Humanities & Social Sciences Communications

ARTICLE

https://doi.org/10.1057/s41599-020-00655-z OPEN

Futuramas of the present: the "driver problem" in the autonomous vehicle sociotechnical imaginary

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The visions surrounding "self-driving" or "autonomous" vehicles are an exemplary instance of a sociotechnical imaginary: visions of a future technology that has yet to be developed or is in the process of development. One of the central justifications for the development of autonomous vehicles is the claim that they will reduce automobility related death and injury. Central to this narrative is the assumption that more than 90% of road crashes are the result of "driver error." This paper describes the process by which this statistic has been constructed within road safety research and subsequently accepted as a received fact. It is one of the principal semiotic components of the autonomous vehicle sociotechnical imaginary: if human drivers are responsible for ~90% of road crashes, autonomous vehicles should in principle be able to reduce road death and injury rates by a similar percentage. In this paper, it is argued that death and injury are not an aggregate of events that can be distributed across the three central variables of traditional road safety research: the driver, the vehicle, and the environment. The autonomous vehicle sociotechnical imaginary has embraced the central assumption of road safety research, that road violence is not an intrinsic property of automobility but is contingent because largely due to driver error. On the basis of this assumption it has been possible to configure autonomous vehicles as the solution to road violence. Although sociotechnical imaginaries are typically oriented towards the future, it is the significance of the autonomous vehicle sociotechnical imaginary in the present that is the focus of this paper. Autonomous vehicles are not the radically transformational technology their proponents claim but simply the most recent of a succession of automobility sociotechnical imaginaries. They are not transformational because their promotion ensures the continued reproduction of more of the same: namely, more automobility.

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Introduction

"How would you account for this discrepancy between you and the twin 9000?"

"Well, I don't think there is any question about it. It can only be attributable to human error. This sort of thing has cropped up before, and it has always been due to human error."

"Listen HAL. There has never been any instance at all of a computer error occurring in the 9000 series, has there?"

"None whatsoever, Frank. The 9000 series has a perfect operational record."

"Are you certain there has never been any case of even the most insignificant computer error?"

"None whatsoever, Frank. Quite honestly, I wouldn't worry myself about that."

—2001: A Space Odyssey

The visions surrounding "self-driving" or "autonomous" vehicles are an exemplary instance of a sociotechnical imaginary as described by Jasanoff and Kim (2009; Jasanoff, 2015): visions of a future technology that has yet to be developed or is in the process of development. It is a sociotechnical imaginary co-produced through the efforts of a multiplicity of epistemic actors—marketing and advertising agencies, the academy, states, intergovernmental organizations, transport, and road safety experts, social and mass media, automobile manufacturers, and automobiles themselves in the guise of prototypes and concept cars—that are engaged in, either tangentially or as a primary work task, the process of interpreting, defining, and predicting the contours of an imagined autonomous automobility future.[1] The autonomous vehicle sociotechnical imaginary is not the first but the most recent of a series of automobility sociotechnical imaginaries (Curts, 2015; Gundler, 2013; Möser, 2003), each of which predicted a utopic automobile future, none of which came to pass as envisaged and promised. Nor is the current autonomous vehicle sociotechnical imaginary the first autonomous vehicle sociotechnical imaginary (Kidd, 1956; Braun, 2019). Automobility, to borrow the metaphor used to name the Norman Bel Geddes exhibit at the General Motors pavilion at the 1939/1940 New York World's Fair, is a continuous "Futurama" (Jam Handy Organization, 1940).

Arguments for an autonomous mobility future revolve primarily around increased road safety and secondarily congestion reduction, as well as other potential benefits such as travel cost reduction and increased parking space (Litman, 2019; Fagnant and Kockelman, 2015).[2] In this paper we focus on the claim that a technological solution to one of the intractable problems of automobility, namely death and injury, has been found (Sparrow and Howard, 2017). Central to the increased traffic safety narrative is the frequently cited statistic that 93% of automobile "accidents" are due to human error (Treat et al., 1979; Singh, 2018).[3] If the human driver can be replaced with a computer—or described slightly differently, if the car–driver hybrid entity (Randell, 2017; Urry, 2006) can be substituted with a computer-controlled robot within which humans can be transported—death and injury rates could in principle be reduced by ~90% (Fagnant and Kockelman, 2015, p. 173). We argue that this claim is based on a mistaken premise. It is mistaken not because the predicted reduction in percentage is questionable on its own terms (Favarò et al., 2018), or because of the specific ethical questions that have been raised in respect to autonomous vehicles (Himmelreich, 2018), or because road death and injury can and does occur for reasons not related to accidents (Balkmar, 2018; Sorin, 2020; Seo, 2019). It is mistaken because the ostensible problem in need of a solution, namely human error as the primary cause of accidents, is a technologically deterministic construct. It is a construct that originates in the codebooks, data collection, and analytical procedures of accident causation methodologies. This statistical construct is the central justification for moving towards an autonomous vehicle transport future.

There is an accumulating body of critical social scientific research that has questioned the optimistic claims made on behalf of autonomous vehicle technologies (Braun, 2019; Stilgoe, 2018). The crux of these arguments is that autonomous vehicles are primarily social, not technological, artefacts and must be so conceptualized; that roads are social spaces that cannot be adequately understood within an engineering discourse; that objects such as automobiles are not simply technologies that operate within or inside a social context but that the social, as in the case of all technologies, is intrinsic to and inseparable from the technology (Latour, 2005, p. 5). The disagreement with proponents of autonomous vehicle technologies is over the probable accuracy of their visions of the future and the desirability of that future, not just because the visions might not come to pass as imagined, but because the very vision is problematic, not least because of the complex ethical issues these vehicles raise. Employing also the concept of a sociotechnical imaginary, Miloš Mladenović et al. (2020), for example, are critical of the optimistic assumptions embedded in the autonomous mobility sociotechnical imaginary and point to tensions in the meaning making processes between governance and engineering as opposed to citizen-focused narratives. Similarly, Antonia Graf and Marco Sonnberger (2020) argue for a citizen focused approach to mitigate the potential adverse social impacts of self-driving futures.

The above are all valid concerns, but to focus on the future is to engage the argument entirely on the terrain of the proponents of the autonomous vehicle sociotechnical imaginary. That terrain is the future. It is to accept the claim that an autonomous vehicle future would be a radically different future; the disagreement is over what that future might look like. Moreover, to focus on the future is to neglect the significance of the autonomous vehicle sociotechnical imaginary in the present. As John Urry (2016, pp. 7–8) has argued, "past, present and future are mutually intertwined […] The point […] is not to test present assumptions against some predictive future, but to use the future to question, unpack, invent what is going on and what can be done within the present. More generally, […] people's anticipation of the future can have profound consequences for the present." We need, in other words, to turn from speculation about an unknown future, to the discourses, visions and desires in the present surrounding autonomous vehicles. In this paper, we do this by analyzing how the construct of "the accident" is intertwined with the past, present and future of automobility writ large.

An alternative way to describe the autonomous vehicle future is as simply more of the same: more roads, more cars, more investment of public resources in automobility infrastructure, more state aid and automobility subsidies, more negative externalities, fewer alternative mobility possibilities (Urry, 2004; Featherstone et al., 2005; Manderscheid, 2014). As with the many automobility sociotechnical imaginaries of the past, their negative impacts and the unfulfilled promises of automobility should be seen not as something that might or might not have contingently come to pass but as already present within and inseparable from those sociotechnical imaginaries (Jasanoff, 2015, pp. 4–5). As the invention of the ship produced the shipwreck (Virilio, 2007), so the invention of the automobile produced the automobile "accident." Accidents, as Paul Virilio has argued, are not accidental but are intrinsic to technology. Within the road safety research paradigm, in contrast, in locating the accident within the (human) driver the accident has been constructed as extrinsic to automobility. It is upon the veracity of this assumption that the autonomous vehicle sociotechnical imaginary has been promoted as a solution.

