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A Laboratory on the Road: Europe's Regulatory Response to the Opacity of Autonomous Vehicles

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Abstract

Established frameworks for vehicle regulation are not equipped to certify autonomous driving systems, given that their behaviour in real-world conditions cannot be fully inspected or verified in lab situations. This article examines how European regulators have responded to this challenge in Regulation 2022/1426, the first type approval framework for automated driving systems in Europe. The article extends Burrell's three forms of algorithmic opacity to also capture the opacity of behaviours emerging from interactions in open, physical environments and uses this to analyse how the regulation responds to each form of opacity and how it distributes responsibilities between vehicle manufacturers, regulators and the public. The analysis identifies three regulatory transformations: operational design domains limit the scope of autonomous driving; scenario-based testing evaluates overall system behaviour rather than the mechanisms of specific components; and a shift towards on-road testing and after-market surveillance dissolves the boundary between testing and deployment. The result is a real-world experiment in which the public have been enrolled as subjects of a continuously extended laboratory. The article concludes that the current regulatory framework never resolves the uncertainties and risks within the type approval process, and instead opts for a continuous modulation of both regulation and technology after its market deployment.

***Keywords**:* Autonomous vehicles; algorithmic opacity; type approval; regulation; real-world experimentation.

1. Introduction

The European type approval process, where vehicle types and systems are tested and certified before market entry, has historically relied on the ability to inspect and verify discrete mechanical and electrical components. Autonomous driving systems challenge this kind of inspection process. Their software components complicate direct auditing and their behaviour emerges from interactions with physical environments that cannot be explored fully in lab situations. As a response to these challenges, EU Regulation 2022/1426[1] proposes a new type approval process for the certification of autonomous vehicles in Europe. This article investigates how the new regulation responds to the opacity of autonomous driving systems, how requirements and methods of verification change and how responsibility for risk and safety is distributed between manufacturers, regulators and the public.

The aim of the article is to find out how the regulation responds to the opacity of autonomous driving systems and to discover the consequences for the role of type approval and for the public. The article proceeds by first giving a background to the development of autonomous vehicles and the socio-legal debates to which it has given rise, and provides an overview of the development of the type approval system and its regulations. It then develops a theoretical framework that extends Burrell's framework[2] of algorithmic opacity with a fourth form of opacity, capturing the unknowability that arises when algorithmic systems must translate between digital representations and actions in physical space. After describing the methods and materials of analysis, it undertakes a detailed reading of EU Regulation 2022/1426. The result is an extension of the type approval system

[1] *Regulation (EU) 2022/1426.*
[2] Burrell, "How the Machine 'Thinks.'"

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in space onto public roads and in time through continued post-certification monitoring. The article then discusses the broader relevance of this shift for the regulation of autonomous driving and challenges for the regulation of other autonomous systems operating in open environments.

2. Background

2.1 Autonomous Driving in Open Environments

Automation has made significant advances in controlled environments such as factories and in aviation, where the system operates within well-defined parameters and does not have to interact with other actors in complex environments. Autonomous driving is different because it involves automated behaviour in open, yet crowded environments.[3] As autonomous vehicles move from closed testing facilities onto public roads, they must analyse and interact with an open-ended range of complex traffic situations comprising other vehicles, pedestrians, road infrastructure, different environmental conditions and local driving norms. Autonomous driving is traditionally classified in SAE levels from 0–5, with L-0 implying no automation and L-5 full automation without human supervision in any situation.[4] As autonomous driving technologies continue to be tested both in closed spaces and on public roads,[5] current systems have yet to reach level 5.[6]

Autonomous driving is therefore a good case to examine if we wish to understand the kinds of regulation that can emerge around autonomous technologies interacting in complex social and physical spaces, and the challenges of regulators attempting to govern emerging technologies by anticipating their future impact.[7] At stake is not only the safety of passengers and other road users, but also broader transformations of the rules, norms and patterns of use of the traffic system itself as autonomous vehicles become more prevalent.[8]

2.2 From Traffic Norms to Technical Requirements

Autonomous driving systems have attracted attention from the social, legal and behavioural sciences from the beginning. Several regulatory issues have been identified in the literature, from 'trolley problem'-style moral issues of how vehicles should respond in the case of unavoidable accidents[9] to questions of legal liability.[10] These issues highlight how what previously fell within the human driver's judgement must now be deliberately specified in the design of autonomous driving systems.[11] Regulators face the task of translating ethical considerations about what constitutes good and safe driving into precise technical requirements.[12]

Since autonomous driving systems in the European Union are only permitted after having gone through the type approval process, there is little risk of a "law lag" where technological development outruns regulation.[13] Where software-based technologies can be deployed and disseminated before regulators have a chance to address their negative effects, autonomous vehicle manufacturers must instead adapt and shape their systems to meet regulatory requirements before market entry.

