cyber security, social acceptance, cloud systems, actuators, hardware, GPS, environmental perception, sensors (ultrasonic, LiDAR, radar, camera), software architecture, safeguarding, HMI, ergonomics, AI |
| | Autonomous System Development as Hard-/ Software problem | Still separated fields, shift from hard-to software, cannot be separated, only software |
| | Most important areas regarding L5 | Safety/simulation, communication, HMI, Planning, legal questions, Algorithms, Sensors, System of System, Interpretation, environmental perception, software, hardware |
| | Decisive technology areas for L5 | Efficient computing power, simulation, data science, microelectronics, localization/navigation, infrastructure, Algorithms, cyber security, social acceptance, ethical issues, perception/sensors, LiDAR, AI |
| | Coverage L4/L5 | Never/not in own lifetime, 10-20 years, unrealistic in short time, in many decades, 5-10 years, <5 years, depending |

*(Continued)*

small-scale nature of research and the lack of embedding it in the overall research field. Overall, hardly any of the interview partners directly cooperates with the military and a skeptical attitude toward military applications exists. It seems difficult for most interviewees to assess what the military is currently investigating in terms of autonomous driving and how far they have progressed, since little is made public. Furthermore,

TABLE III
*(Continued.)* CODING SCHEME. SOURCE: OWN RESEARCH

| | | |
|---|---|---|
| | | on intended use/context, difficult to answer |
| Dual-use in the context of autonomous driving | Transfer of knowledge from autonomous driving to military affairs | Control engineering, Data fusion/data strategies, situational awareness/decision-making, object recognition/identification, localization, Algorithms, AI, actuators, sensors (camera/Laser/LiDAR/Radar) humanitarian aspects, environmental perception, transfer within years, possible in the future, easily possible, already taking place, military sector better positioned/faster, difficult/abstract |

we discovered that interviewees are not familiar with documents reflecting on dual-use. Generally, few documents seem to exist in Germany to date that familiarize employees in the field of autonomous driving with possible dual-use issues. Even though the study could not identify an explicit connection between documents that critically examine dual-use and dual-use awareness among individuals, we see great potential in (risk) education and creating policies. Not only the individual should be held responsible for reflecting on dual-use but we also see responsibility at a higher level—with institutions and employers.

Our work aims to initiate further discussion on dual-use. In the long term, we hope that guidelines will be formulated that will potentially raise awareness on dual-use in the context of autonomous driving in the future. This is important in order to control possible transfer of civilian research into the military sphere and to create an overall picture. In a follow-up article, we aim to discuss which technical developments should be particularly monitored and where the interviewees see a high risk of misuse.

## APPENDIX

See Tables I–III.

## ACKNOWLEDGMENT

The authors would like to specially thank Maaike Verbruggen and Thea Riebe for their helpful comments.