In the following section, we briefly outline the central characteristics of the autonomous vehicle sociotechnical imaginary; its relationship to other past and present automobility sociotechnical imaginaries; how these sociotechnical imaginaries sustain and reproduce automobility writ large. We then turn to the construction of the problem the autonomous vehicle sociotechnical imaginary is claimed to solve, which problem is not death and injury *simpliciter;* rather the problem has been constructed as "the driver." Here we describe how road accident statistics have been constructed as taken-for-granted established fact; the theoretical, ethical, empirical, epistemological and metaphysical assumptions embedded within those statistics; their dissemination, location and significance within the automobility imaginary; their rhetorical and performative characteristics. Through the dissemination of visions of roads populated by safe, autonomous, computer-driven vehicles, the sociotechnical imaginary upholds the reproduction of automobility by defining counter-visions of an alternative future as unnecessary and obsolete. The central premise of the autonomous vehicle sociotechnical imaginary is that risks, both in terms of general social impacts and as actual traffic crashes, are problems that can be managed through technological solutions (Mladenović et al., 2020).

The autonomous vehicle sociotechnical imaginary

In a frequently cited passage in the introductory chapter to *Dreamscapes of Modernity: Sociotechnical Imaginaries and the Fabrication of Power*, Jasanoff (2015, p. 4) defines sociotechnical imaginaries as

> collectively held, institutionally stabilized, and publicly performed visions of desirable futures, animated by shared understandings of forms of social life and social order attainable through, and supportive of, advances in science and technology.

Jasanoff and Kim's concept of a sociotechnical imaginary serves as a useful starting point for thinking about the public promotion and marketing of autonomous vehicles. It is a sociotechnical imaginary composed of visions of a desirable future (Ardente et al., 2019, pp. 60–67); it is institutionally stabilized through the efforts of private and state actors (McKinsey and Company, 2013; Bertoncello and Wee, 2015; Aptiv Services US LLC et al., 2019); it is regularly discussed and analysed in the mass media and other virtual and physical public spaces (Topham, 2020; Fraedrich and Lenz, 2016); it is represented as a significant scientific and technological development, thus appealing to shared positive evaluations of science and technology (KPMG, 2012).

Automated vehicles are being developed by a complex of large and small firms, including traditional automobile manufacturers and component suppliers, such as Robert Bosch AG, as well as "technology" firms such as Google LLC, Microsoft Corporation and Intel Corporation. It is these same firms that are promoting an autonomous vehicle future, as are local, national and supranational governments, most notably the US Department of Transportation (2020) and the European Commission (Alonso Raposo, 2019; Ardente et al., 2019). In "seeking to realize the future they envisaged," as John Urry (2016, p. 9) observed, they "deploy complex rhetorical imaginaries and visions of a future 'heaven.'" It is a complex of positive visions that are promoted and disseminated in newspapers and specialist automotive magazines, at motor shows (North American International Auto Show, 2019; Mercedes-Benz, 2020), in academic publications (see, for example, Lipson and Kurman, 2016; Sumantran et al., 2017; Wadhwa and Salkever, 2017) and even museum exhibitions. A recent exhibition entitled "Cars: Accelerating the Modern World" at the Victoria and Albert Museum—"the world's leading museum of art and design"—informs the visitor that "Four trends promise to completely revolutionize the car…. First, a switch to electric engines… Secondly, the driverless car…. Third is a shift from car ownership to on-demand services…. And finally… the flying car." These technological developments are represented as radically different futures, yet it is "the car" that remains (Victoria and Albert Museum, 2019–2020). Similarly, at the 2019 North American International Auto Show (Detroit, January 19–27, 2019) prototypes of flying cars were exhibited, while at the Mercedes Benz pavilion at the 2019 Frankfurt motor show (Internationale Automobil-Ausstellung, Messe Frankfurt, September 12–22, 2019) autonomous vehicles were presented in a setting of moving escalators, lighting, visuals and sound that more than anything else resemble a Disneyland exhibit (see Figs. 1–3, Supplementary Information). To paraphrase Carl Becker's (1932) *The Heavenly City of the Eighteenth-Century Philosophers*, these might be described as visions of the heavenly city of the 21st century engineers.

The concept of a sociotechnical imaginary is useful precisely because it provides pointers for mapping this loose network of institutional power; to ask how power is exercised within and across this network (Jasanoff, 2015, p. 4) to promote autonomous vehicles; to identify the diverse agents that are engaged in the task of persuading us that an autonomous vehicle future is both superior to existing automobility and a solution to problems that it has become no longer possible to ignore or deny (Organization for Economic Co-operation and Development, 2008; World Health Organization, 2015); to ask what makes the sociotechnical imaginary so persuasive. On the basis of their technical knowledge the central actors within this network of institutional suasion that is the autonomous vehicle sociotechnical imaginary assume themselves to be, and so present themselves as, uniquely qualified to divine the autonomous vehicle automobility future. The claim to possession of specialized knowledge is the illocutionary force (Austin, 1965) that job titles, professional, academic and business qualifications, company affiliation and so forth bestow upon claims makers.

The suasiveness of these visions is achieved through the routine invocation of the technological and engineering properties of the vehicles, advances and improvements of which are seen as desirable for their own sake. That they do so in largely uncritical terms is not surprising; the alternative would require moving outside the engineering-business paradigm they inhabit and within which they work (Kuhn, 1970); more fundamentally, to question their very *raison d'être* as promoters of a depoliticized technological determinism (Mladenović et al., 2020), which is none other than a future that is presented as natural and inevitable. Also relevant here is how constructive critics of the autonomous vehicle sociotechnical imaginary frame their criticisms, such as thought experiments in the form of the classic trolley problem. The MIT moral machine experiment (Awad et al., 2018), for example, addresses the ethical questions of autonomous driving rather than more general ethical concerns related to artificial intelligence and machine learning in general (Basl and Behrends, 2019).

A recurrent Futurama, sociotechnical imaginaries have been, and continue to be—from the Model-T Ford, to annual new models, to fins, to electric, connected and autonomous vehicles (Norton, 2008)—essential to the continued reproduction of automobility. Invoking a technologically improved future embedded in justificatory technological determinism (Mladenović et al., 2020), sociotechnical imaginaries typically cannot but refer to lacks, deficiencies, failures and problems in the existing state of affairs. In the case of automobility, several parallel sociotechnical imaginaries to the autonomous vehicle sociotechnical imaginary are at work. One such parallel construct is the electric vehicle sociotechnical imaginary, wherein electric vehicles are being promoted as a solution to climate change, and death and disease from exhaust emissions. In the case of the autonomous vehicle sociotechnical imaginary, it is death and injury resulting from road accidents, for which autonomous vehicles are being promoted as the solution. Central to the autonomous vehicle sociotechnical narrative is the assertion that driver error is a causal factor in 93% of automobile crashes. It is to the construction of this statistic that we now turn.

The construction of road accident statistics

The statistic that 93% of road crashes are due to "human error" (or "driver error") is regularly cited in academic publications (Salmon et al., 2010; Stanton and Salmon, 2009; Petridou and Moustaki, 2000), in governmental and inter-governmental reports (National Highway Traffic Safety Administration, 2015; International Road Transport Union, 2007), in the mass media (Times of India, 2019), in reports (Walker-Smith, 2013), at automobile industry events and company web sites (Mercedes-Benz, 2020). We here review the institutional origins of this statistic and its replication in recent studies.