Regulators are under pressure to be at the forefront of innovation and allow the introduction of autonomous vehicles as early as possible,[14] yet a premature introduction would come with safety risks for passengers and other road users, as well as disruptions to the flow of the traffic system.[15] For higher levels of automation, where the system must respond autonomously in traffic situations, this places regulators in a form of Collingridge dilemma,[16] where they must specify appropriate requirements and find adequate methods to test and verify systems before their widespread introduction, even though many of the effects of autonomous driving will only become apparent after large-scale adoption. The challenge is compounded by the opacity of automated driving systems where their complexity makes it difficult to specify exactly how they should operate and

[3] Shanmugam, "Autonomous Intelligent Vehicles."
[4] Kukkala, "Advanced Driver-Assistance Systems."
[5] Eastman, "A Comparative Look."
[6] Khan, "Level-5 Autonomous Driving?"
[7] Guston, "Understanding 'Anticipatory Governance'."
[8] Schreurs, "Autonomous Driving."
[9] Bonnefon, "The Social Dilemma."
[10] Cohen, "Self-Driving Technology."
[11] Eriksson, "The Normativity of Automated Driving."
[12] Bin-Nun, "How Should Autonomous Vehicles Drive?"
[13] Moses, Recurring Dilemmas.
[14] Hemesath, "Framing the Approval."
[15] Johnsen, Literature Review.
[16] Collingridge, The Social Control of Technology.

to test them against the many different situations they could potentially encounter. These different forms of opacity are further developed in the theoretical framework in the next section.

2.3 The Type Approval Framework

Prior to the recent reform of the European regulation, the type approval was regulated in Directive 2007/46/EC. Under this system, manufacturers gained approval for discrete components and subsystems, such as steering, braking and emissions, each tested in isolation by technical services against standardised thresholds and rigorously defined criteria.[17] The legislation was based on a principle whereby if all relevant components were individually approved, the vehicle as a whole gained approval. Around this system, a body of legislation and authoritative organisations was built up.[18] Individual component testing first became unsustainable once more advanced software and automation functions were introduced that integrated several subsystems in one functional behaviour.[19] Type approval regulation has for some years already contained aspects of autonomous vehicle control through the regulation of Advanced Driver-Assistance Systems (ADAS), such as collision avoidance and adaptive cruise control.[20] This provides one departure point for regulating more advanced forms of autonomous driving.

The work with adapting type approval for autonomous driving through regulations has taken place in international negotiations at the EU and UN level, with UN working group 29 having been tasked with identifying legal obstacles to the implementation of automated driving and influencing international regulation in a direction that can accommodate automation.[21] They are mainly concerned with two topics, involving the driverless driving situation and the design of autonomous driving systems, respectively. The first is the need to find a way around the driver as a fundamental concept in traffic regulation as the person pinpointed to always be responsible for the operations of the vehicle – something that is challenged by autonomous systems.[22] The second topic, which is the focus of this article, relates to the type approval of vehicles and the testing and verification of technologies that is always performed before a technical component, such as a braking or steering system, can be allowed to be included in vehicles running on public roads. This work resulted in Commission Implementing Regulation (EU) 2022/1426,[23] which describes in detail the implementation of regulation (EU) 2019/2144,[24] which deals with type approval for automated driving systems (ADS).

3. Theoretical Framework

The focus of this article is the regulatory problems for regulators created by the opacity and complexity of higher level (mainly 4 and above) automated driving systems and their responses to these issues. These problems are mainly due to the way vehicles have been certified in the past, where the regulators have specified in detail how a technical component of a vehicle should function and how it should be tested and verified. Here, the article will develop a theoretical framework later used in the analysis that makes use of the literature on the opacity of algorithms from Burrell[25] and Dourish,[26] as well as the difficulties of studying algorithms as laid out by Kitchin[27] and Deville,[28] to argue that these issues also present difficulties for regulators of algorithmic systems.

The difficulties facing the traditional type approval when regulating automated vehicles can be compared with the three forms of opacity in algorithms presented by Burrell in the article 'How the Machine "Thinks": Understanding Opacity in Machine Learning Algorithms'.[29] Burrell considers the problems created by opacity of algorithms in socially consequential mechanisms of classification and sorting – in other words, the different ways in which the inner logic and functions of software-based algorithmic systems are difficult to grasp and audit. She compares three different forms of opacity, all relying on various degrees of access to the source code of algorithms. These are: '(1) opacity as intentional corporate or state secrecy, (2) opacity as technical illiteracy, and (3) an opacity that arises from the characteristics of machine-learning algorithms and the scale required

[17] *Directive 2007/46/EU of the European Parliament and of the Council.*
[18] Gnazzo, "Legislative Framework."
[19] Zöldy, "Investigation of Autonomous Vehicles."
[20] van Wees, "Vehicle Safety Regulations."
[21] Ferrari, Future Mobility.
[22] Bin-Nun, "How Should Autonomous Vehicles Drive?"
[23] *Regulation (EU) 2022/1426.*
[24] *Regulation (EU) 2019/2144.*
[25] Burrell, "How the Machine 'Thinks'."
[26] Dourish, "Algorithms and Their Others."
[27] Kitchin, Thinking Critically.
[28] Deville, "Seeing the Invisible Algorithm."
[29] Burrell, "How the Machine 'Thinks'."

to apply them usefully'. The first form of opacity regards code that is intentionally kept away from the auditor for secrecy reasons. The type approval authorities could theoretically get a legal mandate to gain access to the source code of automated driving systems in order to audit them. There would, however, be an inherent tension between auto manufacturers' desire to keep the internal workings of their autonomous driving systems to themselves as intellectual property or quasi-intellectual property rights in order to gain a competitive advantage over others, and legal ideals of transparency in regulation, which would require the public and competitors to understand why some systems have been approved and others not. Algorithmic secrecy thus threatens the transparency ideals upon which regulation depends.[30] Regulators instead inspect systems from the outside, looking at inputs and outputs rather than source code. While a mechanical system is fixed so a given input generates a specific output, a digital system can turn any input into an arbitrary output. This is precisely what made the notorious Volkswagen scandal possible, where emission systems were instructed to behave differently when in a testing lab compared with in the real world.[31]

