

# Smart automotive technology adherence to the law: (de)constructing road rules for autonomous system development, verification and safety

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## ABSTRACT

Driving is an intuitive task that requires skill, constant alertness and vigilance for unexpected events. The driving task also requires long concentration spans, focusing on the entire task for prolonged periods, and sophisticated negotiation skills with other road users including wild animals. Modern motor vehicles include an array of smart assistive and autonomous driving systems capable of subsuming some, most, or in limited cases, all of the driving task. Building these smart automotive systems requires software developers with highly technical software engineering skills, and now a lawyer's in-depth knowledge of traffic legislation as well. This article presents an approach for deconstructing the complicated legalese of traffic law and representing its requirements and flow. Our approach (de)constructs road rules in legal terminology and specifies them in 'structured English logic' that is expressed as 'Boolean logic' for automation and 'Lawmaps' for visualization. We demonstrate an example using these tools leading to the construction and validation of a 'Bayesian Network model'. We strongly believe these tools to be approachable by programmers and the general public, useful in development of Artificial Intelligence to underpin motor vehicle smart systems, and in validation to ensure these systems are considerate of the law when making decisions.

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## INTRODUCTION

When powered vehicles first hit the roads at the beginning of the 20th century, they brought in their wake major changes to the law. Road traffic law emerged as a legal field in its own right. With complex rules that made it difficult for citizens to conduct their business in a lawful manner potentially turning everyone (or at least everyone driving) into a criminal, and as a result, assigning significant discretionary power to our police. Policing also changed dramatically, requiring new laws, new organizational structures and new procedures. To give an example, the only police force in the UK that is permitted to enforce the law across all of England and Scotland, is the British Transport Police. The legal ramifications were felt in all parts of society, and by all people: whether drivers or not. Some jurisdictions introduced new offences such as jaywalking that resolved conflicts about control of public spaces: non-drivers had to give up historical rights to allow an inherently dangerous technology to be deployed safely.

Today a wide array of legislation, regulation and standards ascribe complex legal responsibilities on manufacturers, importers and distributors, owners, and vehicle users. Rules impact elements of the design, materials and manufacturing process. They set minimum standards for safety and protection of occupants and other road users in actual and potential accident situations. Soon, two complementary sets of rules evolved, one set is directed at the manufacturer of cars, the other at their drivers. In [Figure 1](#), these are represented by the bottom three categories. The other set of rules is directed at the driver and can take the form of laws such as the Road Traffic Act, but also intersect with rules not specific to the domain such as criminal and civil liability laws. This separation of responsibilities benefits both, drivers and manufacturers. Take the example of ‘brakes’. Their design and manufacturing is covered by a detailed set of rules including the succinctly named: ‘Commission Directive 85/647/EEC of 23 December 1985 adapting to technical progress Council Directive 71/320/EEC on the approximation of the laws of the Member States relating to the braking devices of certain categories of motor vehicles and their trailers’.<sup>1</sup> It is the shared duty of the designer, the supplier who manufactures the brakes, and the vehicle manufacturer who integrates them into the car to know and adhere to these rules. But this is also where their responsibility stops. They need not ensure that the driver actually uses the brakes when, and only when, it is appropriate. Drivers are in turn subject to road traffic law that requires they drive with ‘due care and attention’. This includes a duty to brake when necessary in order to prevent a collision, and not to brake unnecessarily when it may result in one (so not randomly when driving at speed on the motorway for instance). The driver’s task is to make correct and appropriate decisions regarding when to brake, without a requirement to understand the minute details of how their brakes work or whether they can rely on them.

1 <<https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A31985L0647>>. Last accessed: February 8, 2022

United Kingdom		Australia	
Other Related	Motor Vehicle	Motor Vehicle	Other Related
<div>European Convention on Human Rights (ECHR) General Data Protection Regulation (GDPR) EU Privacy Regulation (EU 679)</div> <div>Criminal Law Act 1967 Data Protection Act 2018 Intellectual Property Act 2014 Contract (Applicable Law) Act 1990</div> <div>Privacy and Electronic Communications Regulations</div> <div>Employment: Statutory CoP (Equality Act 2010)</div> <div>Guide to the General Data Protection Regulation (GDPR)</div> <div>ISO/IEC 30011:2017 Introduction, Development of User Interface Accessibility</div> <div>AS/NZS 6094:2017 Software Component Testing</div>	<div>Vienna Convention on Road Traffic (1968)</div> <div>Road Traffic (Driver Licensing and Information Systems) Act 1989 Road Traffic Act 1991 Consumer Rights Act 2015 Sale of Goods Act 1979</div> <div>Motor Vehicle Driving (Licensing) Regulations 1999 The Highway Code (revised 2019) The Highway Code (Miscellaneous Amendments) Regulation 2015</div> <div>Vehicle Safety Defects and Recall CoP Code of Good Conduct for Heavy Vehicle and Private-hire Drivers A Pathway to Driverless Cars: A CoP for Testing</div> <div>HBS in Motor Vehicle Repair and Assoc. Industries (HSCB1)</div> <div>Vehicle Safety Standards (VSS) IEC 61880: Electric Vehicle Wireless Power Transfer Systems</div> <div>Motor Industry CoP for Vehicle Sales Motor Industry CoP for New Cars</div>	<div>International Convention on the Harmonised Commodity Description and Coding System</div> <div>Road Transport Legislation - Driver Licensing 2006 Road Transport Legislation - Motor Vehicle Insurance 2010 Motor Vehicles (Third Party Insurance) Act 1942</div> <div>Australian Road Rules Australian Vehicle Standards Rules</div> <div>The Australian Automotive Code of Practice 2008 National CoP for Light Vehicle Construction and Modification Roadworthy in-use Light Vehicle Maintenance Standard (N. 2019)</div> <div>Guidance Note: Safe movement of vehicles at workplaces</div> <div>Australian Design Rule ISO 21566:2018 Road Vehicles - Ergonomic Aspects of Transport Information and Control Systems</div> <div>Guiding Principles for Privacy and Cooperative Intelligent Transport (C-ITS) Systems Intrusion Guide to the Australian Consumer Law Voluntary CoP for Motor Vehicle Advertising</div>	<div>Trade Related Aspects of Intellectual Property Rights 1995 (TRIPS)</div> <div>Criminal Code Act 1995 Copyright Act 1968 Copyright Act 1995 Evidence Act 1995</div> <div>Insurance Contracts Regulations 1985 Heavy Regulated Vehicle (HRV) Regulations (Commercial Passenger Vehicle Transport Services)</div> <div>Employment Services CoP (Just Govt) Disability Employment Services CoP</div> <div>Australian Privacy in Charged Work Environments Privacy Impact Assessments Guide (OAG)</div> <div>ISO/IEC 24786:2018 Information User Interfaces - Accessible User Interface for Accessibility Settings</div> <div>Software Reviews and Audits (AS 4029:1992)</div>

Figure 1: Motor vehicle laws, regulations and standards.

We note already here what we call the ‘semantic normative gap’: while the aim of technical regulations is ultimately to enable drivers to drive lawfully—as defined by the laws directed to drivers—they do not make this connection explicit. For the norm addressee, this has several benefits. It allows them to make design decisions without necessarily having to worry about ‘the big picture’. It simplifies the rules into easily actionable instructions that do not need interpretation. It also means that translating them into formal representations that can be understood by a computer is relatively straightforward, certainly far more easily than any other field of law, and they embody the formalist ideal of law as a system of clear and unambiguous rules that are self-applying. In contrast, laws directed at drivers typically use vague terms that are considerably more flexible than the technical guidelines and standards imposed on manufacturers, such as ‘reasonable care and attention’, and are therefore able to respond to unforeseen circumstances and involve balancing between often competing values. Their correct application requires considerable contextual knowledge not just about the physical but also the social world. As a consequence, they are much more difficult to capture formally.

As more and more parts of the car became ‘smart’ and driven by software, the paradigm of ‘compliance by architecture’ or ‘software code as law’ becomes more and more feasible, and reaches its pinnacle in semi- or fully automated cars. The idea of software code as a form of regulation became popular in the wake of Lessig’s ‘pathetic dot’ and the idea of ‘law as code’ in the late 1990s. While Lessig does not require the software code be isomorphic to legal rules to be considered ‘coded law’, the idea was quickly picked up by the law and artificial intelligence (AI) community that developed

4 L Vinsel, 'The smart road not taken [Tech History]' (2016) 53 IEEE Spectrum 46–51.

explicit formal representations of applicable law to ensure for instance that electronic agents behave in accordance with contract law. Wendell Wallach and Colin Allen 'Moral Machines: Teaching Robots Right from Wrong' from 2009 was another milestone. Compliance software did indeed become one of the commercial success stories of legal AI.

Some more recent papers have already applied this idea to autonomous cars, most notably Henry Prakken's formalization of the Dutch Traffic Code.<sup>5</sup> or Giovanni Sator's proposal of an 'ethics knob' for cars that would allow them to resolve ethical decisions in alignment with their user's preferences.<sup>6</sup>

While of great academic interest, these attempts to deploy legal reasoning on the side of the car while it navigates through traffic faces significant obstacles. Some of them are of a purely technical nature—the type of languages best suited to formally express legal rules are not the ones used to power smart cars, and the computational costs to reach split second decisions would be prohibitively high. Other more fundamental issues relate to the characteristics of legal language and the semantic–normative gap we identified above: Those rules most amenable to formalization are insufficient to ensure 'top level compliance' with rules directed to human drivers, while laws directed at human drivers use features tailored at human readers, including the use of vague terms, that make them difficult to formalize and also in many cases irrelevant for an automated driver.

In contrast, one of the most ambitious and interesting projects in the attempt to use legal AI to build law-compliant internet of things (IoT) devices is the 'SmarterPrivacy' project at the Karlsruhe Institute of Technology (KIT).<sup>7</sup> In their approach to build a 'law compliant' smart grid energy infrastructure, the legal AI does not reside on the side of the IoT (in our case, not in the smart car) but in the design environment of the engineers that build them.

We can think of them as a more intelligent form of Clippy<sup>8</sup> that assists the designer with legal advice. Imagine a grid developer decides where in the smart energy grid to put an AI that looks for fraudulent patterns, and for this needs data from three sources. At that point the legal AI that observes the design proposals that are made pops up and says: It looks like you are routing personal identifiable data about credit worthiness to the electricity supplier. Under Article 6.5 GDPR, this requires consent, and currently the consent forms given to the electricity supplier do not contain information about credit rating agencies, so your current solution is not compliant. To be able to perform this function, the legal design AI has an explicit formal representation of the applicable rules of the General Data Protection Regulation (GDPR), together with an ontology that enables it to subsume design decisions that talk about specific objects such as credit cards or electricity under the legal rules.

5 H Prakken, 'On the Problem of making Autonomous Vehicles Conform to Traffic Law' (2017) 25 'Artificial Intelligence Law' 341–63.

6 G. Contissa, F. Lagioia and G. Sartor 'The Ethical Knob: Ethically-Customisable Automated Vehicles and the Law' (2017) 25 Artificial Intelligence and Law 365–78.

7 <<https://kawa.nazemi.net/en/projects/smarter-privacy/>>. Last accessed: February 8, 2022

8 Clippy was the default paperclip-shaped animated character in English language versions of the *Microsoft Office Assistant* that came bundled with versions of the Microsoft Office productivity application set from 1997 to 2003.