US crash studies. The first of several studies to conclude that 93% of road crashes are due to "human error" was conducted by the Institute for Research in Public Safety at Indiana University Bloomington, published as the *Tri-Level Study of the Causes of Traffic Accidents* (Treat et al., 1977a, 1977b, 1979). In the body of the report there is some qualification regarding the contribution of "human error" as a causal factor (Treat et al., 1977a, p. 28): "conservatively stated, the study indicates human errors and deficiencies were a cause in at least 64% of accidents, and were probably causes in about 90–93% of accidents investigated." In the Abstract to the Executive Summary (Treat et al., 1979, Technical Report Documentation Page) it is stated that "Human factors were cited as probable causes in 92.6% of accidents investigated…. Environmental factors were cited as probable causes in 33.8% of these accidents, while vehicular factors were identified as probable causes in 12.6%." Rounded up to 93% in the "Capsule Summary" to the Executive Summary, it is this latter figure from the Tri-Level Study that is regularly cited.

Three decades later the 2008 National Motor Vehicle Crash Causation Survey Report to Congress noted that (United States Department of Transportation NHTSA, 2008b):

> Nearly 30 years have passed since the last on-scene crash causation study was conducted (the Indiana Tri-Level Study in 1979). The information from the Indiana Tri-Level Study is seriously outdated due to the changing nature of the vehicle fleet and vehicle technologies. Also, since the last study, driver behaviour has changed due to a variety of dashboard electronics, also called telematics pertaining to entertainment, navigation, and communication. Furthermore, the Tri-Level Study was not nationally representative in that it was only conducted in one small part of the country and was not based upon a statistical design.

Although critical of some aspects of the earlier Tri-Level Study, this second study by the US National Highway Traffic Safety Administration (NHTSA) employed a virtually identical empirical and theoretical framework: causality is assumed to lie within "the vehicle, the roadway, the environmental conditions, and the human behavioural factors" (United States Department of Transportation NHTSA 2008a, p. 2). Crashes were investigated at the crash scene to collect driver, vehicle, and environment-related information pertaining to crash occurrence, with a focus on the role of the driver. The targeted information was captured mainly through four data elements: movement prior to critical pre-crash event; critical pre-crash event; critical reason for the critical pre-crash event; and the crash-associated factors. While this latter US report is more sophisticated in respect to the data analysis and, unlike the Tri-Level Study, is based on a representative sample of the United States, it arrives at similar estimates (Singh, 2018):

> The critical reason, which is the last event in the crash causal chain, was assigned to the driver in 94 percent (±2.2%) of the crashes. In about 2 percent (±0.7%) of the crashes, the critical reason was assigned to a vehicle component's failure or degradation, and in 2 percent (±1.3%) of crashes, it was attributed to the environment (slick roads, weather, etc.).

European crash studies. From the early 1970s, parallel to the Indiana University accident causation study, several institutions in Europe began to investigate the causes and consequences of road crashes. In the late 1990s the European Automobile Manufacturers Association (ACEA) initiated a *European Accident Causation Survey* with the support of the European Commission and under the auspices of the European Road Safety Federation (ERSF). Five partners from Germany, Italy, Finland and France collaborated in the development of a data bank containing information on accident causes. The methodology follows the traditional assessment of accidents, locating causality in "human, road and environmental factors as well as traffic conditions" (Chenisbest et al., 1998). Although the study does not provide a summary statistic, a parallel study, the European Truck Accident Causation Study, funded by the European Commission (EC) and the International Road Transport Union concluded that "the main accident cause is linked to human error in 85,2% of all cases [while] other factors play a minor role" (International Road Transport Union, 2007, p. 4).

Constructing the facts of road crashes. The ESRF paper begins with the observation that: "Sufficient information on the causes of accidents is still lacking, although it is well known that more than 90% are related to human errors" (Chenisbest et al., 1998, p. 415). Similarly, the *Handbook of Traffic Psychology* claims that "it is widely accepted that driver error contributes to more than 90% of all automobile crashes" (Porter, 2012, p. 73). "Did you know," Mercedes-Benz (2020) asks on its web site, "that 60% of people believe that humans are better drivers than computers?" "At the same time," they add, "it is a fact that ninety percent of all accidents come as a consequence of human error." That it is reported as "well known," "widely accepted" and "a fact" is evidence of the performative success of the statistic, achieved through its recurrent citation, even in the face of an acknowledged absence of "sufficient information on the causes of accidents." A summary of the results of *The National Motor Vehicle Crash Causation Survey* (Singh, 2015), "Critical Reasons For

Crashes Investigated in the National Motor Vehicle Crash Causation Survey," as of October 18, 2020 had been cited 490 times according to Google Scholar. The citations are evidence that it is well known in the sense that the statistic is familiar to some numerically significant number of people held to be relevant, which citations ensure it remains well-known. The description of the statistic as "well known" is at the same time an epistemological claim: that it is an empirically established "fact," proof of which is its replication across the studies cited above. In short, the US and European iterations of the statistic have rendered it an established fact that "human error" is the primary cause of automobile crashes, albeit with minor quibbling over the precise percentage.

The construction of the facts begins with the initial formulation of the study, its parameters, purpose and scope; the construction of variables and their associated values; the development of a codebook for translating observations and responses into values for each variable; the investigative work at the scene of the crash; the assigning of causes under human, vehicle or environment variables; the recoding, analysis and interpretation of the data. There is no empirical study that has taken these routine work tasks as a topic of investigation (Lynch, 2011, p. 835), but imagining what such a study would look like allows us to identify what was required to construct the facts.

Such a "study of the study" would focus on how responses, observations and other details were entered into the survey instruments at the scene of the crash; their subsequent coding, specifically the "ad hoc" procedures for making decisions according to a rulebook—which in this case is the coding manual (United States Department of Transportation, 2008)—that specifies how to categorize and code the information along the chain through which the data is conveyed (Garfinkel, 1967, pp. 19–22). Coders—who for the subject at hand includes police officers, accident fieldworkers and statisticians—as Harold Garfinkel observed, do the work of coding as socially competent members. Their social competence derives from their membership in an automobilised society wherein responsibility for automobility crashes is commonsensically assumed to reside in either drivers, vehicles or the environment.

That the results of the original Tri-Level Study have been repeatedly verified is unsurprising, given the later studies have all employed the same theoretical framework and empirical assumptions. Entirely untheorized in these studies is a set of background common-sense assumptions wherein automobility is assumed to be normal and safe; that "accidents" and automobility violence are not an intrinsic property of automobility but contingent. That contingency is assumed to be located in its components: the driver, the road/environment or the vehicle; each crash occurring for contingent reasons that can be accounted for post-hoc, for which there is in principle a perspective from which the crash can be adequately explained, even if in each case it may be difficult in practice to do so. While causes are attributed to either the driver, the vehicle or environment, which causes are then additively calculated to provide percentages, no causality is attributed to automobility in its entirety. While causal aggregates are attributed to drivers, vehicles and the environment, and while blame and responsibility may be allocated for each individual crash, *automobility in its totality is not conceptualized as even a possible causal entity*.