The second source of opacity stems from technical illiteracy. Modern algorithmic systems are designed by large teams, each working on parts of the code with other parts black-boxed to them,[32] and they rely on chains of third-party libraries and components. Bugs and unexpected behaviour can arise through the unexpected interactions of otherwise functional components, including sensor input. Kitchin characterises algorithms as 'embedded within complex socio-technical assemblages made up of a heterogeneous set of relations', rendering the code and its behaviour potentially opaque even for its designers.[33] As Tennant and Stilgoe point out, so-called autonomous vehicles are reliant on numerous attachments outside of the vehicle system, such as internet connection, GPS and real-time maps.[34] Auditing the source code of automated driving systems built up over years, including making use of third-party libraries, would be too time-consuming for regulators, and there is no guarantee that a full understanding of system functionality can be reached. Transparency of code and models alone will therefore not solve the challenge.[35]

The third form of opacity highlighted by Burrell relates to the special characteristics of machine-learning algorithms. While regular human-coded algorithms can be difficult to inspect, machine-learning algorithms do not rely on a conscious decision to classify and sort, but on outcomes of statistical use of data to train an algorithm to match a pattern. From a large amount of training data – for example, pictures of cyclists – a machine-learning algorithm can learn to classify objects as cyclists or non-cyclists. Its success would depend both on the learning algorithms and on the correct use of input data, making sure there are no biases and limitations in the data sets.[36] Without trying out the behaviour of these algorithms in real-world conditions, it is difficult, if not impossible, to know how they will respond to a particular input data. Current iterations of autonomous driving systems only rely partly on machine-learning algorithms to guide the behaviour of the vehicle, and combine it with physical modelling techniques that respond algorithmically to traffic situations.[37] Machine learning, on the other hand, is fully used to classify objects picked up by the sensors, such as other vehicles, cyclists and pedestrians, and to read the environment of the vehicle. The reliability of those AI-based identifications of road users around the vehicle could become a crucial factor to determine the reliability of the performance of the vehicle. It does not matter how well-crafted the behavioural models of the vehicle are if it has a false world picture of the objects in its surroundings. This is demonstrated by the fatal crash involving a Tesla vehicle with autopilot turned on, which rammed into a truck because the sensors falsely thought the large truck was an overhanging road sign.[38]

This article adds a fourth form of opacity to the three above, which makes auditing autonomous driving systems even more difficult. Burrell's article focuses on algorithms running as programs in a digital space and lacking the connection to interactions with physical space that is characteristic of autonomous driving. The autonomous driving systems must be evaluated not only on their internal operations, but ultimately on how these internal operations correspond to behaviour of the vehicle in a physical space. In autonomous driving, the algorithms are connected to the physical world by relying on the input from its sensor network. Aside from unpredictable machine-learning algorithms, errors in the capturing of raw environmental data by the sensors can create false representations, which the vehicle then tries to act upon. When the autonomous system finally creates outputs meant to steer, accelerate or brake the vehicle in physical space, both false representations and unexpected road conditions can make the behaviour deviate from the intended action. A fourth kind of opacity in algorithms therefore pertains

[30] Hildebrandt, Smart Technologies.
[31] Bovens, "The Ethics of Dieselgate."
[32] Pasquale, The Black Box Society.
[33] Kitchin, Thinking Critically.
[34] Tennant, "The Attachments of "Autonomous" Vehicles."
[35] Koivisto, The Transparency Paradox.
[36] Käll, "Governing Smart Spaces"; Mehrabi, "A Survey on Bias."
[37] Tennant, "The Attachments."
[38] Stilgoe, "Machine Learning."

to a particular kind of algorithmic system that can be called cyber-physical systems.[39] Highlighting this form of opacity echoes the urge of Dourish to not focus on the seduction of algorithms at the expense of other aspects of computer systems, including the non-algorithmic aspects of code and the data structures within which they operate – as exemplified by the uncertainties introduced in this case from the algorithms operating on a representation of physical space.[40]

The fourth form of opacity has a direct consequence for testing due to differences in how human drivers and autonomous systems generalise.[41] While autonomous systems can outperform humans in many scenarios due to superior reaction speed and situational awareness, they can also fail in surprisingly simple edge cases where the environment is misread or no adequate response can be found. AI safety literature identifies one source of such failures as 'distributional shift', where conditions encountered in deployment differ from those in training,[42] as exemplified when autonomous vehicles from Volvo were confused by the movement patterns of kangaroos while testing in Australia since they had not been part of the training data.[43] Testing therefore validates only the specific scenarios tested, but it cannot be assumed that the system would perform equally well under different parameters. It may be difficult to determine where the boundary of such generalization from test scenarios lies. The four dimensions of opacity of algorithmic systems map neatly onto Wynne's distinctions between *risk* (known probabilities), *uncertainty* (known parameters, unknown probabilities), *ignorance* (unknown parameters) and *indeterminacy* (open-ended system behaviour):[44]

- Secrecy and technical illiteracy map onto uncertainty (parameters of the system are known, but are hidden or unintelligible).
- Machine-learning opacity operates at the level of ignorance (how the system will behave is unknown).
- Cyber-physical opacity finally maps onto indeterminacy (the behaviour cannot be known by just studying the system since the potential encounters in open environments are unknown).