Our article follows this general philosophy. It differs however in some crucial aspects from SmarterPrivacy. In SmarterPrivacy, all the design decisions are taken centrally, and the designer has full access to, and knowledge of, the model of the grid that is constructed. All design decisions furthermore are in binary form: data either 'is or is not' personally identifiable, and it either 'is or is not' accessible. In contrast, designers and manufacturers in the highly complex car supply chain often work under uncertainty. There are at least three possible sources for uncertainty in this context, and each will have to be discussed in this article.

The first type of uncertainty can be caused by the very nature of AI as a probabilistic tool: the smart sensors of the car will learn and improve over time, and in ways that are not fully transparent even to the vehicle's developers. Secondly, the uncertainty can be caused by the interdependence of design choices across the chain. Design decisions taken locally for a specific module or sensor a supplier is responsible for can be, based on that supplier's knowledge of the use case for the component, perfectly safe and reasonable. Yet, that module can create danger when it interacts with another 'equally safe and reasonable' component. We accommodate these two types of uncertainty through the choice of formalism used in this article, which differs from the one proposed by SmarterPrivacy. On the one hand, while we start like them with a simple formalization of laws as binary rules, we show how our system can be translated into a Bayesian network that allows reasoning with uncertainty. Secondly, we combine the formal representation of laws as propositions with a visualization technique, Lawmaps. Lawmaps are a highly intuitive tool that is particularly suited for collaborative tasks. In this way, we hope to assist engineers making design decisions for their component of the autonomous vehicle. Aiding them to make explicit how their efforts may contribute to the ultimate aim of a 'law complaint car', while creating sharable digital objects that then can be augmented by groups working on adjacent tasks. Additionally, we consider these Lawmaps also as a first answer to the semantic–normative gap we mentioned above: they enable designers to see how compliance with low level standards and regulations ultimately enabled the compliance with the top level laws currently directed at human drivers. Thirdly, uncertainty can come from the law itself. As noted above, laws directed at human drivers contain significant vagueness and open texture to accommodate unpredictable future scenarios. It is not straightforward to anticipate how the law will have to change once the driver as crystallization point of obligations is replaced by an AI. The aim is, as the UK government expressed, to have a car that 'abides by the relevant law', but due to the semantic–normative gap, it is not straightforward how compliance with laws from the set currently directed at human drivers can be subsumed by the set that have prescribed the design decisions. For some laws, the answer is simple: human drivers are currently prohibited from speeding. For self-driving cars, this means their AIs must also be able to ensure the car remains within posted speed limits. But how should we think about rules like Highway Code Rule 161 that prescribes that 'all mirrors should be used effectively throughout your journey'? Mirrors are a design choice based on human requirements, and the fact that our two eyes have only a limited field of vision. For the autonomous car this rule may not be necessary as their sensors can look directly behind the vehicle or into those areas that often constitute a blind spot for us. Is it therefore still necessary to attach mirrors to the autonomous car? Finally, we will see rules where the legislator will have a choice. We will









‘Centre for Connected & Autonomous Vehicles Call for Evidence on Safe Use of Automated Lane Keeping System’ (ALKS).<sup>22</sup> The primary monitoring test described at section 5.1.2 calls for compliance with all road rules relevant to the dynamic driving task being performed by the active autonomous system. For example, this would mean a vehicle with ALKS and LCA should not cross double centre lines where the line closest to the vehicle is solid.<sup>23</sup>

### Advanced driver assistance systems

The most significant advances for enabling autonomous vehicles have been the ‘advanced driver assistance systems’ (ADAS). ADAS are technologies that improve or automate a function of the driving process previously performed by the human driver. The taxonomy used to classify and describe ADAS is that of the ‘Society for Automotive Engineers’ (SAE) Automated Driving Levels (SAE-ADL) [28, 29]. The six-level SAE-ADL taxonomy shown in Figure 2 describe ADAS driving automation based on the technology’s ability to subsume and automate the driving task. Levels 0–3 are differentiated by who controls two factors: (i) vehicle motion; and (ii) the object event detection and response (OEDR) activities—which the SAE-ADL refer to collectively as the ‘dynamic driving task’ (DDT). Levels 4 and 5 are differentiated based on whether the automation feature is capable of automation unrestricted by conditions imposed on or arising out of ‘geographic, road, environment, traffic, speed’ or other limitations—which the SAE-ADL refer to as the ‘operational design domain’ (ODD). Level 4 allows for automation constrained by one or more of these limitations at which point the driver must, or has the option to, take control of the vehicle. Level 5 allows for complete autonomous system independence. Table 1 provides a list of common ADAS and describes their function and classification based on SAE-ADL.

### (DE)CONSTRUCTING SIMPLE REPRESENTATIONS OF LAWS

Use of ‘Boolean Algebra’ (Boole, 1847) for expressing the final structure of law or legal rules after thorough analysis, including rules of precedence, is not new.<sup>24</sup> More recently this approach has been applied in ‘Temporal’ and ‘Boolean Logic’ to model traffic law and road rules.<sup>25</sup> Its application in this work is intended to provide the

22 <[https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment\\_data/file/980644/Safe-Use-of-Automated-Lane-Keeping-System-ALKS-Call-for-Evidence-FINAL-accessible.pdf](https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/980644/Safe-Use-of-Automated-Lane-Keeping-System-ALKS-Call-for-Evidence-FINAL-accessible.pdf)>. Last accessed: February 8, 2022

23 The Highway Code, Rule 129—which results by operation of *The Road Traffic Act 1988* s 36 and *The Traffic Signs Regulations and General Directions 2002* ss 10 and 26.

24 F Kort, ‘Simultaneous Equations and Boolean Algebra in the Analysis of Judicial Decisions’ (1963) 28 *Law and Contemporary Problems* 143–63; and, L Allen and M Caldwell, ‘Modern Logic and Judicial Decision Making: A Sketch of One View’ (1963) 28 *Law and Contemporary Problems* 213–70.

25 H Prakken, ‘On the Problem of Making Autonomous Vehicles Conform to Traffic Law’ (2017) 25 *Artificial Intelligence and Law* 341–63; and, G Alves, L Dennis and M Fisher, ‘Formalisation and Implementation of Road Junction Rules on Autonomous Vehicle Modelling as an Agent’ (2020) 12232 *Springer Nature* <[https://doi.org/10.1007/978-3-030-54994-7\\_16](https://doi.org/10.1007/978-3-030-54994-7_16)>. Last accessed: February 8, 2022

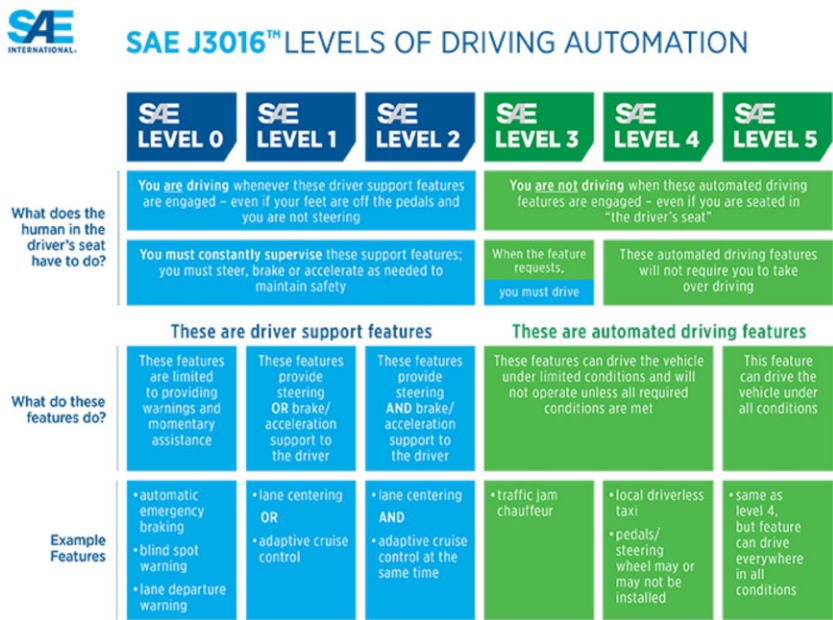


Figure 2: SAE six levels of driving automation.

basis for aiding AI developers and decision scientists in their efforts to develop machine learning (ML), neural networks (NN) and other forms of AI.

The process of deconstructing law and regulation has previously been demonstrated for property law and conveyancing processes.<sup>26</sup> and occurs through investigation of the underlying structure of the law or regulation infers the inherent intention and flow; identifying the key points, actors, processes and chronology of operations and representing them by application of Boolean algebra and logic. For example, if we were examining the requirements of section 5(1) of 'The Motor Vehicles (Wearing of Seat Belts) Regulations' 1993 (MVWSBR) shown in Figure 3, which are already the underlying basis for Road Rule 99 shown in Figure 4, we see that: (i) the actors are adults and persons over the age of 14 years; (ii) that they are driving or riding in a motor vehicle; and (iii) they must wear a seat belt; (iv) where that seat belt has been fitted or is available. Table 2 provides the resulting structured English pseudocode meeting the requirements of MVWSBR section 5(1) as expressed by Road Rule 99.

Boolean Algebra is well-established, mathematically sound, complete and utilizes the following operators: 'conjunction' ( $\times$ , A), 'disjunction' ( $+$ ,  $\varpi$ ) and 'negation' ( $\sim$ ,  $\neg$ ). This algebra is simple and is sufficient to express most legal rules in a way that most people would understand. Using Boolean Algebra, the Boolean logic and Boolean equations of Rule 99 would be expressed as shown in Table 3.

26 S McLachlan and others, 'Lawmaps: Enabling Legal AI Development through Visualisation of the Implicit Structure of Legislation and Lawyery Process' (2021) Journal of Artificial Intelligence and Law <<https://doi.org/10.1007/s10506-021-09298-0>>. Last accessed: February 8, 2022

**Table 1: ADAS Technologies**

ADAS		DESCRIPTION	SAE Level
ABS	Anti-lock braking system	Avoids wheel lock-up and loss of control during full-force braking. Uses wheel speed sensors in a feedback system to regulate brake pressure on individual wheels as they begin to skid.	1
ACC	Adaptive cruise control	Maintains desired speed while also ensuring a safe distance between the vehicle and the vehicle ahead. Uses mid- and long-range radar and forward-looking cameras to detect vehicles ahead and a feedback system to control braking and engine acceleration.	1
ANS	Automotive navigation system	Provides location and turn-by-turn directions. Uses digital mapping tools and global positioning (GPS) signals.	0
AP	Automated parking	Capable of identifying suitable parking spaces and taking control of some or all of the functions to set the gear selector, steer, accelerate and brake in order to park the vehicle. Uses radar-based parking sensors and cameras and control mechanisms for braking, steering and acceleration (where supported).	1–2
BSD	Blind spot detection	Provides visual and/or audible warnings when another vehicle is located in or crosses into the blind spot of your vehicle. Uses short-range radar sensors.	0
BUC	Back up camera	Automatically engages when the driver selects the reverse gear. Uses rear-facing camera.	0
DDD	Driver drowsiness detection	Provides audible and sometimes tactile alerts in situations where an algorithm believes the driver may be drowsy or otherwise inattentive. Uses motion sensors, internal driver-facing cameras and data on recent tactile inputs such as steering or indicator use.	0

(Continued)