The remit for these studies might be described thus: "The individual causal factors that produce automobile crashes are to be identified, but automobility in its entirety is not to be identified as a causal factor. Drivers and the environment may be held responsible, as may one class of vehicles, namely those that can be identified as 'defective,' but not all vehicles." It is, of course, a remit unlikely to have ever been explicitly articulated. In the idiom of speech act theory (Austin, 1965), it is the illocutionary force of the official remit of studies financed and supported by automobile manufacturers, states and governmental departments (Nader, 1972, pp. 199–252) that are fiscally, infrastructurally and in terms of policy, heavily invested in automobility (see, for example, University of Michigan Transportation Research Institute, 2013). As reflected in the first legal cases that dealt with road "accidents," "automobiles [were] considered as fundamentally benign products that were harmful only when driven negligently" (Lochlann Jain, 2004, p. 65). A similar assumption is the belief that automobility is neither good nor bad, that automobiles are simply neutral technologies, that the problem lies primarily with the users of the technology (see, for example, Nader, 1972, pp. 208–209). Automobility as a complex is thus essentially removed from the realm of possible critique; that it might be "automobility itself" that is the source and cause of road violence. To so conclude would lead one to what for many is the unthinkable: that the elimination of automobility related death and injury would require abolishing automobility. Indeed, the very concept of automobility, a basic concept within the field of automobility studies (Böhm et al., 2006, pp. 3–4), is absent in these studies; there is no "automobility" variable for which even a simple descriptive statistic could be calculated (see, for example, Singh, 2008).

There is no reason to doubt that road safety researchers and advocates are motivated by concern, or doubt that their efforts have contributed to a reduction of death and injury rates, at least within western automobilised societies. But in refraining from critiquing the *sui generis* entity that is automobility, their efforts have had minimal, if any, effect on the reproduction and expansion of automobility across the planet and its accompanying increasing death and injury rates. Similar to the early days of automobility when road safety officials concentrated exclusively on driver education and traffic engineering (Lochlann Jain, 2004; Bonham, 2006), the policy recommendations in these studies and reports hold out the continual promise that automobility is remediable, that automobile death and injury can be massively reduced, that it is contingent.

Accident causation theory. Steffen Böhm, Campbell Jones, Chris Land and Matthew Paterson (2006, pp. 4–5) observe that "In contemporary societies, the car stands in place of automobility itself." In the studies cited above it is "the car" under the term "the vehicle" that stands for automobility. The vehicle is a causal factor only when technologically defective, against a background of what are defined as non-defective vehicles. If we take the estimate in the 1979 study, that "vehicular factors were… probable causes in 12.6% [of crashes]" and invert this statistic, the claim is that vehicular factors were *not* probable causes in 87.4% of cases.

If neither vehicles nor "the environment"—both of which are undertheorized yet always present, as are drivers—were not probable causes it would be very strange indeed. To make one of these the "cause," a specific theory of accidents is required in which the accident is defined as "an unsuccessful interaction between the person, technology and organization" and a "probable cause" as a critical event that is "the single immediate precursor to the accident defined to describe an action of a person" (Thomas et al., 2013b, p. 14). When an accident and a probable cause are so defined it is unsurprising that automobile crash studies using such a methodology find precisely what they are looking for and identify the human as the probable cause in the overwhelming majority of crashes. An alternative conclusion to arrive at would be that automobiles (not as artefacts but as entangled techno-social phenomena) are "probable causes" in

100% of automobile crashes. Or, more precisely, that it is a car–driver–environment assemblage entity (Urry, 2006) that is the causal factor in 100% of automobile crashes.

Aristotle remarked in his *Metaphysics* (Aristotle and Ross, 1981, VI) that "there is no science" of the accident. With the emergence of "vehicle accident causation theory" (Thomas et al., 2013b) such a science for automobility has been developed, with the goal of identifying the root causes of road accidents. Their identification, it is assumed, will open possibilities for their alleviation through improved technologies.

The "natural science of accidents" has its history in the 20th century. Thomas et al. (2013b, p. 13) note that the first accident causation model, the domino theory, was developed in the context of a search for the cause of industrial accidents (Heinrich, 1931). The model accounted for accidents via a simple linear sequential model: an accident is a misstep in a sequential chain of events, each dependent on the preceding event. By removing one of the events the consequences may be avoided and the accident prevented. Amongst the categories within this model, one is "the fault of the person," thus early theories of accident causality focused on human culpability. Since the 1930s, accident causation models have modified the original linear, sequential model. The "Haddon matrix" employed a modified sequential epidemiological model to capture the complexity of accidents, assumed to be caused by a combination of driver, vehicle and infrastructure, for each of which a pre-crash, crash and post-crash phase can be identified (Haddon, 1968; Thomas et al., 2013b, p. 13).

Later models conceptualized accidents as possible outcomes within tightly coupled socio-technical systems in which humans are assumed to have control and thus the opportunity to adapt their behaviour, thus the system is able to accommodate adverse conditions. However, minor human errors can result in accidents with major outcomes (Thomas et al., 2013b, pp. 13–14). Addressing road accidents specifically, Reason (2000) pointed to the different types of "unsafe acts" that are committed by persons *qua* components of the system, with human errors and latent system conditions being identified as root causes. Adding further complexity to the systems approach, the cognitive reliability and error analysis method (CREAM) developed by Hollnagel (1998) conceptualized accidents as "an unsuccessful interaction between person, technology and organization" (Thomas et al., 2013b, p. 14).

Following Haddon, this approach points to risks associated with human behaviour, identifying the critical event as the single immediate precursor to an accident, which is defined as a (failed) action by a person. The model identified nine classes of factors which, together, describe all types of physical interaction within the complex operation of a sociotechnical system. Each factor is sub-divided and related to a specific cause, thus the chain of events can be reconstructed within a causation sequence. All events are related to further antecedents with a set of predefined relationships specified by the method. The model allows for the ascription of a single general causal factor as the root cause of an accident (Thomas et al., 2013b, p. 14).

Applying the CREAM method to road safety, but substituting "Cognitive" with "Driver," M. Ljung (2002) developed a driver reliability and error analysis method (DREAM). Between 2004 and 2008 the European Commission (Thomas et al., 2013a) supported the establishment of a European Road Safety Observatory (ERSO) that involved the development of a new approach to investigate crash causation for policymaking purposes (Paulsson, 2005). DREAM in its 3.0 version (Warner et al., 2008) was adapted and specified as appropriate for traffic safety analysis. Referred to as "SafetyNet Accident Causation System" (SNACS), it follows the traditional DVE (driver–vehicle–environment) schema: "DREAM method has a Human–Technology–Organization perspective, which implies that accidents happen when the dynamic interaction between people, technologies and organizations fails in one way or another, and that there are a variety of interacting causes creating the accident" (Paulsson, 2005, pp. 9–10).

Notwithstanding qualifications and disclaimers within the US and European studies described above, and they are not absent, the repeated citation of the statistic that 93% of road crashes are due to "human error" is the ascription of a *single general causal factor* as the root cause of 93% of all accidents. Although most safety studies arrive at the conclusion that human error is the main cause of accidents, there are many possible instances and categories of human error.

The development of autonomous vehicles requires that those errors be identified and that a machine be constructed that is able to not make the errors that fallible humans make. The Traffic Accident Causation in Europe (TRACE) project investigated the different types of "errors" creating a classification model based on typical "Human Functional Failures" (HFF) present in road accidents. Failures were delineated by following a sequential theoretical chain of human functions involved in information gathering, processing, decision and action. Accidents are conceptualized as ruptures, occurring when the driver is confronted with an unexpected difficulty that leads her to lose control of a situation which until that point was more or less regulated. HFF is an extreme version of DVE in that the driver is assumed to be in full control of both vehicle and the environment. In systems that are imagined as DVEs, it is primarily humans that cause accidents. Rune Elvik (2004, p. 1) has argued that "if humans were perfectly rational, and always in perfect control of hazards that are subject to human control, there would be very few serious accidents." It is assumed that external and internal factors limit human rationality in the control of hazards: accidents are thus inversely related to learning, human ability to managing complexity, and the fact that humans have a limited cognitive capacity, therefore they are prone to failure. If the driver is taken out, so the argument proceeds in the DVE/HFF model(s), and the driver–vehicle hybrid is turned into a vehicle–environment only interaction, accidents will be eliminated or significantly reduced. Accidents in DVE/HFF models are conceptualized from the vantage point of the driver. Hazards of the road are to be controlled by rationality *inside the car* (Fischer et al., 2020).