## REFERENCES

[1] P. D. Scharre, *Army of None: Autonomous Weapons and the Future of War*. New York, NY, USA: W.W. Norton Company, 2018.
[2] O. Hudyma, "Unmanned aircraft as a source of information for providing the state defense management system in crisis situations," *Spec. Multidiscipl. Sci. Res.*, vol. 6, pp. 132–135, Dec. 2020.
[3] R. Iliev and A. Genchev, "Possibilities for using unmanned aerial vehicles to obtain sensory information for environmental analysis," *Inf. Security Int. J.*, vol. 46, no. 2, pp. 127–140, 2020.
[4] T. Gillespie and S. Hailes, "Assignment of legal responsibilities for decisions by autonomous cars using system architectures," *IEEE Trans. Technol. Soc.*, vol. 1, no. 3, pp. 148–160, Sep. 2020.
[5] D. Bissell, T. Birtchnell, A. Elliott, and E. L. Hsu, "Autonomous automobilities: The social impacts of driverless vehicles," *Current Sociol.*, vol. 68, no. 1, pp. 116–134, 2020.
[6] R. M. Gandia *et al.*, "Autonomous vehicles: Scientometric and bibliometric review," *Transp. Rev.*, vol. 39, no. 1, pp. 9–28, 2019.
[7] M. Kyriakidis *et al.*, "A human factors perspective on automated driving," *Theor. Issues Ergon. Sci.*, vol. 20, no. 3, pp. 223–249, 2019.
[8] P. Mallozzi, P. Pelliccione, A. Knauss, C. Berger, and N. Mohammadiha, "Autonomous vehicles: State of the art, future trends, and challenges," in *Automotive Systems and Software Engineering*, Y. Dajsuren and M. van den Brand, Eds. Cham, Switzerland: Springer, 2019, pp. 347–367.
[9] F.-X. Meunier, "Construction of an operational concept of technological military/civilian duality," *J. Innov. Econ.*, vol. 29, no. 1, pp. 159–182, 2019.
[10] Q. Zeng, B. Jiang, and Q. Duan, "Integrated evaluation of hardware and software interfaces for automotive human-machine interaction," *IET Cyber-Phys. Syst. Theory Appl.*, vol. 4, no. 3, pp. 214–220, 2019.
[11] M. Verbruggen, "The role of civilian innovation in the development of lethal autonomous weapon systems," *Global Policy*, vol. 10, no. 3, pp. 338–342, 2019.
[12] M. Martínez-Díaz, F. Soriguera, and I. Pérez, "Autonomous driving: A bird's eye view," *IET Intell. Transp. Syst.*, vol. 13, no. 4, pp. 563–579, 2019.
[13] J. Altmann, U. Bernhardt, K. Nixdorff, I. Ruhmann, and D. Wöhrle, *Naturwissenschaft—Rüstung—Frieden: Basiswissen für die Friedensforschung*, 2nd ed. Wiesbaden, Germany: Springer, 2017.
[14] J. Forge, "A note on the definition of 'dual use,"' *Sci. Eng. Ethics*, vol. 16, no. 1, pp. 111–118, 2010.
[15] P. Maxwell and M. Nowatkowski, "The unforeseen in unmanned vehicles," in *Proc. Int. Symp. Technol. Soc.*, 2019, pp. 60–65.
[16] A. Kott and E. Stump, *Intelligent Autonomous Things on the Battlefield*. Elsevier Inc., 2019.
[17] S. Schwartz and C. Reuter, "90.000 tonnen diplomatie 2.0: Die integration von unbemannten systemen in den operativen Flugzeugträgerbetrieb am Beispiel der X-47B," *Zeitschrift Außen Sicherheitspolitik*, vol. 13, no. 1, pp. 23–45, 2020.
[18] S. A. Bagloee, M. Tavana, M. Asadi, and T. Oliver, "Autonomous vehicles: Challenges, opportunities, and future implications for transportation policies," *J. Mod. Transp.*, vol. 24, no. 4, pp. 284–303, 2016.