**Table 1: (continued)**

ADAS		DESCRIPTION	SAE Level
ESC	Electronic stability control	Provides assistance to maintain vehicle stability to avoid oversteer and understeer through selective braking on a per-wheel basis. Uses accelerometers and gyroscopic sensors, wheel speed sensors, driver input sensors and information regarding engine rpm and torque.	1
FCM	Forward collision mitigation	Also known as Automated Emergency Braking System (AEBS), FCM is an upgrade on FCW that identifies situations where the driver has not reacted and autonomously applies the brakes. Uses the mid-range radar and forward-facing cameras and control mechanisms for braking.	1
FCW	Forward collision warning	Uses audible and visual warnings to alert the driver to an imminent frontal collision. Uses mid-range radar and forward-facing cameras.	0
HUD	Heads up display	Reduces the need for looking away from the road, displays essential information such as current speed, posted speed limit, current gear and turn-by-turn directions on windshield in front of driver. Uses input from multiple systems including speed sensors, TSR and ANS.	0
LCA	Lane change assistant	Performs autonomous lane changes either to ensure the vehicle is in the correct lane for a highway interchange or to exit a motorway in support of a course set in the navigation system, or as a result of commanded input from the driver. Uses input from the LKC, PS, ACC, ANS and input from the cameras, lidar and ultrasonics to ensure a lane change is only performed when it is safe to do so.	2–3

(Continued)

**Table 1: (continued)**

ADAS		DESCRIPTION	SAE Level
LDW	Lane departure warning	Provides audible and sometimes tactile warning if the driver accidentally wanders across the boundary of the current lane. Uses the forward-facing camera to detect the position of lane markings.	0
LKC	Lane keeping and centring	An extension of LDW that can prevent unintentional lane departure and return the vehicle to the centre of the current lane. Uses the forward-facing camera and a feedback system to apply suitable control inputs to the steering wheel.	1
NV	Night vision	Uses fixed light infra-red (FLIR) thermal imaging cameras to enable vision of obstacles in very low light conditions.	0
PS	Parking sensors	Provide audible alerts to assist in avoiding obstacles at very low speeds. Uses ultrasonic sensors positioned on the front and rear bumpers.	0
TCS	Traction Control System	Prevents the wheels from slipping by cutting torque and keeping the vehicle stable. Uses ESC sensor system.	1
TSR	Traffic sign recognition	Identifies and alerts the driver to the current speed and other posted road rules. Uses forward-facing cameras attached to the windshield and often integrate with information from ANS.	0
TJA	Traffic jam assistant	Subsumes the driving task in low-speed, high-traffic congestion situations such as a traffic jam on a busy motorway. Uses cameras, lidar and ultrasonic sensors to identify the vehicle's in-lane position and that of other proximal vehicles, and is able to maintain distance, lane, and perform the entire task of low-speed stop-start driving.	3

These logic models simplify creation of machine interpretable state transition visualizations known as Lawmaps<sup>27</sup>; giving Lawmaps a sound formal basis. Lawmaps are an intelligent, clear and concise but democratized tool for visualizing the

27 *ibid.*

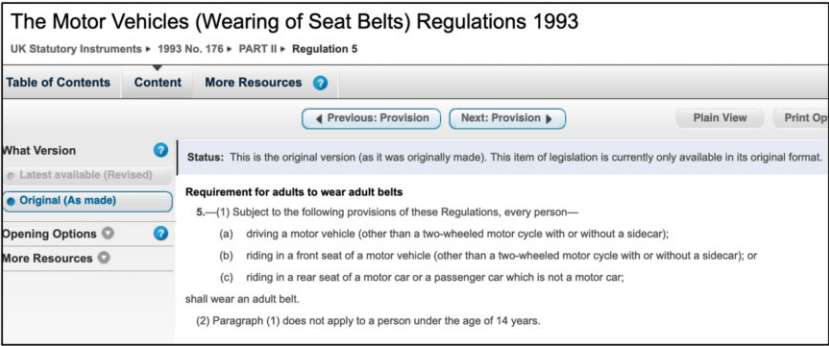


Figure 3: MVWSBR section 5(1).

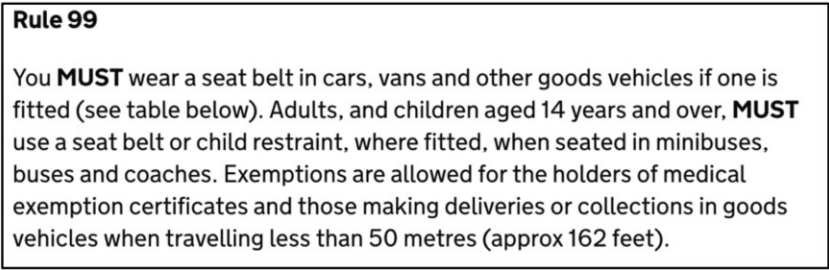


Figure 4: Road Rule 99.

Table 2: Structured English logic for MVWSBR section 5(1) as represented in Road Rule 99.

IF:
[A] Vehicle occupant is:
a. An adult; or,
b. A minor over:
i. 14 years of age; or,
ii. 1.35 metres in height.
EXCEPT:
[C] Where seat belt is not fitted or available;
THEN:
[X] Seat belt cannot be worn.
ELSE:
[Y] Seat belt MUST be worn.

structure and flow of law and lawyerly processes.<sup>28</sup> Lawmaps provide a visual primer of the potential paths and decision points that result from review of a particular law, regulatory rule or legal process. Exemplar Lawmaps are provided for Road Rules in

28 *ibid.*

**Table 3: Boolean Logic and Boolean Equations for MVWSBR section 5(1) as represented in the structured English**

Boolean Logic	Boolean Equations
IF A and C THEN X ELSE IF A and NOT C THEN Y	$X = A \times C$ $Y = A \times \sim C$  where $A = a + b$

the practical evaluation section of this work. We believe that construction of these logic models and their representation as Lawmaps is within the ability of legal practitioners, and will enable and expedite creation of legal software decision-making support tools, law-adherent AI, and validation of the consideration of and adherence to the rules of law in the decision-making processes and output of the tools and AI once created.

**METHOD OF EVALUATION**

This section presents the method used for a practical evaluation and assessment of whether current model vehicles with SAE Level 2 and 3 vehicle ADAS and autonomous systems are capable of adhering to the UK’s traffic regulations as (de)constructed using the methods described in the previous section.

**Process used in evaluation experiments**

In the method used for these evaluation experiments the abilities of three vehicles are assessed against the requirements of 23 UK Road Rules. Figure 5 presents the five-step process followed in conducting this evaluation. Steps 1–3 are the ‘representation’ steps that analyse the text of law and embody it in text more approachable to those from domains outside of law. Steps 4–5 focus on identifying and evaluating the relevant technology solutions employed by vehicle manufacturers. ‘Step 1’ reviews, analyses and describes the rule of law under evaluation. This can include relevant legislation, policy and resulting regulations, byelaws or rules. In this step we provide a plain language description of the rule of law that we term a ‘structured English rule’, and compose the ‘Rule description’ section for each practical evaluation experiment. ‘Step 2’ draws on the structured English rule and represents it in the form of Boolean logic and as a Boolean algorithm. ‘Step 3’ visualizes the process described by the structured English rule in the form of a Lawmap. This step also validates the visualization by ensuring that a solution path can be identified through the Lawmap that is consistent with each Boolean algorithm. ‘Step 4’ reviews the manual and other publicly available documentation to identify and describe the Manufacturer’s technology responses relevant to the circumstances and requirements of this particular rule. During this step the ‘Technology response’ section is prepared for each practical evaluation experiment. The final step in the process, ‘Step 5’, evaluates and reports on the operational response of the technology in simulated and real-world conditions. This step seeks whether the vehicle’s technology responds consistent to one (or more, as needed) of the required paths through the Lawmap and the overall





only vehicle to include ‘mis-acceleration detection and mitigation’—a system that identifies and prevents acceleration of the vehicle from a stationary position that would result in an impact with another stationary object, such as when Drive is unintentionally selected instead of Reverse when the vehicle is parked facing a solid wall in a parking garage. It was the only vehicle that did not include ‘automated lane keeping assist’. Since 2016 this vehicle and specification has also been sold by Mitsubishi under the model names Pajero Sport in Australia and New Zealand and Montero Sport in North America.

### *2020 BMW 7 Series 740Li*

This luxury sedan was supplied with the ‘Technology Plus Pack’ and ‘Driver Assistant Professional’ (DAP) which BMW say make highway driving ‘more autonomous’.<sup>31</sup> DAP provides ‘active navigation guidance’, ‘lane keeping assist, lane change assistant, emergency lane assistant, adaptive cruise control with automated braking, adaptive distance control, no passing indicator, forward collision avoidance, side and rear collision avoidance, pedestrian detection, lane departure’ and ‘blind spot warning, rear cross traffic alert’, that subsumes the driving task in very low speed congested traffic. The vehicle also monitors the driver and provides audible and visual warnings if the driver’s attention is diverted from the driving task, or when the drivers hands have been away from the steering wheel for too long, and can bring the car to a complete stop on the shoulder or emergency lane, where present, should the driver become unresponsive such as might occur in a cardiac health emergency.

### **Traffic light (RAG) rating**

For each Road Rule that is evaluated, the rule description and test result a visual outcome indicator based on traffic lights (also known as a RAG rating) will also be provided. [Table 4](#) describes the traffic light images and provides a definition for each colour rating.

## **RESULTS**

### **Evaluation experiment**

#### *Rules 99–100*

*Rule description.* Road Rules 99–100 mandate all vehicle occupants use seat belts and/or approved child restraints. While it is possible in some distant future that vehicles may become so safe that occupant restraints are no longer necessary, for the foreseeable future these rules mandate the use of seat belts for adults and child restraints for children under 14 years of age or 1.35 meters in height.

These rules exists as an amalgamation of: *The Road Traffic Act* 1988 sections 14 and 15, ‘The Motor Vehicles (Wearing of Seat Belts) Regulations’ 1993, ‘The Motor Vehicles (Wearing of Seat Belts by Children in Front Seats) Regulations’ 1993, and ‘The Motor Vehicles (Wearing of Seat Belts)(Amendment) Regulations’ 2005 and 2006. Analysis of these legislation to create structured English logic resulted in three

31 <<https://www.bmwblog.com/2020/05/27/bmw-driving-assistant-professional/>>. Last accessed: February 8, 2022

Table 4: Traffic Lighting Images and Descriptions




 <p><b>Green</b> ADAS solutions currently meet the all requirements of this Rule</p>	 <p><b>Amber</b> Existing ADAS solutions could meet the requirements of this Rule with altered or extended software</p>	 <p><b>Red</b> Existing ADAS solutions cannot meet the requirements of this Rule without redesign and/or additional hardware</p>
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Table 5: Structured English Logic for Road Rules 99–100