Revealing accidents. "[T]o invent the family automobile is to produce the pile-up on the highway," Paul Virilio (2007, p. 10) observed. Following Hannah Arendt, Virilio viewed accidents as the other side of technology; "profane miracles" that reveal things that otherwise remain hidden in technology. Road accidents are not extrinsic to automobility, nor are they errors committed by the human driver, but are an intrinsic part of automobility sociotechnical reality. They reveal the essence of automobility: a violent socio-political order (Böhm et al., 2006, p. 10). Virilio is not the only one to look at accidents in terms of such a revelation: Bruno Latour (2005) argues that accidents reveal the agency of objects as actants; Jean Baudrillard (2005, p. 133) talks of the "fatum of technology"; and Slavoj Zizek (1989, p. 70) sees them as a "symptom of modern society."

This point can be made by drawing an analogy to firearm fatalities and injuries. While there is a claim that "it is not guns that kill people but people that kill people," it seems clear that while it is possible to kill someone with one's bare hands, it is much easier to succeed with a firearm, and it is possible to kill many more people, the efficacity increasing with the capacity of the firearm. To suggest that firearms—conceptualized legally as "dangerous instrumentality" (Lochlann Jain, 2004), as were automobiles as early as 1930 in a US Supreme Court decision (Seo, 2019)—are not a probable cause of death in firearm deaths is a peculiar argument, yet it is an identical argument to that found in accident causation research. Automobiles are items of heavy machinery that move at—and are permitted and encouraged to move at—speeds lethal to humans and, for that matter, animals (Davenport and Davenport, 2006, pp. 165–189). Analogously to the situation with firearms, it is very difficult for a person moving through her own efforts to travel at a velocity that is lethal to others.

It is not by chance that autonomous vehicle development is heralded as a solution to the problem of road crashes and has been promoted as the solution within traditional accident causation models (Litman, 2019; Singh, 2015). To identify what is revealed in automobility accidents requires more than to determine what "causes" them. Taking accidents seriously necessitates conceptualizing them not as "human failures" or as flaws in an otherwise functioning system but as inseparable from speed, not only that of the automobile but the speed in which the unexpected (the "a*ccidens*") occurs (Virilio, 2007, p. 12). It is the "virtual speed of the catastrophic surprise" that lies at the centre of every accident. Virilio advises us to look at "what lies beneath the engineer's awareness as producer." What lies there is the coder, working with codebooks and a model that creates an abstraction composed of discreet variables, which mathematical abstraction is not only substituted for the phenomenological reality of the accident, it is assumed *to be* reality (Husserl, 1970, pp. 48–49). It is a model of an in principle flawless system, which would so work if all drivers were perfect drivers. The autonomous vehicle sociotechnical imaginary is a vision of such a driver—it is a machine (Randell, 2017, pp. 672–673). It is a machine we are being urged to accept on the basis of the assurances of automobile and technology manufacturers and associated interests. It is a sociotechnical imaginary constructed by coders and codebooks, further developed and co-created by a confluence of engineering, corporate and state interests (Urry, 2016).

Discussion

Elon Musk, CEO of Tesla, Inc., once proffered the following opinion of public transportation (Marshall, 2017):

> I think public transport is painful. It sucks. Why do you want to get on something with a lot of other people, that doesn't leave where you want it to leave, doesn't start where you want it to start, doesn't end where you want it to end? And it doesn't go all the time. It's a pain in the ass. That's why everyone doesn't like it. And there's like a bunch of random strangers, one of who might be a serial killer, OK, great. And so that's why people like individualized transport, that goes where you want, when you want.

While one of those strangers *might* be a serial killer, if there is a *certain* serial killer, as Musk himself has elsewhere acknowledged, it is the automobile (Lowensohn, 2015). Globally, someone is killed by direct impact with an automobile every 25 s, ~3500 every day. In the United States, Musk's country of residence, almost 40,000 people are killed annually. This normality is part of the background against which road safety research is conducted and policy discussions take place (Culver, 2018).

Perusing the codebooks of the studies discussed above, as well as road safety publications such as those occasionally released by the World Health Organization (2004) and the Organization for Economic Co-Operation and Development (2008), what is striking is the extraordinary number of things that can go wrong on the road. In focusing on producing a number, a percentage, for each of the three ostensible crash causes, sight of the forest (automobility) has been obscured by the trees (variables). That road safety recommendations have to some degree reduced death and injury does not negate this assessment. One policy recommendation that would follow from the above studies would be that the only meaningfully significant way to prevent automobility death and injury is to substitute automobility with safe transportation alternatives; that we need to move to a post-automobility world. Instead, the conclusion that has been drawn is that there are three causal components within each crash—driver, vehicle and environment—each of which is in principle remediable.

Hannah Arendt (1973, p. vii) remarked on the first pages of *Origins of Totalitarianism* that "Progress and Doom are two sides of the same medal… both are articles of superstition, not of faith." Virilio (2007, p. 11) refers to the "eschatological dimension of the calamities caused by the positivist ideology of Progress." Nowhere is this clearer than in the eschatological dimensions of automobility: the 1,250,000 people killed each year and the 50,000,000 that are seriously injured annually (World Health Organization, 2015) in automobile accidents. "Violence" is the appropriate term to describe road death and injury (Furnas, 1935; Watkins-Hughes, 2009). Road accidents cause physical trauma. Injuries result in death, severe disability, inability to work, chronic pain and repercussions for family life and psychological well-being. In the same way that to simply say that people "died" during the Holocaust rather than that they were murdered is an inadequate description (Volmert, 2017, p. 6), similarly the word "violence" is the appropriate term to describe what routinely occurs on roads across the Earth.

More people are killed in road crashes than from any other form of violent death, war included. Since the first death of a pedestrian, Bridget Driscoll, in London in 1896 (The Manchester Guardian, 1896), ~85 million people have been killed in what are commonly referred to as automobile "accidents": roughly 60 million in the 20th century and 25 million to date in the first two decades of the 21st century. To provide some comparison, around 66 million people were killed in World War II. Automobility is arguably the most violent socio-political order on Earth. There is no other area of social or political life where such a constant, routine and violent attrition of human life and the destruction of the human body is considered normal and acceptable (Paterson, 2007, p. 41). We submit that the appropriate conclusion to draw from the data collected by the accident studies is that automobility is *irremediably* violent.

Automobility is a moral economy wherein automobile manufacturers in particular and the automotive industry in general have been relieved of all responsibility for this ongoing calamity, enabled by the research described above and its recurrent citation that locates the cause within the driver. This has in part been achieved through automobile interests having successfully appropriated ownership of "the problem." They own it in the sense that they have been able to define the problem, which problem has been constructed as the human driver (Bucsuházy et al., 2020; Rolison et al., 2018; Zhang et al., 2018). It is a problem jointly owned with road safety researchers, co-owners of the problem in the sense identified by Joseph Gusfield (1989) as it is road safety researchers and automobile manufacturers that are typically consulted when road safety issues become a topic in the current news cycle.

In defining the problem as the driver, the automobile industry has at the same time been able to disavow ownership in the sense of responsibility. Only to the degree they make faulty vehicles is the automobile industry held responsible. Examples are the Ford Pinto and, more recently, Toyota vehicles that unexpectedly accelerated. While financially detrimental to Ford and Toyota, these events serve a useful purpose for automobile manufacturers as a whole; they convince us that all other vehicles leave factories in a normal and safe condition. This is the background against which an individual vehicle (for example, due to inadequate maintenance) or a class of vehicle (such as a Ford Pinto) can be categorized as "defective," thereby allowing all other vehicles to be categorizable as non-defective, hence not causal factors, precisely as categorized in the studies described above.