From the perspective of this framework, the goal of the type approval process can be said to be to transform all of these opacities to risks, where the probabilities are known and the regulators can either approve the system or suggest changes to the manufacturer if the risks are unacceptable. The opacity of autonomous driving systems, and in particular the form of opacity that arises when algorithmic systems must translate between digital representations and physical space, makes the traditional type approval process unsustainable, and a new regulation must answer to these with a new type approval procedure. In other words, technological novelty shapes regulatory procedures. However, in turn, this also gives the regulation a chance to shape the direction of technological development by the requirement specification and verification procedures proposed by the regulation, since autonomous vehicles need to pass through the type approval process to go to market. Regulation and technology therefore end up co-producing each other.[45]

4. Method

This article investigates how the EU Regulation 2022/1426 responds to the challenges of opacity of autonomous driving systems and whatever new regulatory concepts and testing procedures the regulation introduces to inspect and verify systems. Particular attention will be paid to how the new type approval process shifts what is considered to be the object of risk that needs to be regulated, who is responsible for managing that risk and who is considered to be exposed to risks.[46] These questions are investigated through a theoretically informed document analysis of Regulation 2022/1426 and its related preparatory documents, as described in the following section.

The method used is a theoretically informed document analysis[47] of EU Regulation 2022/1426 and complementary regulations. The opacity framework developed in the preceding section provides the analytical lens through which the regulatory documents are subjected to a detailed reading. The aim is to trace how opacity is recognised, managed or left unresolved by the regulatory framework, and how the type approval process is transformed by it. The regulatory text is treated as a conceptual proposal for

[39] Baheti, "Cyber-Physical Systems."
[40] Dourish, "Algorithms and Their Others."
[41] Marcus, "Deep Learning."
[42] Amodei, "Concrete Problems in AI Safety."
[43] BBC News, "Volvo's Driverless Cars."
[44] Wynne, "Uncertainty and Environmental Learning."
[45] Jasanoff, "Making Order."
[46] On the relation between risk and regulation, see Baldwin, Understanding Regulation.
[47] Bowen, "Document Analysis."

how to represent and solve the issues identified in the theoretical framework, inspired by Bacchi.[48] The EU regulation has been selected as case study due to being the first comprehensive type approval framework allowing for automated driving systems. National implementation of the regulation has not started at the time of writing, meaning the analysis focuses on the regulation document itself and not on future implementations.

EU legal documents, such as the sources in this article, are the result of negotiations and compromises, and do not necessarily encapsulate a complete vision of a unified subject.[49] Regulation on the EU level also deliberately leaves some details unresolved to allow for flexibility in different national legislations. Their status as legal documents still has relevance for this article, due to their legally binding application, which will have consequences for how vehicles with autonomous driving show up in shared public spaces. As a socio-legal analysis, the regulation will be analysed for its social consequences, rather than its legal soundness *per se* – what Banakar terms an 'outsiders' view of the law.[50]

The primary material of analysis is Commission Implementing Regulation (EU) 2022/1426 and its technical annexes.[51] The document itself links to other legal and preparatory documents that it references and amends, and this article also analyses these as they are relevant to understanding the current regulation being proposed. The study follows the hierarchy of the legal documents and relates them to each other in terms of references and amendments. Previous regulations replaced by the current regulation have been consulted in order to understand where the new regulation introduced novel regulatory concepts. Complementary materials are the parent regulation (EU) 2019/2144,[52] the preceding document 2007/46/EC[53] and the UN WP.29 preparatory documents.[54]

The analysis first reviews how the regulation specifies the requirements placed on automated driving systems, then proceeds to how the regulation verifies the compliance of these through various methods and finally how the monitoring of systems continue after the type approval.

5. Analysis

5.1 Specifying Requirements

Operational Design Domain

The regulation deals with several types of vehicles, such as fully automated in a predefined area, hub-to-hub (along a predefined route) and automated valet parking.[55] The first category contains all normal driving on public roads, as long as a predefined area is specified. However, the area can be as big as desired – for example, all public roads in a country. The area with which the type approval is concerned is up to the discretion of the manufacturer. An ODD specifies the type of road and traffic situation, but also weather conditions, time of day and geographical area. The ADS should recognize when it is outside its operational design domain and hand over to manual driving or come to a stop.[56] This includes malicious users who disregard safety – something that occurred with how the Tesla autopilot was used beyond its intended functions by beta testing users.[57] It is notable that, instead of defining a scope for the type approval – for example, categorising different SAE levels of automation – the regulation requires a manufacturer to define an operational design domain (ODD) for which they seek type approval. The ODD mechanism thus delegates a significant element of regulatory framing to the regulated party.

Once the operational design domain has been specified and the manufacturer has shown that it is able to police its borders, the type approval of the ODD can begin. The testing process and the scenarios selected for testing are decided on the basis of the ODD specified and what traffic situations could reasonably occur in that ODD. A more expansive ODD means a more difficult testing procedure to get type approval for an ADS, since the testing should be adequate for the defined domain. Manufacturers are thus incentivized to take a conservative approach when defining their operational design domains so as not to overreach and risk failing the type approval. The ODD as a concept therefore shifts the regulation to specific traffic scenarios and not an

[48] Bacchi, What's the Problem?
[49] Boeger, "How Regulatory Networks."
[50] Banakar, "Integrating Reciprocal Perspectives."
[51] *Regulation (EU) 2022/1426.*
[52] *Regulation (EU) 2019/2144.*
[53] *Directive 2007/46/EU.*
[54] NATM Guidelines; NATM Master Document.
[55] *Regulation (EU) 2022/1426,* Art. 1.
[56] *Regulation (EU) 2022/1426,* Annex II, point 3.
[57] Widen, "Autonomous Vehicle Regulation."

overall SAE level of automation of the vehicle as a whole.[58] For example, a manufacturer could define the ODD in such a way that the vehicle is certified for autonomous driving on highways, but not in urban traffic scenarios.