<p><b>STRUCTURED RULE 1:</b></p> <p>IF:</p> <ul style="list-style-type: none"><li>[A] Vehicle occupant is:<ul style="list-style-type: none"><li>a. An adult; or,</li><li>b. A minor over:<ul style="list-style-type: none"><li>i. 14 years of age; or,</li><li>ii. 1.35 metres in height.</li></ul></li></ul></li></ul> <p>EXCEPT:</p> <ul style="list-style-type: none"><li>[C] Where seat belt is not fitted or available;</li></ul> <p>THEN:</p> <ul style="list-style-type: none"><li>[X] Seat belt cannot be worn.</li></ul> <p>ELSE:</p> <ul style="list-style-type: none"><li>[Y] Seat belt <b>MUST</b> be worn.</li></ul>
<p><b>STRUCTURED RULE 2:</b></p> <p>IF:</p> <ul style="list-style-type: none"><li>[A] Vehicle occupant is a minor; and</li><li>[B] Under 3 years of age.</li></ul> <p>EXCEPT:</p> <ul style="list-style-type: none"><li>[C] Where vehicle is a taxi; and,<ul style="list-style-type: none"><li>a. Correct restraint is unavailable;</li></ul></li></ul> <p>THEN:</p> <ul style="list-style-type: none"><li>[X] Minor may be unrestrained.</li></ul> <p>ELSE:</p> <ul style="list-style-type: none"><li>[Y] Correct child restraint <b>MUST</b> be used.</li></ul>
<p><b>STRUCTURED RULE 3:</b></p> <p>IF:</p> <ul style="list-style-type: none"><li>[A] Vehicle occupant is a minor;</li><li>[B] 3 years of age or older; and,<ul style="list-style-type: none"><li>a. Under:<ul style="list-style-type: none"><li>i. 1.35 metres in height; or,</li><li>ii. 14 years of age.</li></ul></li></ul></li></ul> <p>EXCEPT:</p> <ul style="list-style-type: none"><li>[C] Where child restraint is:<ul style="list-style-type: none"><li>a. unavailable;<ul style="list-style-type: none"><li>i. In a licensed taxi or private hire vehicle; or,</li><li>ii. For reasons of unexpected necessity;<ul style="list-style-type: none"><li>a. over a short distance; or,</li></ul></li><li>iii. If two occupied restraints prevent fitment of a third.</li></ul></li></ul></li></ul> <p>THEN:</p> <ul style="list-style-type: none"><li>[X] Adult restraint must be used.</li></ul> <p>ELSE:</p> <ul style="list-style-type: none"><li>[Y] Correct child restraint <b>MUST</b> be used;<ul style="list-style-type: none"><li>a. Where:<ul style="list-style-type: none"><li>i. Seat belts are fitted.</li></ul></li></ul></li></ul>

**Table 6: Variables and Boolean Equations for Road Rules 99–100**

Factual variables	Boolean Equations:
$q = (\text{adult})$ $r = (\text{child } 14 \text{ yrs or over})$ $s = (\text{child over } 1.35 \text{ m tall})$ $t = (\text{baby under } 3)$ $u = (\text{child } 3 \text{ yrs or over})$ $v = (\text{child under } 14 \text{ yrs})$ $w = (\text{under } 1.35 \text{ m tall})$	<b>Structured Rule 1:</b> $B = (q \vee (r \vee s)) \wedge y$ $D = (q \vee (r \vee s)) \wedge \neg y$
<b>Situation variables:</b> $p = (\text{where child restraint is unavailable:}$ (i) taxi or (ii) unexpected necessity or (iii) two occupied restraints) $x = (\text{where seat belts are fitted})$ $y = (\text{where seat belt is neither fitted}$ nor available) $z = (\text{Where vehicle is a taxi and}$ correct restraint is unavailable)	<b>Structured Rule 2:</b> $A = t \wedge z$ $E = t \wedge \neg z$
<b>Decision variables:</b> $A = \text{Minor may be unrestrained.}$ $B = \text{Seat belt cannot be worn.}$ $C = \text{Adult restraint must be used.}$ $D = \text{Seat belt MUST be worn.}$ $E = \text{Correct child restraint MUST be used.}$ $F = E \wedge x$	<b>Structured Rule 3 :</b> $C = (u \vee v \vee w) \wedge p$ $F = (u \vee v \vee w) \wedge \neg p$

structured rules provided in Table 5 that together provide the sum of all requirements for Road Rules 99–100. It was necessary to variabilize the requirements of these structured rules before the Boolean equations in Table 6 could be constructed for them. The resulting Lawmap is provided in Figure 6 and a solution for each Boolean equation is provided in Table 7.

*Technology response.* Using pressure sensors in some seats and circuit detection in the seat belt connection point, most current vehicles are able to indicate using visual and/or audible warnings either when a seat is occupied, or when a seat belt is not currently in use. All of the test vehicles provided a visual indicator showing all seats in the vehicle. On engine start all three vehicles illuminated indicators for the three rear seats irrespective of whether they were occupied or not. If at any point after driving off a rear seat passenger in the Vauxhall unplugged a seatbelt that was plugged in when the car had started to move, the indicator for that seat would illuminate red. The other vehicles initially only lit indicators for all three rear seats whether or not the seat was occupied or the seatbelt was plugged in. On reviewing and discussing notes from these tests, a BMW technician verified the presence of sensors in all three rear seat belt receivers, and circuit-tested them in an effort to identify why they were not indicating in the instrument cluster when a rear seat passenger unplugged a seat belt. A software update was received from BMW after initial testing was complete but prior to submission of this work that, as shown in the right-most image of Figure 7, enabled green illumination when a rear seat passenger plugged in their seat belt, and red illumination and an alert if they later unplugged that seat belt while the vehicle gear selector remained in Drive.

Bayesian Networks (BNs), also described as ‘causal probabilistic models or belief networks’, are ‘directed acyclic graphical’ (DAG) models<sup>32</sup> in which the nodes represent variables and the arcs represent causal, probabilistic or influential relationships

32 J Pearl, *Probabilistic Reasoning in Intelligent Systems: Networks of Plausible Inference* (Morgan Kaufmann Publishers Inc 1988).

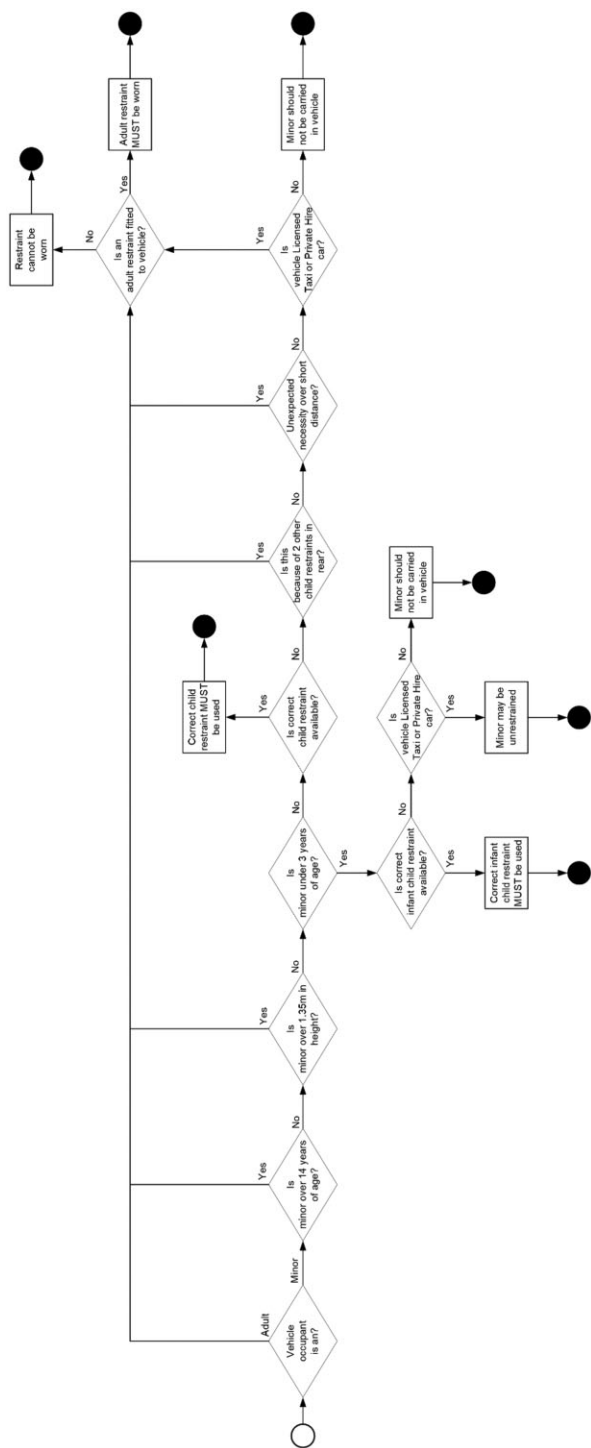
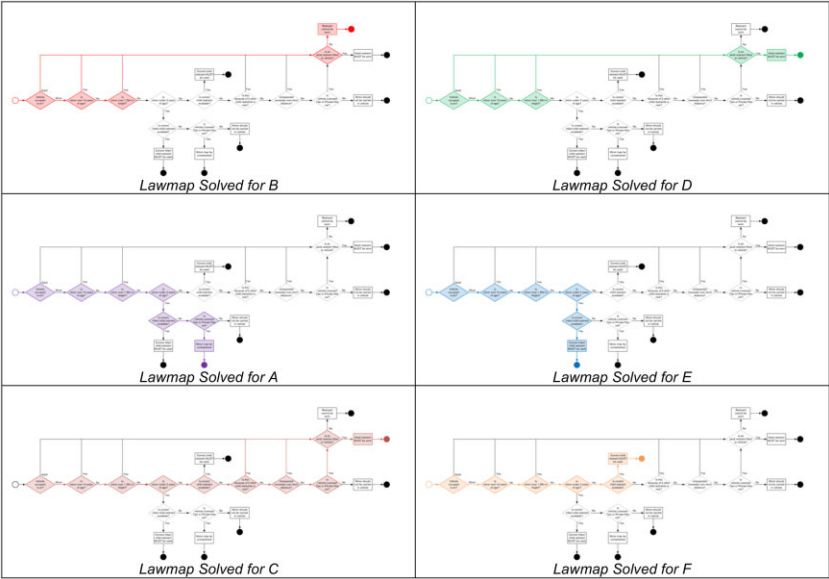


Figure 6: Lawmap for Road Rules 99–100

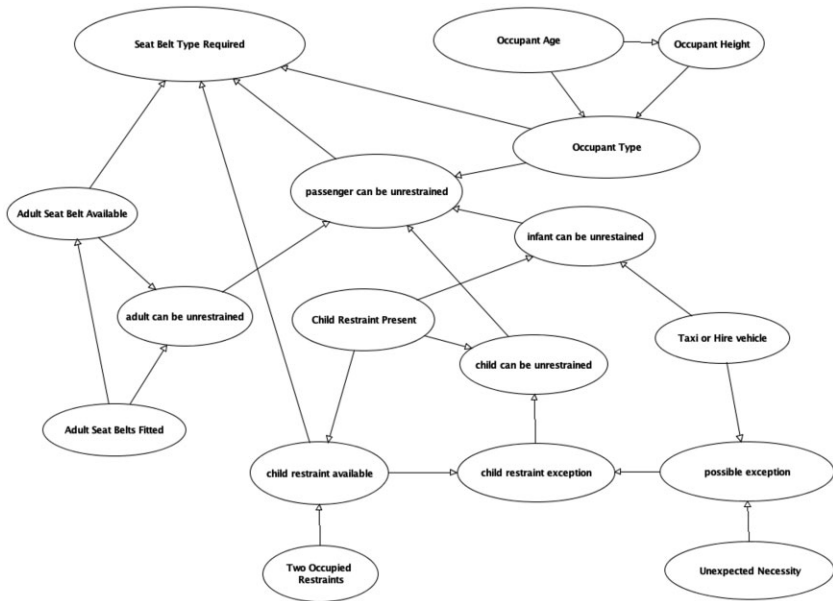
**Table 7: Lawmap for Road Rules 99–100 Showing Path for each Boolean Equation Solution**



**Figure 7: Rear passenger seatbelt indicators on Mitsubishi (L), Vauxhall (M), and BMW (R).**

between variables. BN models have previously been used to represent and evaluate legal arguments.<sup>33</sup> to compute the probability for whether an adjudicated outcome was correctly or randomly decided.<sup>34</sup> to calculate the probability for success in litigation.<sup>35</sup> and to evaluate the likelihood of guilt given the presence and weighted credibility of particular evidence.<sup>36</sup> Drawing on the structured rules and Boolean

33 M Neil and others 'Modelling Competing Legal Arguments using Bayesian Model Comparison and Averaging' (2019) 27 Artificial Intelligence and Law 403–30.  
 34 FE Guerra-Pujol, 'A Bayesian Model of the Litigation Game' (2011) 4 European Journal of Legal Studies 204.  
 35 S McLachlan, E Kyrimi and NE Fenton, 'Public Authorities as Defendant: Using Bayesian Networks to Determine the Likelihood of Success for Negligence Claims in the Wake of Oakden' (2019) Preprint available: <<https://arxiv.org/abs/2002.05664>>. Last accessed: February 8, 2022  
 36 N Fenton and others, 'Analyzing the Simonshaven case using Bayesian networks' (2020) 12 Topics in Cognitive Science 1092–14.