[19] C. Charatsis, "Dual-use research and trade controls: Opportunities and controversies," *Strateg. Trade Rev.*, vol. 3, no. 4, pp. 47–68, 2017.
[20] M. Ekelhof, "Moving beyond semantics on autonomous weapons: Meaningful human control in operation," *Global Policy*, vol. 10, no. 3, pp. 343–348, 2019.
[21] H. Huelss, "Deciding on appropriate use of force: Human-machine interaction in weapons systems and emerging norms," *Global Policy*, vol. 10, no. 3, pp. 354–358, 2019.
[22] J. Morley, L. Floridi, L. Kinsey, and A. Elhalal, "From what to how: An initial review of publicly available AI ethics tools, methods and mesearch to translate principles into practices," *Sci. Eng. Ethics*, vol. 26, no. 4, pp. 2141–2168, 2020.
[23] M. Schulzke, "Drone proliferation and the challenge of regulating dual-use technologies," *Int. Stud. Rev.*, vol. 21, no. 3, pp. 497–517, 2019.
[24] A. F. Winfield, K. Michael, J. Pitt, and V. Evers, "Machine ethics: The design and governance of ethical AI and autonomous systems," *Proc. IEEE*, vol. 107, no. 3, pp. 509–517, Mar. 2019.
[25] J. B. Tucker, *Innovation, Dual Use, and Security: Managing the Risks of Emerging Biological and Chemical Technologies*. Cambridge, MA, USA: MIT Press, 2012.
[26] V. Boulanin and M. Verbruggen, *Mapping the Development of Autonomy in Weapons Systems*, Sipri, Stockholm, Sweden, 2017.
[27] T. Riebe, S. Schmid, and C. Reuter, "Measuring spillover effects from defense to civilian sectors—A quantitative approach using LinkedIn," *Defence Peace Econ.*, vol. 32, no. 7, pp. 773–785, 2020.
[28] D. Shim, "Autonomous vehicle systems in the civil sphere," in *Lethal Autonomous Weapons Systems*. Berlin, Germany: Federal Foreign Office, 2017, pp. 268–273.
[29] J. Borenstein, J. R. Herkert, and K. W. Miller, "Self-driving cars and engineering ethics: The need for a system level analysis," *Sci. Eng. Ethics*, vol. 25, no. 2, pp. 383–398, 2019.
[30] C. Luetge, "The German ethics code for automated and connected driving," *Philos. Technol.*, vol. 30, no. 4, pp. 547–558, 2017.
[31] J. Borenstein, J. R. Herkert, and K. W. Miller, "Self-driving cars: Ethical responsibilities of design engineers," *IEEE Technol. Soc. Mag.*, vol. 36, no. 2, pp. 67–75, Jun. 2017.
[32] "Germany Will Be the World Leader in Autonmous Driving." Federal Ministry of Transport and Digital Infrastructure. May 2021. [Online]. Available: https://www.bmvi.de/SharedDocs/EN/Articles/DG/act-on-autonomous-driving.html
[33] P. Kavouras and C. A. Charitidis, "Dual use in modern research," in *Handbook of Research Ethics and Scientific Integrity.*, R. Iphofen, Ed. Cham, Switzerland: Springer, 2020, pp. 181–202.
[34] C. Marris, C. Jefferson, and F. Lentzos, "Negotiating the dynamics of uncomfortable knowledge: The case of dual use and synthetic biology," *Biosocieties*, vol. 9, no. 4, pp. 393–420, 2014.
[35] S. Oltmann, "Dual use research: Investigation across multiple science disciplines," *Sci. Eng. Ethics*, vol. 21, no. 2, pp. 327–341, 2014.