Dynamic Driving Task

Within this operational design domain, the regulation suggests different dynamic driving tasks that should be possible. Normal driving conditions include adapting behaviour to surrounding traffic and safety risks, anticipating the behaviours of other road users, responding adequately to objects and events, and complying with traffic rules.[59] Later in the regulation, it is specified that the systems should also show "reasonable cooperative and anticipatory behaviour."[60] This would indicate that a system that behaves legally but not according to the expected behaviour would still come across as a safety risk or risk blocking traffic flow – for example, if the system is overly cautious and would have a tendency to freeze up in difficult situations.

Apart from these normal conditions, the system should be able to handle critical driving conditions such as detecting risk of collision.[61] The regulation stresses that, in doing so, no weighing on the basis of personal characteristics of humans, and no subordination of the protection of human life outside the vehicle to the one inside the vehicle, should be allowed. The vulnerability of road users such as cyclists should also be taken into account.[62] These requirements account for points also made in discourses outside the regulatory process, such as in the famous Moral Machine project that raised awareness of the ethical issues with autonomous vehicles taking personal characteristics of different road users into consideration when determining the course of action in critical and dangerous situations.[63]

Specified Traffic Scenarios

The type approval authority selects traffic scenarios appropriate for the ODD to be tested in-use, by simulation or on test track.[64] In some instances, the adequate responses to the scenarios are detailed in the regulation down to the precise formula to use to determine time to collision when merging traffic lanes.[65] Human drivers do not have to learn and comply with this level of driving precisions, meaning vehicle regulation for autonomous driving reaches comparatively further into the precise regulation of traffic situations. Still, they are presented as individual scenarios, while real traffic situations can consist of a combination of several of these scenarios, and possibly others. As an example, precise calculations are specified for turning manoeuvres crossing the opposite traffic direction, as well as for avoiding collisions with cyclists,[66] but no mention of how a situation involving both potential safety risks should be handled. Specifying detailed requirements must also assume that the programming of the ADS allows for this kind of precise inputs of responses to individual traffic situations – in other words, that the legal regulation and the technology developed are using the same heuristics, or at least heuristics of the same scale and scope.[67] This could, for example, clash with technical methods based on machine learning, where the responses of the ADS system in certain situations cannot be derived from precise predetermined calculations. Rather than resembling real-world traffic scenarios, these specifications instead look like models that can easily be tested in simulations.

The scenario approach is precisely a way to avoid having to specify, in documentation, every type of response that the vehicle is programmed to do – for example, emergency braking when it detects a crossing pedestrian.[68] The scenario approach is therefore itself an opaque form of testing, where what is being tested is that the ADS completed the scenario without safety incidents but not how or why it completed it or how changing some parameters of the scenario would have changed the response. The result is a stochastic approach that covers some reasonably expected testing scenarios, but it is not possible to determine with this method what automated responses lie right outside the tested scenario and where the limits to the safe behaviour are located. One way to continue monitoring performance over time is the 'after-market surveillance' that will be described below and that transforms the type approval from certifying at a fixed point to a continuous monitoring of real-world behaviours.

[58] Stayton, "It's Time to Rethink Levels."
[59] *Regulation (EU) 2022/1426,* Annex II, point 1.
[60] *Regulation (EU) 2022/1426,* Appendix 4, part 3, point 1.
[61] *Regulation (EU) 2022/1426,* Annex II, point 2.
[62] *Regulation (EU) 2022/1426,* Annex II, point 2.
[63] Awad, "The Moral Machine Experiment."
[64] *Regulation (EU) 2022/1426,* Annex III, part 1, point 1.
[65] *Regulation (EU) 2022/1426,* Annex III, part 1, point 1.3.2.
[66] *Regulation (EU) 2022/1426,* Annex III, part 1, point 1.3.3.
[67] Sütfeld, "Automated Vehicle Regulation."
[68] Ciuffo, Interpretation of EU Regulation 2022/1426.

5.2 Verifying Compliance

Requirements

To verify these requirements, different test sites can be chosen that correspond to the requirements for the specific ODD under review. Physical tests will be performed on real roads or in test tracks, where it is possible to reproduce the ODD conditions.[69] Environmental conditions, for example weather conditions should also be tested, and when possible, tests should occur at the limit conditions of the defined ODD.[70]

Documentation

Apart from the tests, the manufacturer is required to provide documentation outlining their tested performance and software architecture, showing that their system is mature enough to handle the specified operational design domain and should document 'that the automated driving system is free of unreasonable safety risk' – for example, using existing traffic incidents data to show that their system is not adding additional risk in their operational design domain.[71] The comparison is made to a baseline of the current accident level in ODD resulting from human drivers, even though research shows that the public has less tolerance for accidents caused by automated vehicles.[72]

Manufacturers also need to make sure that suppliers of components and systems comply with the requirements.[73] As mentioned previously, an autonomous system is assembled from physical and software components that are developed by subcontractors and third parties. Manufacturers then have to describe how they will ensure monitoring and updating of the system throughout its lifetime – for example, regarding wear and tear of components or new traffic scenarios that may emerge.[74] This again shows that the type approval is no longer a one-time affair, but rather a continuous responsibility throughout the life-cycle of the ADS equipped vehicles.