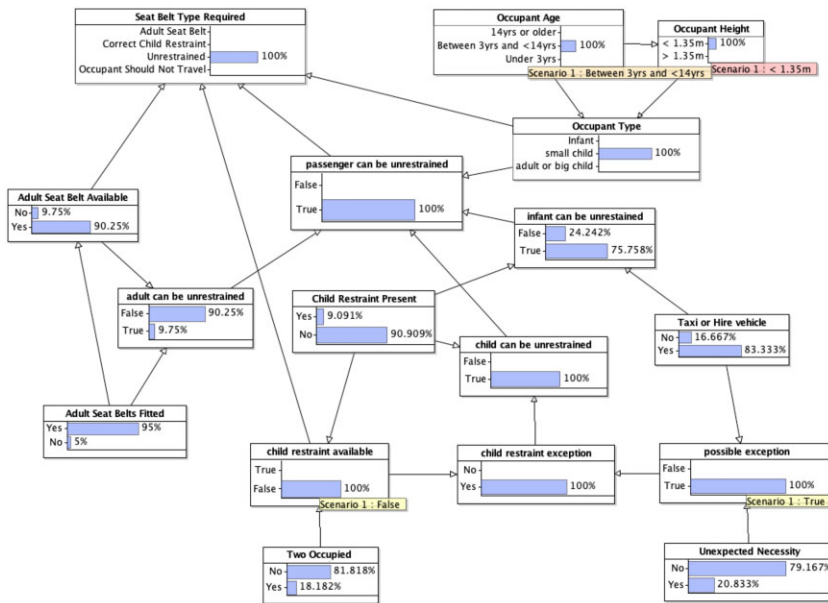
**Figure 8:** BN model for Road Rules 99–100.

equations to identify requirements that are represented by the ‘nodes’ and relationships between those requirements which are denoted by the ‘arcs’, a BN for ‘Road Rules 99-100’ was developed in AgenaRisk (<https://www.agenarisk.com>) and is shown in [Figure 8](#). This model was validated through instantiation of the variables of each Boolean equation as ‘observations’ on the model. [Figure 9](#) demonstrates the solution when we observe all variables required for the scenario represented by the Boolean equation for C resulting from Structured Rule 3.

*Experimental findings.* The Vauxhall extinguished the indicator for any given seat when the seat belt was plugged into the receptacle. All three vehicles used an audible warning if one of the front seat occupants unplugged their seatbelt while the vehicle was moving. Two (Vauxhall and BMW) also alerted when a rear seat passenger unplugged their seatbelt while the vehicle was in motion. However, none of the vehicles ceased operation of ADAS systems if any seatbelt was unplugged. Given that other ADAS and autonomous functions were capable of safely bringing the vehicle to a stop either in-lane or on a hard shoulder, it would be a simple matter for future vehicles or software updates to extend an alert to unrestrained occupants and, if that warning goes unheeded, to safely cease travel until occupants engage their seat belt. Future vehicles should also come installed with pressure sensors in all seats to ensure the driver or autonomous system is aware of the presence and seat location of all occupants. However, new technology would need to be able to measure the height or estimate the age of child passengers and determine whether a child restraint was required.







**Figure 9:** BN model for scenario representing Boolean equation C.

### Rules 103–105

*Rule description.* Rules 103–105<sup>37</sup> concern use of and attention to various signals and traffic directions. To: (i) use indicators and brake lights to signal other road users and pedestrians prior to and as intended changes to course, direction and speed occur<sup>38</sup>; (ii) cancel the engaged signal after use<sup>39</sup>; (iii) be attentive to for the indicator and brake light signals of other vehicles and proceed only when it is safe to do so<sup>40</sup>; (iv) remain alert for situations where it is possible that the signal of another vehicle may be erroneous because it has not been cancelled<sup>41</sup>; and (v) obey the traffic directions of a range of authorized persons.<sup>42</sup> This final provision arises by operation of: ‘The Road Traffic Regulation Act’ 1984 (RTRA) section 28, ‘The Road Traffic Act’ 1988 (RTA) section 35, and ‘The Function of Traffic Wardens (Amendment) Order’ 2002 (FTWAO). These laws collectively mandate compliance with the traffic directions of constables, traffic officers, traffic wardens and school crossing patrols. Table 8 provides the structured English logic for the general operation of Road Rule 103, which results in the Boolean logic and equations in Table 9, and was then applied in development of the Lawmap shown in Figure 10. Table 10 and Figure 11

37 <<https://www.gov.uk/guidance/the-highway-code/general-rules-techniques-and-advice-for-all-drivers-and-riders-103-to-158>>. Last accessed: February 8, 2022

38 Rule 103.

39 *ibid.*

40 Rule 104.

41 *ibid.*

42 Rule 105.

Table 8: Structured English Logic for the General Operation of Road Rule 103

IF:
[A] When in control of a motor vehicle; and,
[B] There is an intention to:
a. Change course; or,
b. Direction; or,
c. Stop; or,
d. Move off.
EXCEPT:
[C] Where it would be misleading to signal at that time;
THEN:
[X] Signalling should be delayed;
a. until:
i. Signalling would not be misleading;
ELSE:
[Y] Other road users should be alerted by:
a. Clear signals;
b. Given in plenty of time.

Table 9: Boolean Logic and Boolean Equations for Road Rule 103

Boolean Logic	Boolean Equations
IF (A and B) and C	$X = (A \times B) \times C$
THEN X	$Y = (A \times B) \times \sim C$
ELSE IF (A and B) and NOT C	
THEN Y	

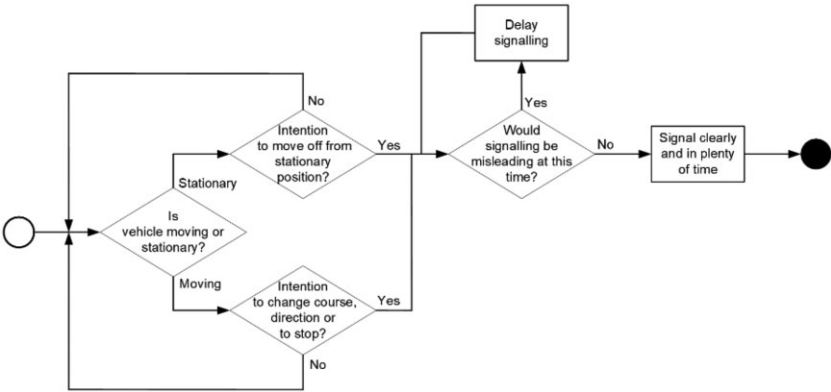
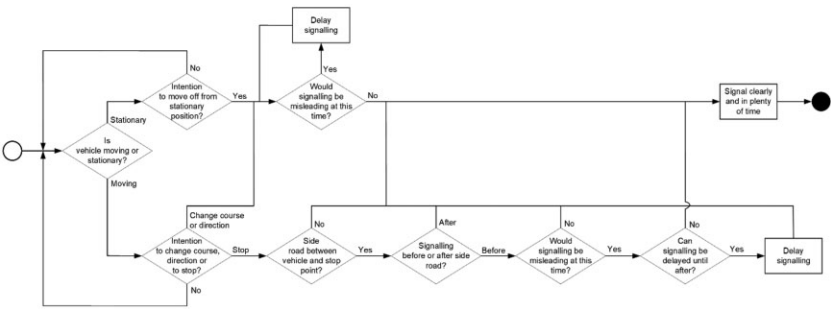


Figure 10: Simple Lawmap for the general operation of Road Rule 103.

**Table 10: Structured English Logic for an Example Scenario Application of Road Rule 103**

IF:
[A] When in control of a motor vehicle; and,
[B] There is an intention to:
a. Turn or exit the current road;
i. Immediately after passing a <i>side road</i> on;
ii. The same side as the intended turn.
EXCEPT:
[C] Where it would be misleading to signal at that time;
b. Because other drivers may believe it signals an intention to;
i. Turn into the <i>side road</i> .
THEN:
[X] Signalling should be delayed;
a. Until:
i. The vehicle has passed the <i>side road</i> .
ELSE:
[Y] Other road users should be alerted by:
a. Clear signals;
i. Brake lights to warn when slowing down; and,
ii. Indicators to warn of change in course;
b. Given with sufficient time to;
i. Adjust their own course and speed; and,
ii. Avoid potential for an accident.



**Figure 11:** Extended simple Lawmap for the example scenario operation of Road Rule 103.

provide an example scenario for Road Rule 103 where the intention is to pull off and stop on the side of the road just after a side road.

*Technology response.* Two test vehicles (Vauxhall and BMW) came equipped with camera-based systems affixed to the upper windscreen in the area above and forward of the rear-vision mirror. These were in addition to forward-facing ultrasonic sensors and, in the case of the BMW, radar. Both make claims in their driver manuals and online marketing materials regarding these vehicles ability to detect and identify speed limit signs, however BMW goes one step further and promotes its system as capable of recognizing a range of road signs to warn drivers when they must yield ('stop' or 'give way'), or even when they are entering a restricted one-way street.<sup>43</sup>

43 <<https://www.bmw.com/en/innovation/the-main-driver-assistance-systems.html#pwjt-road-sign-recognition>>. Last accessed: February 8, 2022

*Experimental findings.* While none of the vehicles was able to identify when indicator or brake lights were illuminated on the vehicle they immediately followed, all were able to detect and react appropriately when that vehicle's forward velocity reduced, whether passively or because the brakes had been applied. In each case all three vehicles first alerted to the changed velocity and potential for collision and, if no immediate corrective action was taken, each applied the brakes and was capable of autonomously bringing the vehicle to a complete stop. The Vauxhall and BMW vehicles both identified speed limit signs and adjusted the displayed speed limit in both the instrument cluster and heads up display, as shown in Figure 12. However, on occasion both were prone to error. One example of these errors is shown in Figure 13 where the BMW vehicle on repeat trips past a 30mph sign on an urban lane consistently mis-read the value as 80mph. Other examples occurred where the speed limit sign was small, or where stickers on the rear of a delivery van or lorry (Figure 14) were incorrectly identified as a speed limit traffic sign. Our evaluation of each speed limit error suggested the vision-based value overrides the 'known good' value provided by the map system.<sup>44</sup> resulting in the mis-read speed being shown to the driver as the current speed limit.