[36] D. B. Resnik, "What is 'dual use' research? A response to miller and selgelid," *Sci. Eng. Ethics*, vol. 15, no. 1, pp. 3–5, 2009.
[37] F.-X. Meunier and R. Bellais, "Technical systems and cross-sector knowledge diffusion: An illustration with drones," *Technol. Anal. Strategic Manage.*, vol. 31, no. 4, pp. 433–446, 2019.
[38] D. Elliott, W. Keen, and L. Miao, "Recent advances in connected and automated vehicles," *J. Traffic Transp. Eng.*, vol. 6, no. 2, pp. 109–131, 2019.
[39] S. Liu, L. Li, J. Tang, S. Wu, and J. L. Gaudiot, *Creating Autonomous Vehicle Systems*. San Rafael, CA, USA: Morgan Claypool, 2018.
[40] J. Saballa. "Israel Deploys Semi-Autonomous Machine Gun Robot to Gaza Border." The Defense Post. Jul. 2021. [Online]. Available: https://www.thedefensepost.com/2021/07/01/israel-machine-gun-robot-gaza-border/
[41] P. Lin, "Why ethics matters for autonomous cars," in *Autonomous Driving: Technical, Legal and Social Aspects*, M. Maurer, J. C. Gerdes, B. Lenz, and H. Winner, Eds. Heidelberg, Germany: Springer, 2016, pp. 69–85.
[42] T. Riebe and C. Reuter, "Dual-use and dilemmas for cybersecurity, peace and technology assessment," in *Information Technology for Peace and Security—IT-Applications and Infrastructures in Conflicts, Crises, War, and Peace*, C. Reuter, Ed. Wiesbaden, Germany: Springer, 2019, pp. 165–183.
[43] T. Reinhold and C. Reuter, "Verification in cyberspace," in *Information Technology for Peace and Security—IT-Applications and Infrastructures in Conflicts, Crises, War, and Peace*, C. Reuter, Ed. Wiesbaden, Germany: Springer Vieweg, 2019, pp. 257–275.
[44] T. Reinhold and C. Reuter, "Arms control and its applicability to cyberspace," in *Information Technology for Peace and Security*. Wiesbaden, Germany: Springer Vieweg, 2019, pp. 207–231.
[45] Á. Gómez de Ágreda, "Ethics of autonomous weapons systems and its applicability to any AI systems," *Telecomm. Policy*, vol. 44, no. 6, 2020, Art. no. 101953.
[46] H. J. Ehni, "Dual use and the ethical responsibility of scientists," *Arch. Immunol. Ther. Exp.*, vol. 56, no. 3, pp. 147–152, 2008.
[47] "Ethik-Kommission. Automatisiertes und Vernetztes Fahren." Bundesministerium für Verkehr und digitale Infrastruktur (BMVI). 2017. [Online]. Available: https://www.bmvi.de/SharedDocs/DE/Publikationen/DG/bericht-der-ethik-kommission.pdf?__blob=publicationFile
[48] E. D. Harris, *Governance of Dual-Use Technologies: Theory and Practice*. Cambridge, MA, USA: Amer. Acad. Arts Sci., 2016.
[49] S. Engel-Glatter and M. Ienca, "Life scientists' views and perspectives on the regulation of dual-use research of concern," *Sci. Public Policy*, vol. 45, no. 1, pp. 92–102, 2018.
[50] N. G. Evans, "Dual-use decision making: Relational and positional issues," *Monash Bioethics Rev.*, vol. 32, nos. 3–4, pp. 268–283, 2014.
[51] I. Pitas, "Privacy protection, ethics, robustness and regulatory issues in autonomous systems," in *Proc. 10th Mediterr. Conf. Embed. Comput.*, 2021, p. 1.
[52] J. Svegliato, S. B. Nashed, and S. Zilberstein, "Ethically compliant planning in moral autonomous systems," in *Proc. CEUR Workshop*, vol. 2640, 2020, pp. 1–8.
[53] K. Michael, R. Abbas, G. Roussos, E. Scornavacca, and S. Fosso-Wamba, "Ethics in AI and autonomous system applications design," *IEEE Trans. Technol. Soc.*, vol. 1, no. 3, pp. 114–127, Sep. 2020.
[54] S. E. Davis, *Individual Differences in Operators' Trust in Autonomous Systems: A Review of the Literature*, Aust. Government. Dept. Defence, Edinburgh, U.K., 2019.
[55] A. Martinho, N. Herber, M. Kroesen, and C. Chorus, "Ethical issues in focus by the autonomous vehicles industry," *Transp. Rev.*, vol. 41, no. 5, pp. 556–577, 2021.
[56] T. Reinhold and C. Reuter, "Towards a cyber weapons assessment model—Assessment of the technical features of malicious software," *IEEE Trans. Technol. Soc.*, early access, Dec. 1, 2021, doi: 10.1109/TTS.2021.3131817.
[57] M. Velmans, "How to define consciousness: And how not to define consciousness," *J. Conscious. Stud.*, vol. 16, no. 5, pp. 139–156, 2009.
[58] B. J. Baars, "The conscious access hypothesis," *Trends Cogn. Sci.*, vol. 6, no. 1, pp. 47–52, 2002.
[59] C. Müller. (German Res. Center Artif. Intell., Kaiserslautern, Germany). *Autonomous Driving*. (2020). [Online]. Available: https://www.dfki.de/en/web/research/competence-centers/autonomous-driving/
[60] "OICA, Estimated Passenger Car Production in Selected Countries in 2019." 2020. [Online]. Available: https://www.statista.com/statistics/226032/light-vehicle-producing-countries/
[61] A. Moser and I. Korstjens, "Series: Practical guidance to qualitative research. Part 3: Sampling, data collection and analysis," *Eur. J. Gen. Pract.*, vol. 24, no. 1, pp. 9–18, 2018.
[62] M. Meuser and U. Nagel, "The expert interview and changes in knowledge production," in *Interviewing Experts*, A. Bogner, B. Littig, and W. Menz, Eds. London, U.K.: Palgrave Macmillan, 2009, pp. 17–42.
[63] H. Kallio, A. M. Pietilä, M. Johnson, and M. Kangasniemi, "Systematic methodological review: Developing a framework for a qualitative semi-structured interview guide," *J. Adv. Nurs.*, vol. 72, no. 12, pp. 2954–2965, 2016.
[64] T. Wilson, K. Zhou, and K. Starbird, "Assembling strategic narratives: Information operations as collaborative work within an online community," in *Proc. ACM Human-Comput. Interact.*, vol. 2, pp. 1–26, Nov. 2018.
[65] P. Mayring, "Qualitative content analysis," in *A Companion to Qualitative Research*, U. Flick, E. von Kardorff, and I. Steinke, Eds. London, U.K.: SAGE Publ., 2004, pp. 266–270.
[66] M. Kappel, E. Krune, M. Waldburger, and B. Wilsch, "Die Rolle der KI beim automatisierten Fahren," in *Künstliche Intelligenz—Technologie—Anwendung—Gesellschaft*, V. Wittpahl, Ed. Berlin, Germany: Springer, 2019, pp. 176–193.
[67] R. Campbell and S. M. Wasco, "Feminist approaches to social science: Epistemological and methodological tenets," *Amer. J. Community Psychol.*, vol. 28, no. 6, pp. 773–791, 2000.