Test Tracks

Certain functions of the specified ADS are chosen by the type approval agency to be tested on a test track to ensure compliance, including responses to various objects and domains, as well as malfunctioning of connectivity or on-board systems .[75] Many ODDs will put additional requirements for test tracks to be able to realistically reproduce complex traffic situations for the ADS to react to, especially the distractions that can come from the presence of numerous simultaneous road users in realistic traffic scenarios. Traffic agents can be introduced on a test track through dummy devices or direct sensor stimulation, making the ADS think objects are present.[76] If test tracks capable of reproducing these conditions realistically are unavailable, on-road testing and simulation would be left to test with.

Simulation

For scenarios that are difficult to assess on a test track or in real driving conditions, simulation can be used. Manufacturers need to demonstrate that the simulation tool provides an accurate and realistic representation of traffic scenarios and vehicle responses.[77]

Virtual testing was present already in the previous regulation,[78] but then in the form of calculation for how components would be able to handle certain environmental conditions and pressures. The novelty in the new regulation is that simulations can be used to model traffic situations.

[69] *Regulation (EU) 2022/1426*, Appendix 4, part 3, point 2.
[70] *Regulation (EU) 2022/1426*, Appendix 4, part 3, point 3.
[71] *Regulation (EU) 2022/1426*, recital 5.
[72] Othman, "Public Acceptance."
[73] *Regulation (EU) 2022/1426*, Annex I.
[74] *Regulation (EU) 2022/1426*, Annex II, point 7.2.
[75] *Regulation (EU) 2022/1426*, Appendix 1, Part 2, point 4.1.1.
[76] *Regulation (EU) 2022/1426*, Appendix 1, Part 4, point 2.12.
[77] *Regulation (EU) 2022/1426*, Annex III, Appendix 1, point 4.2.
[78] *Directive 2007/46/EU of the European Parliament and of the Council.*

On-Road Testing

As a final method of testing, the regulation suggests the use of real-world testing on public roads, sometimes conducted with a lead vehicle[79] and recommended to replicate various road and sign conditions, as well as traffic situations.[80] According to the regulation, these should be varied out 'safely and without any risk to other road users'.[81]

Complementary documents from the working group WP.29 further elaborate on the motivation and risks of real-world tests. The real world is used for its stochastic scenario-generating properties and ability to uncover 'unknown unknowns' – situations that testing authorities were not aware that they had not tested for.[82] However, simply logging incident-free hours on public roads is no guarantee that the system has explored its entire capability space.[83] Research from Kalra and Paddock suggests that hundreds of millions of hours would be needed to guarantee safe operation, defined as over 95 per cent confidence that failure rates are below those of human drivers.[84] On the other hand, if incidents do occur on public roads that were determined to have been the result of the system, they indicate that the system cannot respond properly to that class of scenarios. In other words, failing the test scenarios would indicate a system that is not up to par, but passing the testing scenarios is not a guarantee that the system itself is safe. This is relevant since the regulation defines both functional and operational safety as the 'absence of unreasonable risk', which in turn is defined as when the risk is increased compared with manually driven vehicles.[85] The regulators therefore recommend selecting for specific conditions where particular scenarios are likely to occur,[86] and using real-world testing to validate simulations and vice versa.[87]

While on-road testing is introduced in only a short section in 2022/1426, it represents a significant shift in the type approval process. Traditionally, type approval has consisted of a set of procedures through which vehicle systems go to before they are deployed on public roads, but here public roads become part of the type approval testing infrastructure. As a direct consequence of the opacities described in the theoretical framework, the regulation recognizes that behaviour of automated driving systems and their responses to particular traffic situations cannot be exhausted by documentation, simulation and test tracks, but needs to be exposed to the complexity of real-world scenarios on public roads. As a consequence, the public and other road users are involuntarily drawn into the type approval process to test systems that, by definition, are not yet completely evaluated and approved as safe. The public become test subjects in the type approval process without any meaningful way of consenting and subject to risk – this particularly impacts vulnerable road users such as pedestrians and cyclists, who are at the same time prioritised road users that the systems need to take into special consideration. Testing can be made safer by the use of lead vehicles or testing in less populated traffic situations, but this would come at the expense of realism, especially if the ODD is specified to be able to handle more difficult scenarios. The line between the testing phase pre-type approval and the deployment phase post-type approval thus becomes blurred and systems are tested on public roads after presumably having been deemed safe enough after the first three modes did not discover significant flaws. This blurring is further extended with the addition of mandatory post-approval reporting, so-called after-market surveillance detailed in the next section.

5.3 *Market Surveillance and Continuous Testing*

Another significant addition to the recent regulation is the introduction of market surveillance, where type approval authorities are responsible for monitoring the performance of automated driving systems after their market introduction in order to keep track of critical incidents and how they respond to traffic situations that were not evaluated during the testing phase.[88] The significance is even greater since software updates can alter vehicle responses after certification. The introduction of market surveillance transforms the type approval from a certification of a fixed type to a continual monitoring of a dynamic and evolving system.