Of the three vehicles, only the BMW 'Driver Assistant Professional' (DAP) was capable of and correctly identified fixed mounted 'Give Way' and 'Stop' signs. However, the BMW system failed to identify a 'Stop' sign when it was held by a school crossing patrol guard who, in almost 50 per cent of instances, it also incorrectly identified as a stationary small vehicle. Also, the BMW vehicle did not apply or perform the direction given of these signs, even when in full DAP 'SAE Level 3' mode. Finally, none of the tested vehicles identified traffic lights, a capability now found in some 'hardware three' (HW3) based Tesla Autopilot equipped vehicles.



### Rule 113

*Rule description.* Rule 113 requires all sidelights and rear registration plate lights are lit between sunrise and sunset, that headlights are used at night<sup>45</sup> except on a road which has lit street lighting.<sup>46</sup> and when visibility is seriously reduced. This rule arises from 'The Road Vehicles Lighting Regulations' 1989 sections 3, 24 and 25.

*Technology response.* Like most current model vehicles, all three in this test were fitted with automatic headlights as standard. All three used photoelectric sensors to identify low light situations.

*Experimental findings.* Each vehicle correctly identified low light situations and, when triggered by the sensor, activated the headlights, tail lights and registration plate

44 We believe this was intended as a safety feature whereby the system would update and alert the driver to reduced speed limits, for example when indicated on temporary signs for roadworks.

45 Night, or the hours of darkness, are described in the Road Rules as the period between half an hour after sunset and half an hour before sunrise.

46 The notes with Rule 113 identify these as roads that are generally restricted to a speed limit of 30mph unless otherwise specified.



**Figure 12:** Heads Up Display (HUD) showing Speed Limit Sign Detection. Vauxhall (L) and BMW (R).



**Figure 13:** Example of traffic sign recognition error indicating 80mph in a 30mph urban area (Vehicle: BMW).



**Figure 14:** Speed limit stickers on the rear of a semi truck trailer.

lights.



### Rules 127–132

*Rule description.* Rules 127–132 describe the standard for line markings and dividers used on UK roads. This includes the broken white line at the centre which a vehicle should not cross unless the road is clear and there is an intention to overtake or turn off; and which, when the line lengthens and gaps shorten, indicates a hazard ahead. It also includes where there are double white lines at the centre of the road that generally mean you ‘must not’ straddle or cross the centre line; ‘unless’ (i) the line closest to you is broken which indicates that overtaking is permissible; (ii) it is safe to do so and you are passing a stationary vehicle or overtake a bicycle, horse or road maintenance vehicle; or (iii) you are crossing to enter an adjoining property or side road.

*Technology response.* Two vehicles (Vauxhall and BMW) included automated lane keeping and centring. Both rely on visual input from windscreen-mounted cameras to identify lane markings and have escalating levels of functionality from warning the driver when they are about to cross a lane boundary through to an ability to take corrective action by autonomously steering the vehicle back into the centre of the current lane. Only the BMW was also fitted with ‘lane change assistant’ (LCA), an additional software system that uses the camera, lidar and blind spot detectors and receives input from the driver for an intended lane change. LCA scans if it is safe to proceed in the commanded direction and then autonomously performs the lane change operation. The Mitsubishi was not fitted with a lane keeping assistant feature and was unable to be tested against this rule.

*Experimental findings.* The Vauxhall and BMW vehicles correctly identified and provided an audible alert when the vehicle was about to cross out of a lane. The BMW vehicle’s next level of response was to perceptively vibrate the steering wheel without affecting driveability or the current vehicle heading. The final level for both was to autonomously steer the vehicle back into the centre of the current lane. When tested, both could be overridden by the driver through the application of slightly greater than normal force on the steering wheel in the driver’s chosen direction. Testing of the BMW’s LCA showed that it does not differentiate circumstances where there were double centre lines, nor whether the nearest line was unbroken. On a large four-lane (two-a-side) country road it was still willing to perform a lane change manoeuvre that would have resulted in crossing the double solid centre line.



### Rules 137–138

*Rule description.* Rules 137–138 govern the use of different lanes on dual carriageways, including for overtaking and right-hand turns. Rule 137 provides that a vehicle may use the right-hand lane of a two-lane dual carriageway and Rule 138 extends

this by allowing use of the middle or right lanes on a three-lane carriageway for overtaking or performing a right turn. However, both rules stipulate driving in the left-most lane generally, and where the vehicle has left the left-most lane to overtake, returning to the left lane when it is safe to do so. The structured English logic for Rules 137–138 is provided in Table 11, and the Boolean logic and equations are provided in Table 12.

*Technology response.* While both the Vauxhall and BMW were fitted with LDW and LKA, only the BMW also had LCA. BMW's LCA and LDW work together using the various ultrasonic, radar and camera sensors fitted to the vehicle to ensure that the vehicle's LCA only changes lanes where it is safe to do so.<sup>47</sup>

*Experimental findings.* BMW's current iteration of LCA operates in two modes: one autonomous and the other semi-autonomous. The 'first' or autonomous mode occurs in full DAP with navigation enabled, and will perform some lane changes on main highways and freeways to ensure the vehicle is in the correct lane to exit or change highways as required by a pre-programmed course. The 'second' or semi-autonomous mode performs lane changes only after commanded input from the human driver. In this second mode the driver is required to apply a small amount of pressure to the indicator stalk in the direction of the intended change, and the system commences scanning to ascertain whether it is safe before taking control of the direction of travel via steering inputs necessary to perform the requested lane change. Neither mode saw the vehicle autonomously return to the left-most lane as required by Rules 137–138 without additional commanded input on the indicator stalk.



### Rules 191–199

*Rule description.* Rules 191–199<sup>48</sup> provide directions for approaching and negotiating pedestrian crossings. The UK has several types of pedestrian crossings defined as 'controlled' and 'uncontrolled': differentiated by the presence or absence of traffic lights and how those traffic lights function. How crossings function is also altered by the presence of pedestrian havens, known as 'central islands'. Uncontrolled crossings include standard zebra crossings, zebra crossings with central islands, and school warden crossings. There are four types of controlled crossing: (i) The 'Pelican Crossing' is controlled by a set of traffic lights and a button for the pedestrian to press in order to request to cross. Once vehicles have stopped at the red light, the pedestrian will observe a green man to indicate it is safe to cross. After a period the green man will begin to flash, at which time vehicles will see a flashing amber light. As long as the crossing is now free of pedestrians vehicles may move on; (ii) The 'Puffin Crossing' acts similar to a pelican crossing with the addition of sensors on the traffic lights and

47 <<https://www.bmw.com/en/innovation/the-main-driver-assistance-systems.html#pwjt-lane-change-assist>>. Last accessed: February 8, 2022

48 <<https://www.gov.uk/guidance/the-highway-code/using-the-road-159-to-203>>. Last accessed: February 8, 2022



Table 11: Structured English logic for Rules 137–138

IF: [A] Where a vehicle is on a two-lane or three-lane dual carriageway;
EXCEPT: [C] Where there is an intention to: a. Overtake; or, b. Turn right;
THEN: [X] The vehicle may: a. Use: i. The right lane on a two-lane dual carriageway; or, ii. The middle or right lane on a three-lane dual carriageway b. Until: i. It is safe to move back into the left lane.
ELSE: [Y] The vehicle should stay in the left lane.

Table 12: Boolean Logic and Boolean Equations for Road Rule 137-138

Boolean Logic	Boolean Equations
IF A and C THEN X ELSE IF A and NOT C THEN Y	$X = A \times C$ $Y = A \times \sim C$

pavement and will return the traffic lights from red back to green once the pedestrian has completed their crossing; (iii) The ‘Toucan Crossing’ is designed so that cyclists can also cross without dismounting, which is something they are required to do at any other type of crossing. These crossings are differentiated by the addition of a green bicycle alongside the green man; (iv) The ‘Equestrian Crossing’ elevates the pedestrian button to make it accessible without the need to dismount in areas frequented by horse riders. For ‘uncontrolled crossings’ the central island operates to split one crossing into two separate smaller crossings. However, unless a ‘controlled crossing’ is staggered with separate pedestrian buttons on the central island, it should continue to be treated as one contiguous crossing. Road Rules 191–199 arise from requirements prescribed by ‘The Zebra, Pelican and Puffin Pedestrian Crossings Regulations and General Directions’ 1997 (ZPPPCRGD) regulations 18 and 20, the ‘Road Traffic Regulation Act’ 1984 (RTA) section 25(5), and ‘The Traffic Signs Regulations and General Directions’ 2002 (TSRGD) regulations 10, 27 and 28. Table 13 provides the structured English logic for Road Rules 191–199 and Table 14 provides the Boolean logic and equations, while Figure 15 provides a simple lawmap describing their operation.

*Technology response.* The Mitsubishi.<sup>49</sup> Vauxhall<sup>50</sup> and BMW<sup>51</sup> vehicles all included a pedestrian detection system that used the forward-looking windscreen-mounted

49 <<https://www.mitsubishi-motors.co.uk/cars/shogun-sport/safety>>. Last accessed: February 8, 2022  
50 <<https://gb-media.vauxhall.co.uk/en-gb/07-05-insignia>>. Last accessed: February 8, 2022  
51 <[https://preview.thenewsmarket.com/Previews/NCAP/DocumentAssets/358227\\_v2.pdf](https://preview.thenewsmarket.com/Previews/NCAP/DocumentAssets/358227_v2.pdf)>. Last accessed: February 8, 2022

Table 13: Boolean Logic and Boolean Equations for Road Rule 103

IF:
[A] Where a vehicle is approaching a pedestrian crossing;
EXCEPT:
[C] Where there is no person on or entering the pedestrian crossing, and:
a. a flashing amber light;
b. a green light; or,
c. no traffic lights.
THEN:
[X] The vehicle may proceed through the pedestrian crossing with caution.
ELSE:
[Y] The vehicle must stop at the pedestrian crossing until there is:
a. no person on or entering the pedestrian crossing; and,
b. if present, the traffic light has changed to:
i. flashing amber; or,
ii. green.

Table 14: Boolean Logic and Boolean Equations for Road Rule 103

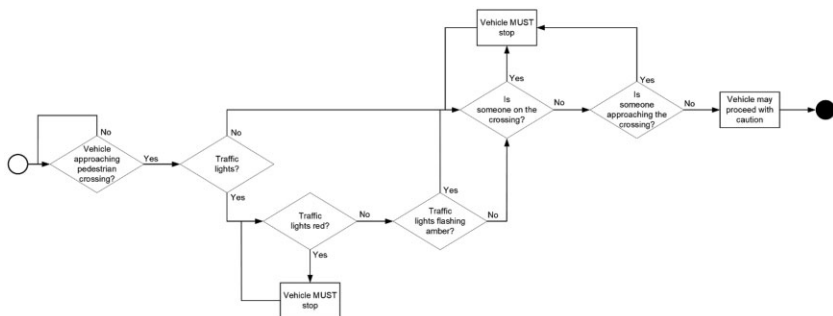
Boolean Logic	Boolean Equations
IF A and C	$X = A \times C$
THEN X	$Y = A \times \sim C$
ELSE IF A and NOT C	
THEN Y	

camera and radar to sense pedestrians in the path of the vehicle. Manufacturers claim their systems will use audible and visual prompts to alert drivers to a pedestrian in the path of the vehicle, and will automatically apply emergency braking if the driver fails to respond by either altering the vehicle’s direction of travel or braking to avoid an imminent collision.