Conclusion

While it is possible to identify at a general level the processes, agents, and activities essential to the construction of the road crash statistics discussed in this paper, we noted above that a detailed study of road safety studies has yet to be undertaken. Such a reflexive study would begin with a reconstruction of the initial formulation of the research project and its methodology, accompany police and any other on scene coders, trace the recoding of variables and their analysis, and document the "writing up" and subsequent dissemination of public documents and reports. Further research at this level of detail would contribute to identifying how, precisely, this widely cited and replicated statistic has been and continues to be routinely reproduced within a realist epistemology as a "well known" and "widely accepted" fact.

The autonomous vehicle sociotechnical imaginary is a sociotechnical imaginary that assures us that a solution has been found to the problem of massive automobile death and injury. Through the promises contained within its publicly performed visions, it constructs an imaginary world in the future perfect tense wherein one of the many problems of automobility has been solved. It provides a ready-made rejoinder to automobility's critics. It is a vision promoted and supported by the automobile industry and related interests, amongst which interests their capital accumulation prospects are not incidental (Paterson, 2007); aided by states that are no less interested (Manderscheid, 2012, 2014). The current model, theory and application of road accident causation both supports and reflects this vision. It is yet to be seen whether a new model could be developed based on sociotechnical imaginaries that lay outside of the dominant engineering-business paradigm referred to earlier. One such alternative model would be a phenomenological approach to road accidents, focusing on embodied experience, perception and action (Merleau-Ponty, 1992) and the situatedness of the habituated practices that result in accidents. In addition to documenting experiences related to actual events ("accidents"), it would focus on non-events (near accidents, accident-like setups). Such an approach would provide grounds for rethinking experience, agency and risks in our knowledge of road violence. Clearly, more research on accidents and road violence based on alternative epistemic constructs (Ihde, 2009) is required.

The success of the many automobility sociotechnical imaginaries of the past and the present is dependent upon convincing us that there are no alternatives; that automobility pasts and futures are determined by technological innovations; that those pasts and envisaged futures are *not* the outcome of political strategies and decisions. Yet there are alternative sociotechnical imaginaries (Jasanoff, 2015, p. 4) based on responsibility, acceptance and co-creation (Graf and Sonnberger, 2020); citizen engagement and participatory deliberation in innovation (Mladenović et al., 2020); and criticism of automobility violence and injustice (Culver, 2018).

The autonomous vehicle sociotechnical imaginary is a complex of publicly performed visions (Jasanoff, 2015) embedded in an engineering-business paradigm and grounded in technological determinism. The autonomous vehicle sociotechnical imaginary, like the automobility sociotechnical imaginaries of the past as well as those contemporaneous with it, most notably the electric vehicle sociotechnical imaginary, will contribute to ensuring the reproduction of the automobility regime under which we live; a regime of continued production of more automobiles and more automobility infrastructure. It is not a radically different future, nor is it even a radically different imaginary. It is a sociotechnical imaginary that ensures in the present the social reproduction and further expansion of automobility. It will result in nothing more than more of the same: namely, more automobility.

Data availability

The references to the Detroit and Frankfurt motor shows and the exhibition at the Victoria and Albert Museum are based on participant observation and photographs taken by one or both authors. Several images are included in the Supplementary File.

Received: 17 June 2020; Accepted: 28 October 2020;
Published online: 02 December 2020

Notes

1 Within industry and government discourses and publications, autonomous vehicles are frequently seen as one component of a multidimensional connected autonomous vehicle future. It is, however, a sociotechnical imaginary that exists on the margins of public awareness, for which reason our focus is the autonomous vehicle sociotechnical imaginary. We here restrict ourselves to noting that multidimensional connectedness augments social reality in multiple ways (Castells, 2009). By transforming the imagined humans of the future from one component of a car–driver cyborg entity (Randell, 2017) into car–consumers divested of agency, they are likely to become, as Avigail Ferdman (2020) has argued, not only passive riders but hyper-consumers within a hyper-connected "attention-economy," allowing mobility providers to capitalize on the in-vehicle attention of passengers.

2 The focus of this paper is not the technology but the sociotechnical imaginary as publicly described and envisaged. Throughout this paper we use the term "autonomous" not because we believe these vehicles are or will be "autonomous" (or "self-driving," which we take to be a synonym) but because this is the term typically used to describe them (e.g., Alonso Raposo, 2019).

3 Within road safety discourses the term "accident" has increasingly been replaced by the term "crash." We employ both terms throughout this paper, depending on the context, but the theoretical focus of the paper is "the accident," not "crashes."

References

Alonso Raposo M (2019) The future of road transport. Publications Office of the European Union, Luxembourg

Aptiv Services Us Llc, Audi Ag, Bayrische Motoren Werke Ag, Beijing Baidu Netcom Science Technology Co. L, Continental Teves Ag & Co Ohg, Daimler Ag, Fca Us Llc, Here Global B.V., Infineon Technologies Ag, Intel, Volkswagen Ag (2019) Safety first for automated driving. https://www.daimler.com/documents/innovation/other/safety-first-for-automated-driving.pdf

Ardente F, Aurambout J-P, Baldini G, Braun R, Christidis P, Christodoulou A, Duboz A, Felici S, Ferragut J, Georgakaki A, Gkoumas K, Grosso M, Iglesias M, Julea A, Krause J, Martens B, Mathieux F, Menzel G, Mondello S, Navajas Cawood E, Pekár F, Raileanu I-C, Scholz H, Tamba M, Tsakalidis A, Van Balen M, Vandecasteele IT (2019) The future of road transport—implications of automated, connected, low-carbon and shared mobility, Jrc116644. Center JR. Publications Office of the European Union, Luxembourg

Arendt H (1973) The origins of totalitarianism. Harcourt Brace Jovanovich, New York

Aristotle, Ross WD (1981) Aristotle's metaphysics. Clarendon Press, Oxford

Austin JL (1965) How to do things with words. Oxford University Press, New York

Awad E, Dsouza S, Kim R, Schulz J, Henrich J, Shariff A, Bonnefon A-F, Rahwan I (2018) The moral machine experiment. Nature 563:59–64. https://doi.org/10.1038/s41586-018-0637-6

Balkmar D (2018) Violent mobilities: men, masculinities and road conflicts in Sweden. Mobilities 13:717–732. https://doi.org/10.1080/17450101.2018.1500096

Basl J, Behrends J (2019) Why everyone has it wrong about the ethics of autonomous vehicles. Bridge 48(4):42–47

Baudrillard J (2005) The system of objects (trans: Benedict J). Verso, London

Becker CL (1932) The heavenly city of the eighteenth-century philosophers. Yale University Press, New Haven

Bertoncello M, Wee D (2015) Ten ways autonomous driving could redefine the automotive world. McKinsey, London

Böhm S, Jones C, Land C, Paterson M (2006) Introduction: impossibilities of automobility. In: Böhm S, Jones C, Land C, Paterson M (eds.) Against automobility. Blackwell, Malden, pp. 3–16

Bonham J (2006) Transport: disciplining the body that travels. In: Böhm S, Jones C, Land C, Paterson M (eds.) Against automobility. Blackwell, Oxford, pp. 57–74

Braun R (2019) Autonomous vehicles: from science fiction to sustainable future. In: Aguiar M, Mathieson C, Pearce L (eds). Mobilities, literature, culture. Palgrave Macmillan, pp. 259–280