Market surveillance was first introduced in regulation 2018/858[89] as a response to the Volkswagen 'Diesel Gate' scandal because it was understood that the lab situation could be manipulated, and manufacturers could prepare systems to pass specific

[79] *Regulation (EU) 2022/1426*, Appendix 4, part 3, point 8.3.2.
[80] *Regulation (EU) 2022/1426*, Appendix 4, part 3, point 8.4.1.
[81] *Regulation (EU) 2022/1426,* Appendix 4, part 3, point 2.
[82] NATM Guidelines, para. 48; NATM Master Document, para. 6.13.
[83] NATM Master Document, para. 15.
[84] Kalra, "Driving to Safety."
[85] *Regulation (EU) 2022/1426*, Article 2, point 28–30.
[86] NATM Master Document, para 8.3.
[87] NATM Guidelines, paras 55, 56.
[88] *Regulation (EU) 2022/1426*, Appendix 2, part 5.
[89] *Regulation (EU) 2018/858*.

tests.[90] This led to requirements for additional monitoring of non-compliance outside of the testing situation. For automated driving, the difficulties with creating certainty through testing procedures rather have to do with the diversity of scenarios that the system can encounter, and market surveillance is a way to keep track of the performance of the system in situations that have not been predicted at the type approval phase. The market surveillance in the regulation suggests a separation between non-critical and critical occurrences. The latter – defined as involving injuries, vehicle damage or potential harm to stationary objects – require immediate reporting to type approval authorities, market surveillance authorities and the European Commission.[91] Manufacturers must also report any non-critical incidents or inconsistencies and how they have been addressed by further development of the system or limiting of its scope.[92]

Market surveillance thus handles two kinds of contingencies that can occur with autonomous driving systems. One is monitoring behaviour in novel traffic situations that were not tested during the type approval process. The other is the autonomous driving system receiving continuous software updates that can introduce unexpected behaviour. With the postponing of additional testing in unknown scenarios to the post-market introduction, the approval process turns into a question of evaluating acceptable risk at market introduction rather than establishing certainty during a type approval process. This risk management extends the test lab into a post-market phase where the system undergoes additional evolution and adjustment in response to the environments and situations it encounters. This reflects a simultaneous transformation of both vehicle technologies and vehicle regulation towards a continuous shaping of responses rather than a fixation according to a fixed requirement.

6. Discussion

The analysis has shown that in responding to the opacity of autonomous driving systems, the type approval process as expressed in 2022/1426 has gone through major transformations compared with its predecessor.

When specifying the requirements for the systems submitted for review, the regulation shifts the object of risk and therefore the object being regulated from the system itself to its behaviour in potential interactions in open traffic environments, as defined for its Operational Design Domain (ODD). What counts as risk to be regulated is thus decided by the manufacturer proposing an ODD for which the system will be evaluated. It is up to the confidence of the manufacturers to propose more or less extensive operational domains, depending on what kind of scrutiny they think they can handle.

The ODD is a recognition that different levels of autonomous driving, from L-0 to L-5, cannot be applied to particular vehicles or vehicle systems as a whole. Instead, systems can change level several times during use, depending on the traffic conditions as well as weather conditions and user modes. Since regulation specifies requirements through traffic scenarios and dynamic driving tasks rather than certifying individual systems, regulators must decide on detailed normative behavioural specifications of proper driving conduct previously left to human judgement. This brings a world of complexity into the type approval process, and the regulation specifies some of these in detail; however, others seem to be left to the manufacturer to decide.

The opacities of automated driving systems, especially their unpredictable interactions in equally unpredictable open environments, create an enormous space of possibility for potential situations where they must showcase desirable behaviour. Verifying that the system meets the requirements is therefore not done with the goal of rendering the system under review transparent, but with various methods trying to exhaust the testing of this possibility space as much as possible. On the one hand, this involves probing the reliability of the internal system and see how it responds given different scenarios in simulations and test tracks. On the other hand, it also requires probing the possibility space of real-world scenarios that the system could potentially encounter in operation through on-road testing. A type approval process would then be considered complete when an adequate (but at the same time arbitrary) subset of this possibility space has been examined, with a special focus on selected critical and common scenarios.

The so-called ‘real world’ is used as an extended lab during the test phase when on-road testing is selected for more complex and unpredictable combinations of traffic scenarios. This extends to continuous testing after market introduction, where manufacturers must continuously report errors, incidents and software updates that can jeopardise the type approval. The introduction of after-market surveillance is a recognition that the exploration of the possibility space is never complete, and autonomous driving systems are in a perpetual testing phase. The regulation therefore recognises that the type approval process does not contain the risks involved in the technology, and its management extends into untested territory after market

[90] Bovens, “The Ethics of Dieselgate.”
[91] *Regulation (EU) 2022/1426*, Appendix 4, Part 5, point 1.3.
[92] *Regulation (EU) 2022/1426*, Appendix 1.

introduction, with those in the industry themselves becoming active participants and regulators. This is consistent with Julia Black's observation that regulation is becoming decentred from the state and should be understood as distributed across actors and beyond formal processes.[93]

Extending the regulatory process beyond the confines of the type approval system and its infrastructures, and out into public roads, enlists road users – especially vulnerable road users (as defined by the regulation itself) – as involuntary and unknowing participants who are unable to give any informed consent. At the same time, those vulnerable road users, such as cyclists and pedestrians, are perhaps those with the least stake in the market introduction of autonomous vehicles. To them, the testing to which they are exposed is invisible, which arguably adds a regulatory opacity on top of the four technical opacities. The on-road tests thus lack all three dimensions of the accountability process as defined by Brandsma and Schillemans:[94]

- *Information:* Road users are not informed that they are being tested.
- *Discussion:* Road users are engaged in the test as passive reactive objects, not active subjects.
- *Consequences:* Road users have no say over the results of the test and how it should affect the approval.