*Experimental findings.* While the BMW in some instances identified the Give Way (red bordered white triangle) sign if present prior to an uncontrolled crossing, no vehicle actually identified the presence of a pedestrian crossing. The Mitsubishi and Vauxhall vehicles in most instances correctly identified pedestrians in both simulated<sup>52</sup> and real-world conditions.<sup>53</sup> However, in every instance the BMW vehicle either did not identify that a pedestrian was in its path, or in 30 per cent of instances it incorrectly identified that pedestrian as a stationary small vehicle on the display in the instrument cluster. The Mitsubishi vehicle was the earliest of the three to brake, with test driver and passengers all suggesting it tended towards overreaction by braking too early and

52 We used a similar approach to the US Institute for Highway Safety in 37, using a padded mannequin as a simulated pedestrian both standing stationary and walking across the path of the vehicle travelling at 20mph (30kph).

53 In real-world situations we stopped the vehicle at a crossing as required by the Road Rules. As we approached a pedestrian crossing, we watched for the vehicle to display a pedestrian icon in the instrument cluster or heads up display as described in the vehicle manufacturer’s description of their pedestrian warning system. We also asked drivers to report serendipitous instances where a pedestrian stepped into the road in front of the moving vehicle. At no time were real pedestrians put in any risk of harm.



**Figure 15:** Lawmap for Road Rules 191–199.

too far away from the pedestrian, and often in circumstances where even if the vehicle's speed had not been altered the pedestrian would no longer have been in the vehicle's path when the vehicle got there. It was also suggested that the Mitsubishi's approach to emergency braking in these situations was too severe, causing discomfort for vehicle occupants even when there was no perceivable risk to the pedestrian or vehicle. The Vauxhall alerted the driver audibly and with an image of a red person in the heads up display, but rarely engaged the brakes until it was too late to avoid some contact with the simulated pedestrian. Likely due to the fact that we never saw the BMW correctly identify a pedestrian even once, the BMW either failed to brake at all in situations where it did not see the pedestrian, or alerted using a red car shape in the heads up display and applied the emergency brakes in those situations where it incorrectly identified the pedestrian as a small vehicle. The failure of BMW's 'Pedestrian Warning with City Brake Application' feature is not new, with our findings being similar to results released by the US Institute for Highway Safety in 2019.<sup>54</sup>



### Rule 229

**Rule description.** Rule 229<sup>55</sup> requires that before you commence a journey you 'must' clear snow and ice from and demist all windows and mirrors and ensure that lights and number plates are clearly visible and legible. This requirement aggregates from a number of legislative sources, including: 'The Road Vehicles (Construction and Use) Regulations' 1996 (RVCUR) section 30(3)<sup>56</sup>; 'The Road Vehicles Lighting Regulations' 1989 (RVLR) section 23<sup>57</sup>; 'Vehicle Excise and Registration Act' 1994

54 <<https://metro.co.uk/2019/03/07/bmws-pedestrian-detection-system-works-really-really-badly-8835917/>>. Last accessed: February 8, 2022

55 <<https://www.gov.uk/guidance/the-highway-code/driving-in-adverse-weather-conditions-226-to-237>>. Last accessed: February 8, 2022

56 s 30(3) states that all glass or other transparent material fitted to a motor vehicle shall be maintained in such condition that it does not obscure the vision of the driver while the vehicle is being driven on the road.

57 s 23(1) provides a requirement for all devices described in the paragraph to be both in *good* 'working order' and 'clean' and s 23(2) describes applicable devices to include headlamps, registration plate lamps,

(VERA) section 43<sup>58</sup>; and ‘The Road Vehicles (Display of Registration Marks) Regulations’ 2001 (RVDRMR) section 11.<sup>59</sup> Rule 229 also requires clearing of any snow and ice that might fall into the path of other road users: for example, snow that has collected on the roof of your vehicle that at speed might slide off and into the path of following traffic, or on braking could slide forward and down your windscreen obscuring your view.<sup>60</sup> Finally, the rule compels a check that the planned route is clear of any delays and that no further snowfalls or severe weather are predicted.

*Technology response.* Many vehicle manufacturers now provide over-the-air (OTA) access to real-time traffic information that can alert drivers to potential hazards and congestion on their planned route, and even suggest alternate routes to avoid those issues. The Vauxhall and BMW vehicles both provided traffic alerts and updates as part of the navigation system.<sup>61</sup> while the Mitsubishi vehicle only provided the public traffic alerts as part of the digital audio broadcast (DAB) system. However, no existing ADAS-enabled or semi-autonomous vehicles can self-identify or autonomously resolve many of the other requirements of this rule. It could be argued that requirements to de-ice and demist the windows might be unnecessary for SDV: that it is sufficient only for the SDV system to be capable of verifying that the cameras and any ultrasonic, radar or lidar sensors supporting the automated or autonomous functions are free of obstruction, interference or error, and where an issue is identified, alert and require the occupant to resolve the problem prior to commencing the journey.

*Experimental findings.* The Vauxhall traffic alert tool was limited to providing delayed notice of traffic accidents and major incidents. Only the BMW tool was able to extend on this to provide near real-time traffic congestion detail by colour-coding roads both on the selected route, and in areas around the vehicle’s current location and path. In testing, several installed ADAS technologies were capable of identifying and refusing to engage where frost, snow and other deliberately applied obstructions were present over the system’s camera, ultrasound or lidar devices. Many were also

front position and side marker lamps, fog lamps, reflectors, stop lamps, running lamps, dim-dip devices, hazard lamps and headlamp levelling devices.

58 s 43 makes it an offence for any required registration mark such as the number plate fixed to a vehicle to be obscured or not easily distinguishable.

59 s 11 provides that it is an offence to affix reflex-reflective material to the number plate or to cause the letters to become retroreflective, or to use fixing devices such as screws in such a way that they change the appearance or legibility of the registration plate.

60 Snow on the roof of a vehicle while driving could result in a £60 fine and could see the person in charge of the vehicle lose 3 demerit points from their driving license if observed falling off by an officer. Where that snow is observed to fall off onto your windscreen or onto another vehicle, an on the spot charge of ‘driving without reasonable consideration for other road users’ which carries a minimum £100 fine and up to 9 demerit points may arise. In the most severe cases (such as <<https://www.bbc.co.uk/news/uk-scotland-tayside-central-55950942>> Last accessed: February 8, 2022), or where either go to or are contested in court, the charge can escalate to ‘dangerous driving’ and the fine may rise to as much as £1000.

61 While Vauxhall provided a traffic alert system as part of ownership of the vehicle, the BMW traffic alert system is provided for only 2 years as part of the original vehicle purchase, and as a user-pays subscription service beyond that initial period.

described by the manufacturer as being capable of identifying errors and malfunctions, and when we introduced faults by disconnecting sensor or camera cables the vehicles correctly identified these issues with appropriate fault codes, and in most cases fully disabled the affected ADAS. However, no single vehicle system was able to identify and alert occupants to instances where the roof, headlights or registration plates were obstructed such that even the advanced vehicles we were using would allow driving in breach of these requirements of Rule 229.



### Summary of findings

Table 15 summarizes results of the practical evaluation. These results show that even the most recent and advanced vehicle, the SAE Level 3 BMW 740Li, was unable to meet half of the requirements identified from the road rules in our test. While, as our traffic light rating indicates, many of the identified shortcomings may eventually be rectified with additional development of the software underpinning the smart automotive system or the inclusion of new or better trained artificial intelligence, it is possible some elements may remain unresolvable.

### DISCUSSION

Most autonomous cars literature in the legal domain discuss either: (i) the issue of legal liability; (ii) novel privacy issues due to the vast amounts of data collected by vehicle systems and the resulting impact autonomous vehicles may have on owners and occupants freedoms; or both.<sup>62</sup> A strong argument has also been made that the two issues are interrelated and that in order to resolve one, legislation must also be cognisant of the other.<sup>63</sup>

Most modern vehicles, but especially those with advanced ADAS or autonomous functionality operate as a collection of interconnected computing systems generating, sharing and consuming vast amounts of data. This data can include current and frequented locations, personal information about the owner or driver.<sup>64</sup> and details about the vehicle's configuration and present serviceable status.<sup>65</sup> However, the data retained by many vehicles in so-called black box 'event data recorders' (EDR) can also include the configuration and disposition of many of the vehicle's systems, some history of driving habits that can include speeding, excessive use of brakes and high g-force manoeuvres, whether safety restraints were in use, recent collisions and near





62 J Boeglin, 'The Costs of Self-driving Cars: Reconciling Freedom and Privacy with Tort Liability in Autonomous Vehicle Regulation' (2015) 17 Yale Journal of law & Technology 171 at 175.

63 *ibid.*

64 Some vehicles now provide a driver profiling platform, allowing the driver and frequent users to create a 'driver profile' that can be accessed using a pin number entered on the infotainment screen, a smartphone app or be linked to the key fob carried by the driver. Profiles can contain the person's name, vehicle settings and preferences, and smartphone details. In some internet-connected vehicles the profile can email log book style details of trips to the driver's email account.




65 The BMW vehicle can send details about the current configuration of the ventilation system, current location, 360 degree camera views around the vehicle and even the remaining fuel volume and mileage to BMW's web servers, from where it can be shared to the BMW apps on any smartphone device that has been paired with the vehicle's VIN number.

**Table 15: Practical Evaluation Results**

Road rule/s		Vauxhall insignia GS	Mitsubishi shogun sport	BMW 740Li
99–100		Identifies when a restraint is required	✓	✓
		Identifies correct restraint type	✗	✗
		Identifies when any restraint is unplugged	✓	✓
		Cease smart function when unplugged	✗	✗
		Smart function reads most speed limit signs	✓	✓
		Smart function identifies most give way signs	✗	✓
		Smart function identifies most stop signs	✗	✗
		Smart function is adherent to sign's instructions	✗	✗
103–105		Smart function automatically alerts when changing lane (LCA)	N/A	✓
		Smart function automatically alerts when braking (ACC)	N/A	✓
		Smart function automatically cancels signal after use	✓	✓
		Smart function can detect and cancel signal if it may be misleading to other road users	✗	✗
		Smart function recognises signals of other vehicles	✗	✗
113		Smart function identifies and responds to low light conditions by activating tail, plate and head lights	✓	✓
		Smart function identifies lane markings	✓	✓
127–132		Smart function alerts driver when about to cross lane markings	✓	✓
		Smart function able to keep vehicle 'in lane'	✓	✓
		Smart function prevents crossing solid double lines	✗	✗

(Continued)

Table 15: (continued)

Road rule/s		Vauxhall insignia GS	Mitsubishi shogun sport	BMW 740Li	
137–138		Smart function correctly identifies when vehicle is not, but should be, in left-most lane	✗	N/A	✗
		Smart function correctly identifies most pedestrians	✓	✓	✗
191–199		Smart function takes appropriate action to avoid accident with pedestrian	✗	✓	✗
		Smart function identifies pedestrian crossings	✗	✗	✗
		Smart function able to verify snow and ice cleared from vehicle	✗	✗	✗
		Smart function able to verify windscreen is free of snow and ice and demisted	✓	N/A	✓
229		Smart function able to verify lights and number plates are visible and free of obstruction	✗	✗	✗
		Smart function provides traffic incident and accident alerts	✓	N/A	✓
		Smart function provides information on traffic congestion on route	✗	N/A	✓
		Smart function suggests routes to avoid incidents and/or congestion	✓	N/A	✓

✓ The ADAS or autonomous smart function consistently met this requirement  
✗ The ADAS or autonomous smart function consistently failed to meet this requirement  
N/A The vehicle was not fitted with a relevant ADAS or autonomous smart function

misses, and in some cases video of these events.<sup>66</sup> Issues regarding manufacturer, insurer and police access to the data retained within an individual’s vehicle have already

66 The Vauxhall vehicle’s documentation included description of a data recorder that retained ‘the last 30 minutes of driving’. The BMW vehicle is capable of recording and transmitting a wide variety of data regarding the driving conditions, driver inputs and even dashcam style video from the BMW Driver Recorder iDrive infotainment app. Both vehicles were configured and capable of using their respective cellular connectivity to alert a vehicle management call centre with severity (whether and how many airbags had triggered) and location data in the event of an accident.



come before the courts.<sup>67</sup> and while much has been written about the fact that many vehicle owners and users remain unaware of the EDR and the data it collects, in all cases to date until it was downloaded the data was at least still physically located within their vehicle.