Bucsuházy K, Matuchová E, Zůvala R, Moravcová P, Kostíková M, Mikulec R (2020) Human factors contributing to the road traffic accident occurrence. Transp Res Procedia 45:555–561. https://doi.org/10.1016/j.trpro.2020.03.057

Castells M (2009) The rise of the network society. Wiley-Blackwell, Oxford

Chenisbest B, Jähn N, Le Coz J-Y (1998) European Accident Causation Survey (EACS) methodology (pp. 414–421). The 16th International Technical Conference on the Enhanced Safety of Vehicles (ESV) Proceedings, Paper Number 98-S2-O-08, Windsor, Ontario, Canada

Culver G (2018) Death and the car: on (auto)mobility, violence, and injustice. ACME 17(1):144–170

Curts K (2015) Temples and turnpikes in "the world of tomorrow": religious assemblage and automobility at the 1939 New York world's fair. J Am Acad Relig 83:722–749. https://doi.org/10.1093/jaarel/lfv041

Davenport J, Davenport JL (2006) The ecology of transportation: managing mobility for the environment. Springer, Netherlands

Elvik R (2004). Laws of accident causation. Paper presented at the 18th ICTCT workshop

Fagnant DJ, Kockelman K (2015) Preparing a nation for autonomous vehicles: opportunities, barriers and policy recommendations. Transp Res Part A 77:167–181. https://doi.org/10.1016/j.tra.2015.04.003

Favarò F, Eurich S, Nader N (2018) Autonomous vehicles' disengagements: trends, triggers, and regulatory limitations. Accident Anal Prev 110:136–148

Featherstone M, Thrift NJ, Urry J (eds) (2005) Automobilities. Sage Publications, London

Ferdman A (2020) Corporate ownership of automated vehicles: discussing potential negative externalities. Transp Rev 40:95–113. https://doi.org/10.1080/01441647.2019.1687606

Fischer J, Nelson T, Laberee K, Winters M (2020) What does crowdsourced data tell us about bicycling injury? A case study in a mid-sized canadian city. Accident Anal Prev 145. https://doi.org/10.1016/j.aap.2020.105695

Fraedrich E, Lenz B (2016) Societal and individual acceptance of autonomous driving. In: Maurer M, Gerdes J, Lenz B, Winner H (eds) Autonomous driving. Technical, legal and social aspects. Springer, Berlin, pp. 621–640

Furnas J (1935) And sudden death. Read Digest 27(160):21–26

Garfinkel H (1967) Studies in ethnomethodology. Prentice-Hall, Englewood Cliffs

Graf A, Sonnberger M (2020) Responsibility, rationality, and acceptance: how future users of autonomous driving are constructed in stakeholders' sociotechnical imaginaries. Public Underst Sci 29(1):61–75. https://doi.org/10.1177/0963662519885550

Gundler B (2013) Promoting german automobile technology and the automobile industry: the motor hall at the deutsches museum, 1933–1945. J Transp Hist 34:117–139. https://doi.org/10.7227/TJTH.34.2.3

Gusfield JR (1989) Constructing the ownership of social problems: fun and profit in the welfare state. Soc Probl 36(5):431–441

Haddon W (1968) The changing approach to the epidemiology, prevention, and amelioration of trauma: the transition to approaches etiologically rather than descriptively based. Am J Public Health 58(8):1431–1438

Heinrich HW (1931) Industrial accident prevention: a scientific approach. McGraw-Hill, New York

Himmelreich J (2018) Never mind the trolley: the ethics of autonomous vehicles in mundane situations. Ethical Theory Moral Pract 21:669–684. https://doi.org/10.1007/s10677-018-9896-4

Hollnagel E (1998) Cognitive reliability and error analysis method (CREAM). Elsevier Science Ltd, Oxford

Husserl E (1970) The crisis of European sciences and transcendental phenomenology. Northwestern University Press, Evanston

Ihde D (2009) Postphenomenology and technoscience: the Peking University lectures. State University of New York Press, Albany

International Road Transport Union (2007) A scientific study "ETAC" European truck accident causation. Geneva. https://www.iru.org/sites/default/files/2016-01/en-2007-etac-study.pdf

Jam Handy Organization (1940) To new horizons. General Motors Corporation, Department of Public Relations, Detroit

Jasanoff S (2015) Future imperfect: science, technology, and the imaginations of modernity. In: Jasanoff S, Kim SH (eds) Dreamscapes of modernity: sociotechnical imaginaries and the fabrication of power. University of Chicago Press, Chicago, pp. 1–33

Jasanoff S, Kim SH (2009) Containing the atom: sociotechnical imaginaries and nuclear power in the United States and South Korea. Minerva 47:119–146

Kidd M (1956) Key to the future. Dudley Pictures Corporation

Kpmg (2012) Self-driving cars: the next revolution. https://assets.kpmg.com/content/dam/kpmg/pdf/2015/12/the-future-of-the-car-report.pdf

Kuhn TS (1970) The structure of scientific revolutions. University of Chicago Press, Chicago

Latour B (2005) Reassembling the social: an introduction to actor-network-theory. Oxford University Press, New York

Lipson H, Kurman M (2016) Driverless: intelligent cars and the road ahead. MIT Press, Cambridge

Litman T (2019) Autonomous vehicle implementation predictions: implications for transport planning. Victoria Transport Policy Institute

Ljung M (2002) Dream—driving reliability and error analysis method. Linköping University, Linköping

Lochlann Jain S (2004) "Dangerous instrumentality": the bystander as subject in automobility. Cult Anthropol 19(1):61–94

Lowensohn J (2015). Elon musk: cars you can drive will eventually be outlawed. https://www.theverge.com/transportation/2015/3/17/8232187/elon-musk-human-drivers-are-dangerous

Lynch M (2011) Introduction. Soc Stud Sci 41(6):835–837

Manderscheid K (2012) Automobilität als raumkonstituierendes dispositiv der modeme. In:Füller H, Michel B (eds) Die ordnung der räume. Westphälisches Dampfboot, Münster, pp. 145–178

Manderscheid K (2014) The movement problem, the car and future mobility regimes: automobility as dispositif and mode of regulation. Mobilities 9 (4):604–626

Marshall A (2017) Elon musk reveals his awkward dislike of mass transit. Wired. https://www.wired.com/story/elon-musk-awkward-dislike-mass-transit/. Accessed 29 Dec 2019

Mckinsey & Company (2013) The road to 2020 and beyond: what's driving the global automotive industry? https://www.mckinsey.com/~/media/mckinsey/dotcom/client_service/automotive%20and%20assembly/pdfs/mck_the_road_to_2020_and_beyond.ashx

Mercedes-Benz (2020) Autonomous. https://www.mercedes-benz.com/en/exhibitions/iaa/autonomous/. Accessed 20 Oct 2020

Merleau-Ponty M (1992) The phenomenology of perception. Routledge, New York

Mladenović MN, Stead D, Milakis D, Pangbourne K, Givoni M (2020) Governance cultures and sociotechnical imaginaries of self-driving vehicle technology: comparative analysis of Finland, UK and Germany. Adv Transp Policy Plan 5:235–262. https://doi.org/10.1016/bs.atpp.2020.01.001

Möser K (2003) The dark side of "automobilism", 1900–30. J Transp Hist 24:238–258

Nader R (1972) Unsafe at any speed; the designed-in dangers of the American automobile, Expanded edn. Grossman, New York

National Highway Traffic Safety Administration (2015) National motor vehicle crash causation report. US Department of Transportation, Washington

North American International Auto Show (2019) Automobili-d. https://naias.com/planetm-exhibition. Accessed 20 Oct 2020

Norton PD (2008) Fighting traffic: the dawn of the motor age in the American city. MIT Press, Cambridge