Downplaying of the agency of other road users in favour of the automobile – automated or not – is certainly not new. In the end, autonomous vehicles are regular personal cars that use the same public roads and are subject to the same issue of automobility that has been highlighted by decades of research addressing both social and environmental issues.[95] The transformation of the type approval process to enable the introduction of autonomous vehicles occurs against a backdrop where substantial public investment in autonomous vehicle infrastructure potentially diverts resources from other modes of transport, such as cycling or public transport, making the question of who bears the risk of ongoing testing politically significant.[96]

The difficulties with evaluating the risks associated with autonomous driving within the type approval process show that the Collingridge dilemma is once again haunting the regulation of technology.[97] The introduction of after-market surveillance is a recognition that no amount of testing or laboratory processes would be able to solve the dilemma and ensure a risk-free introduction of technologies such as automated driving, whose social impact will emerge as their interactions in open-ended environments are scaled up and new situations are encountered. As a result, the regulation brings together manufacturers and regulators into a co-production process[98] that not only shapes the development and testing of new technologies, but remains tightly coupled throughout the whole life-cycle of the technical system through the after-market monitoring, involving a constant adjustment and reshaping by regulators, manufacturers and citizens alike. The opacity of the technical systems and their behaviour have forced this adjustment, and it remains important to ensure its democratic accountability and participation.

The use of real-world testing is becoming a common practice for dealing with the introduction of complex and potentially risky technical systems, and should warrant further analysis. For example, the EU AI Act contains concepts such as regulatory sandboxes (Art. 57), testing in real-world conditions (Art. 60) and after-market monitoring (Art. 72).[99] This is part of an increasing trend to use real-world spaces and often unknowing subjects in exploring how technologies can align with environments involving complex social and physical interactions.[100] Examples include urban labs in technology development [101] and experimental sandboxes in the regulatory field.[102] As shown in this article, this can lead to blurred lines between testing and certification on the one hand and real-world deployment on the other – spaces that were both physically and regulatorily separated in the old type approval process. The move towards real-world testing is based on sound intuitions. Only performance in real-world situations and real reactions for people encountering the systems can give an indication of how a future scaled-up introduction might look, and discovering defects and potential harms early is important. As this method becomes more common in different regulatory scenarios, a broader debate on the design of such testing, its relationship with the public and the kind of knowledge that can or cannot be produced is needed.

[93] Black, Critical Reflections on Regulation.
[94] Brandsma, "The Accountability Cube."
[95] Merriman, "Automobility."
[96] Stilgoe, "The Politics of Autonomous Vehicles."
[97] Collingridge, The Social Control of Technology.
[98] Jasanoff, "Making Order."
[99] *Regulation (EU) 2024/1689.*
[100] Yeung, "From 'Wild West'."
[101] Eriksson, "Laboratory Urbanism."
[102] Ranchordas, "Experimental Regulations for AI."

7. Conclusion

This article has examined how European regulators have responded to the regulatory challenges posed by autonomous driving systems whose behaviour cannot be fully known, inspected or predicted in advance, and that is set to interact in unpredictable traffic environments on public roads. Theoretically, the article has extended Burrell's framework of algorithmic opacity to include a fourth form of opacity specific to systems such as autonomous driving, which translate between digital representations and actions in the physical world. This extended framework has motivated the study of how EU Regulation 2022/1426 responds to these challenges of opacity in the context of the type approval process for autonomous driving.

As a response to this challenge, the regulation performs two main moves that introduce novel concepts compared with the old type approval system. It first changes from inspecting components and their mechanisms to observing the behaviour of the complete autonomous driving system in dynamic traffic situations, specified according to the operational design domain designated by the system under review. It then introduces several modes of verification for these requirements, the most significant of which are on-road testing on public roads outside testing facilities and after-market surveillance that continue monitoring, reporting and evaluation after the type approval has been granted. Taken together, these create a new paradigm where uncertainty is never resolved and safety is never guaranteed, but set up for continuous modulation and adaptation on a sliding scale from unproven systems to acceptable risks for road users.

This article has investigated a single regulatory development in a single jurisdiction, and the findings should be compared with similar developments in other jurisdictions as well as regulations of similar technical systems in other domains. In addition, the future implementation of Regulation 2022/1426 in national legislation needs to be studied.

The normative implications of these findings involve the subjecting of public road users – especially vulnerable road users – to risks associated with interactions with untested systems as they are enrolled as test subjects providing data of system performance in realistic conditions. Ironically, this is for the purpose of evaluating the safety of the autonomous driving system for the very same vulnerable road users.

In addition, it raises questions about legal certainty of regulation processes that dissolve clear lines between the pre- and post-approval stages. This phenomenon, where the test laboratory is extended into public space and the boundary between testing and deployment of systems becomes blurred, is part of a larger trend of testing and evaluating systems in the wild that seeks to balance early testing and evaluation of the alignment of technical systems in social and physical environments with achieving realistic testing conditions of a kind that inevitably introduces the risk of real harmful consequences. The ethical and political stakes of such extended test laboratories should be the subject of further socio-legal scholarship on the governance of autonomous systems.

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