**Sebastian Schwartz** received the M.A. degree in peace and conflict studies from the Goethe University of Frankfurt, Frankfurt, Germany, in 2017.

Since 2020, he has been a German Research Associate, working with the Chair of Science and Technology for Peace and Security, Technical University of Darmstadt, Darmstadt, Germany, where Computer Science is combined with Peace and Security Research. He is a lateral thinker and a sci-fi enthusiast with international work experience in the digital and mobility sector and is actively involved in the military and network policy debate in Germany. His scientific focus is the nexus between technical peace and conflict research and strategic studies in connection with machine autonomy. His research focuses on autonomous systems, human–machine teaming, automation of war, and social impact of autonomous systems.

**Laura Gianna Guntrum** received the M.A. degree in peace and conflict studies from the Goethe University of Frankfurt, Frankfurt, Germany, in 2019. She is currently pursuing the Ph.D. degree in technical peace and conflict studies, focusing on the use of ICT during protests.

She is a German Research Associate and forms part of the Research Group of Science and Technology for Peace and Security, Department of Computer Science with secondary appointment in the Department of History and Social Science, Technical University of Darmstadt, Darmstadt, Germany. Her research interests include dual-use technologies, use of ICT during politically disrupted contexts, and intersectional approaches within peace and conflict studies. Furthermore, she is particularly interested in ethics and ethical debates about the responsibility of researchers.

**Christian Reuter** received the Dipl.-Wirt.Inf. degree in information systems from the University of Siegen, Siegen, Germany, the M.Sc. degree from the École Supérieure de Commerce de Dijon, Dijon, France, and the Ph.D. degree (*summa cum laude*) in information systems from the University of Siegen (Technology Design for Inter-Organizational Crisis Management).

He worked as an IT Consultant. He was a Division Manager with the University of Siegen until he was appointed as a Professor with the Technical University of Darmstadt, Darmstadt, Germany, in 2017 (Department of Computer Science, secondary appointment in the Department of History and Social Sciences). He currently serves as the Associate Dean of the Department of Computer Science and a Full Professor with the Technical University of Darmstadt. His chair Science and Technology for Peace and Security in the Department of Computer Science with secondary appointment in the Department of History and Social Sciences combines computer science with peace and security research. On the intersection of the disciplines A) Cyber Security and Privacy, B) Peace and Conflict Studies, as well as C) Human–Computer Interaction, he and his team specifically address 1) Peace Informatics and technical Peace Research, 2) Crisis Informatics and Information Warfare, as well as 3) Usable Safety, Security, and Privacy.