Organisation for Economic Co-operation and Development (2008) Towards zero. OECD, Paris

Paterson M (2007) Automobile politics: ecology and cultural political economy. Cambridge University Press, Cambridge

Paulsson R (2005) Deliverable 5.2: In-depth accident causation data study methodology development report. SafetyNet. http://www.dacota-project.eu/Links/erso/safetynet/fixed/WP5/SN_Deliverable_5%202%20v3_051123_Final%20submission.pdf

Petridou E, Moustaki M (2000) Human factors in the causation of road traffic crashes. Eur J Epidemiol 16(9):819–826

Porter BE (ed) (2012) Handbook of traffic psychology. Elsevier, Amsterdam

Randell R (2017) The microsociology of automobility: the production of the automobile self. Mobilities 12(5):663–676

Reason J (2000) Human error: models and management. Br Med J 320 (7237):768–770. https://doi.org/10.1136/bmj.320.7237.768

Rolison JJ, Regev S, Moutari S, Feeney A (2018) What are the factors that contribute to road accidents? An assessment of law enforcement views, ordinary drivers' opinions, and road accident records. Accident Anal Prev 115:11–24

Salmon PM, Lenné MG, Stanton NA, Jenkins DP, Walker GH (2010) Managing error on the open road: the contribution of human error models and methods. Saf Sci 48(10):1225–1235

Seo SA (2019) Policing the open road: how cars transformed American freedom. Harvard University Press, Cambridge

Singh S (2008) National motor vehicle crash causation survey (NMVCCS) databook of NMVCCS variables. US Department of Transportation, National Highway Traffic Safety Administration, Washington

Singh S (2015) Critical reasons for crashes investigated in the national motor vehicle crash causation survey. US Department of Transportation. Traffic

Safety Facts Crash Stats. Report no. DOT HS 812 115. National Highway Traffic Safety Administration, Washington
Singh S (2018) Critical reasons for crashes investigated in the national motor vehicle crash causation survey. US Department of Transportation. Traffic Safety Facts Crash Stats. Report no. DOT HS 812 506. National Highway Traffic Safety Administration, Washington
Sorin GS (2020) Driving while black: African American travel and the road to civil rights. Liveright Publishing Corporation, New York
Sparrow R, Howard M (2017) When human beings are like drunk robots: driverless vehicles, ethics, and the future of transport. Transp Res Part C 80:206–215. https://doi.org/10.1016/j.trc.2017.04.014
Stanton NA, Salmon PM (2009) Human error taxonomies applied to driving: a generic driver error taxonomy and its implications for intelligent transport systems. Saf Sci 47(2):227–237
Stilgoe J (2018) Machine learning, social learning and the governance of self-driving cars. Soc Stud Sci 48(1):25–56
Sumantran V, Fine C, Gonsalvez D (2017) Faster, smarter, greener: the future of the car and urban mobility. MIT Press, Cambridge
The Manchester Guardian (1896) Bridget Driscoll, on a day trip to crystal palace, was bewildered by the car's approach, got in its way and was knocked down. https://www.theguardian.com/world/2014/aug/26/uk-first-fatal-car-accident-archive-1896
Thomas P, Hill J, Morris AP, Jr. Welsh, Talbot R, et al. (2013a) Dacota: Road Safety Data, Collection, Transfer and Analysis Deliverable 0.1-Final Project Report. https://hal.archives-ouvertes.fr/hal-01068641
Thomas P, Morris A, Talbot R, Fagerlind H (2013b) Identifying the causes of road crashes in Europe. Ann Adv Automot Med 57:13–22
Times of India (2019) 93% accidents in HP caused due to human error. June 13. https://timesofindia.indiatimes.com/city/shimla/93-accidents-in-hp-caused-due-to-human-error/articleshow/69763927.cms
Topham G (2020) Self-driving cars could be allowed on UK motorways next year. The Guardian. Web: https://www.theguardian.com/technology/2020/aug/18/self-driving-cars-allowed-motorways-industry-risk. Accessed 21 Nov 2020
Treat JR, Castellan NJ, Stansifer RL, Mayer RE, Hume RD, Shinar D, Mcdonald ST, Tumbas NS (1977a) Tri-level study of the causes of traffic accidents: final report, vol I. Causal factor tabulations and assessments
Treat JR, Castellan NJ, Stansifer RL, Mayer RE, Hume RD, Shinar D, Mcdonald ST, Tumbas NS (1977b) Tri-level study of the causes of traffic accidents: final report. vol II: Special analyses
Treat JR, Castellan NJ, Stansifer RL, Mayer RE, Hume RD, Shinar D, Mcdonald ST, Tumbas NS, United States. National Highway Traffic Safety Administration., University of Michigan. Library. Deep Blue. (1979) Tri-level study of the causes of traffic accidents: final report. Executive summary
United States Department of Transportation (2020) Av proving grounds. http://www.nationalavpg.com/. Accessed 20 Oct 2020
United States Department of Transportation NHTSA (2008a) National motor vehicle crash causation survey (NMVCCS) field coding manual. U.S. Department of Trasportation, National Highway Traffic Safety Administration, Washington
United States Department of Transportation NHTSA (2008b) National motor vehicle crash causation survey report to congress. U.S. Department of Transportation, National Highway Traffic Safety Administration, Washington
University of Michigan Transportation Research Institute (2013) Recent sponsors of behavioral sciences. http://www.umtri.umich.edu/who-we-are/behavorial-sciences/recent-sponsors-behavioral-sciences. Accessed 20 Oct 2020
Urry J (2004) The 'system' of automobility. Theory Cult Soc 21(4-5):25–39. https://doi.org/10.1177/0263276404046059
Urry J (2006) Inhabiting the car. Sociol Rev 54(1):17–31. https://doi.org/10.1111/j.1467-954x.2006.00635.x
Urry J (2016) What is the future? Polity Press, Malden
Victoria and Albert Museum (2019–2020) Cars: accelerating the modern world. https://www.vam.ac.uk/exhibitions/cars. Accessed Oct 20 2020
Virilio P (2007) The original accident (trans: Rose J). Polity Press, Cambridge
Volmert M (2017) Landscape, boundaries, and the limits of representation: the Stolpersteine as a commemorative space. Nord Jud/Scand Jew Stud 28:4–21
Wadhwa V, Salkever A (2017) The driver in the driverless car: how our technology choices will create the future. Berrett-Koehler, Oakland
Walker-Smith B (2013) Human error as the cause of vehicle crashes. http://cyberlaw.stanford.edu/blog/2013/12/human-error-cause-vehicle-crashes. Accessed 22 Oct 2020
Warner HW, Ljung Aust M, Sandin J, Johansson E, Björklund G (2008) Dream 3.0, driving reliability and error analysis method. http://publications.lib.chalmers.se/records/fulltext/80432.pdf
Watkins-Hughes P (2009) Cow trailer. https://www.youtube.com/watch?v=R0LCmStIw9E
World Health Organization (2004) World report on road traffic injury prevention. World Health Organization, Geneva
World Health Organization (2015) Global status report on road safety. WHO, Geneva
Zhang Y, Liu T, Bai Q, Shao W, Wang Q (2018) New systems-based method to conduct analysis of road traffic accidents. Transp Res Part F 54:96–109. https://doi.org/10.1016/j.trf.2018.01.019
Zizek S (1989) The sublime object of ideology. Verso, London

Acknowledgements
One of the authors (RB) has received funding in the project NewHoRRIzon (the European Union's Horizon 2020 research and innovation programme) under grant agreement No. 741402, leading to this publication.

Competing interests
The authors declare no competing interests.

Additional information
Supplementary information is available for this paper at https://doi.org/10.1057/s41599-020-00655-z.

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