When the law says you should not drive without wearing your seat belt or that you should not exceed the posted speed limit, questions arise regarding the data collected and stored by the vehicle: whether the driver and occupants can be said to have provided informed consent for data collection.<sup>68</sup> whether they have access to review and request correction or removal, and whether such collection and storage was legal in the context of existing data protection laws. Vehicles like the Vauxhall and BMW models reviewed in this work only increase the potential for privacy and data protection issues as a direct result of their 'always-on' connected nature. Ever-increasing subsets of that data are now transmitted to manufacturer servers for re-transmission to manufacturer-branded smartphone apps and in order to provide training and usage data to improve ADAS and autonomous functionality. Not only does the potential for privacy breaches increase once the data leaves the vehicle, but in some jurisdictions questions may arise regarding at what point the subject who caused the data to be created ceases to retain ownership over data that could: (i) potentially expose them to prosecution for minor (or potentially major) traffic offences<sup>69</sup> that might normally have remained unknown; or (ii) put them or their family at risk.<sup>70</sup>

Some promote the idea of future product infallibility, claiming that significantly improved reliability and safety should justify shifting all liability away from the manufacturer onto the autonomous vehicle owner through an application of strict liability.<sup>71</sup> However, such a solution creates difficulties for owners, insurers and courts and would only increase overall costs and amplify existing litigation tensions where

67 eg *State of Florida v Worsham* [2017] FDCA 4D15-2733 where Worsham had an accident that killed his passenger. Police had downloaded data from the event data recorder before seeking the search warrant, which was denied on the grounds that the search had already occurred. The Florida District Court of Appeal ruled the data inadmissible as the police had taken it without Worsham's approval or a valid search warrant. Also: Antonio Boparan Singh first admitted and was later convicted of causing serious injury by dangerous driving when he crashed into another vehicle causing permanent disabling injuries to a 1-year old child who later died. Singh only admitted culpability after black box data from his expensive high performance V8 SUV showed he had been driving at almost 2.5 times the legal speed limit on a residential street at the time of the accident.

68 J Buhrum, 'Riding with Little Brother: Striking a Better Balance between the Benefits of Automobile Event Data Recorders and Their Drawbacks' (2007) 17 *Cornell Journal of Law & Public Policy* 201 at 217; discusses the current lack of informed consent for EDR data collection and the risk that authorities might use that data as evidence against a driver in civil or criminal proceedings without the driver first having agreed to incur this legal risk.

69 *ibid.*

70 E Bevin, 'Man Pleads Guilty to Stalking and Controlling Ex-girlfriend's Car with his Computer' *ABC News* (6 November 2019) <<https://www.abc.net.au/news/2019-11-06/ract-employee-pleads-guilty-to-using-app-to-stalk-ex-girlfriend/11678980>>. Last accessed: February 8, 2022 A man plead guilty and received a sentence of imprisonment after using details of the victim's car to facilitate access to data created by the victim that was stored in the car including location information regarding where she was and when, and in order to take remote control of her vehicle.

71 41 at 473–74.



Keeping System' (ALKS) 'on GB roads'<sup>77</sup> reinforces not only the suggestion that existing road rules should be considered adequate, but also that autonomous systems must be adherent to them. However, wholesale import of our existing road rules as the model to govern autonomous systems may at best be unreasonable, and at worst could prove impossible. It may also create conflicts with other laws that would not arise where a human is in control of the driving task, including laws that may provide exemption from compliance with particular road rules in special circumstances.<sup>78</sup> Many have concluded that new regulation is likely necessary not only to address barriers to adoption,<sup>79</sup> but also to address the issues of co-existence,<sup>80</sup> liability<sup>81</sup> and whether and how individual road rules will apply to vehicles when the vehicle itself is in autonomous control of the driving task. However, when even the best of human drivers may not adhere to all road rules at all times, it may be especially challenging for autonomous vehicles to co-exist if their software rigidly enforces the requirements of every road rule without exception.<sup>82</sup> Co-existence requires the autonomous system be capable of a degree of flexibility in its decision-making when it encounters the unpredictable moving feast that is human behaviour and response. Our practical experiment demonstrates that existing SAE level 2 ADAS and level 3 autonomous system adherence to the complex requirements of some road rules can at best be variable, and our results would support the contention that holding these systems to strict observance of all current UK road rules will prove impossible. For exactly these reasons it is suggested that it may be necessary to develop and train autonomous systems with a capability for 'strategic rule breaking'.<sup>83</sup>

Another issue exists for human drivers that could be characterized either as over-confidence<sup>84</sup> or complacency.<sup>85</sup> Drivers will use the autonomous systems and become increasingly self-assured of the system's ability to safely perform the driving task. They will progressively develop risk tolerance and become increasingly more willing to allow themselves to be distracted while the autonomous system is in

77 <[https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment\\_data/file/980644/Safe-Use-of-Automated-Lane-Keeping-System-ALKS-Call-for-Evidence-FINAL-accessible.pdf](https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/980644/Safe-Use-of-Automated-Lane-Keeping-System-ALKS-Call-for-Evidence-FINAL-accessible.pdf)>. Last accessed: February 8, 2022 para 5.1.2, p 39.

78 In many jurisdictions other legislation creates medical and disability exemptions for seatbelts. Any system that requires strict compliance with existing road rules must surely provide a human override in cases where such exemption exists.

79 34 at 853.

80 Co-existence with existing non- and semi-autonomous vehicles.

81 Much has been written to expose and discuss the myriad issues surrounding allocation of fault, apportionment of blame and liability when vehicles operating in autonomous control mode are involved in traffic accidents. Others have extended these arguments into the philosophical area of imbuing technology with ethical decision-making.

82 BI Schimelman, 'How to Train a Criminal: Making a Fully Autonomous Vehicles Safe for Humans' (2016) 49 Connecticut Law Review 327.

83 *ibid*.

84 G Innes-Jones and L Scandpower, 'Complacency as a Causal Factor in Accidents-Fact or Fallacy' (2012) *London: IChemE Symposium Series 158, Hazards XXIII*.

85 *ibid*. Complacency in this context is defined as: self-satisfaction which may result in non-vigilance based on an unjustified assumption of satisfactory system state.

control of the vehicle. Proponents of the 'risk homeostasis' theory<sup>86</sup> would suggest that as autonomous vehicle systems like Tesla's 'Autopilot' and BMW's 'Driver Assistant Professional' become more capable and potential increases in vehicle safety are realized, risk tolerant drivers will use the journey as some autonomous vehicle advocates intend: to catch up on work, read or watch movies. While distracted, these autonomous vehicle owners will not observe cues of an impending accident and will fail to take necessary corrective action, resulting in accidents and a rebound to pre-autonomous vehicle accident levels. Examples of this effect can already be seen where misplaced confidence in these newly developed autonomous systems is resulting in accidents arising from reckless and risk tolerant behaviours.<sup>87</sup>

It has recently been suggested that the race to full SAE Level 5 automation is itself the issue: the reason existing philosophies and approaches for creating the safe fully autonomous vehicle have failed to truly realize that which they seek.<sup>88</sup> While the push for automation continues unabated and in many different directions, safety is being considered by technologists only after the primary function of the smart system has already been successfully resolved: often using data collected from large groups of early adoption users to understand and resolve safety-related issues.<sup>89</sup> The approach of many philosophers, ethicists and autonomous car researchers has been to further cloud the safety issue with fundamentally pointless no-win moral dilemmas based on the 'trolley problem'.<sup>90</sup> Barry Lunn and others argue that the safety issue should come first: that AI should be developed to learn from human drivers rather than be developed as empty vessels to replace them, and that improving systems and safety to avoid accidents so that we never have a trolley problem is preferable to continued philosophizing about how we might wish an already established system to respond.<sup>91</sup>

86 GJ Wilde, 'Accident Countermeasures and Behavioural Compensation: The Position of Risk Homeostasis Theory' (1989) 10 *Journal of Occupational Accidents* 267–92. Risk homeostasis theory suggests that as new systems or features increase safety, people become more willing to engage in less safe behaviours, thus serving to maintain the accident or fatality levels at a static level. Examples include that as seat belts, airbags and anti-lock braking systems were implemented and cars became safer with fewer accidents, drivers became more willing to speed and drive too close to the vehicle in front, serving to increase accident and fatality levels and return them to previous levels.

87 Examples include: (i) Devainder Goli of Raleigh in the USA who was charged after being observed watching a movie while Tesla Autopilot drove his car at highway speeds; (ii) Param Sharma of California who has been charged multiple times and had his vehicle confiscated after being seen mid-journey to climb from the drivers' seat into the back of his Tesla while Autopilot was engaged and the vehicle was in motion; (iii) Joshua Brown of Florida whose confidence in the autonomous system led him to watch a Harry Potter movie while Autopilot drove his Tesla into the trailer of a large semi-truck, killing him; and (iv) at least three examples where Tesla vehicles in Autopilot mode drove into the backs of stationary fire trucks while occupants were engaged in reading, watching movies on their phones or other non-driving tasks.

88 D Brown, 'How Should Autonomous Cars make Life-or-death Decisions? In the Best of Worlds, they Won't' *Washington Post* (6 August 2021) <<https://www.washingtonpost.com/technology/2021/08/06/self-driving-ai-death-decisions/>>. Last accessed: February 8, 2022

89 S Edelstein, 'Tesla's Autonomous-car Efforts use Big Data no other Car Maker Has' *Green Car reports* (30 December 2016) <[https://www.greencarreports.com/news/1108065\\_teslas-autonomous-car-efforts-use-big-data-no-other-carmaker-has](https://www.greencarreports.com/news/1108065_teslas-autonomous-car-efforts-use-big-data-no-other-carmaker-has)>. Last accessed: February 8, 2022

90 E Awad and others 'The Moral Machine Experiment' (2018) 563 *Nature* 59–64.

91 See 71.

## CONCLUSION

Our work shows it is possible to ‘deconstruct’ traffic law into a series of structured rules that can then be used to ‘construct’ tools: Boolean equations and visual representations. These tools can be used in development of AI and autonomous systems, and along with the structured rules, in verification and validation of the operation of the rule of law in the resulting system’s decision-making processes and outcomes. We have observed on other projects<sup>92</sup> and in other domains<sup>93</sup> that this (de)construction approach and the resulting tools are within the capabilities of expert practitioners, and that the tools make often highly technical domain-specific knowledge sufficiently comprehensible for AI developers and decision scientists who seek to make legislation and the rule of law an active component of their AI decision-making models.

92 See 10.

93 S McLachlan and others, ‘Real-time Online Probabilistic Medical Computation using Bayesian Networks (No. 2744)’ *Proceedings of the IEEE International Conference on Health Informatics (ICHI 2020)*. DOI: 10.1109/ICHI48887.2020.9374378; and, S McLachlan and others, ‘Clinical Caremap Development: How can Caremaps Standardise Care when they are not Standardised?’ *Proceedings of the 12th International Joint Conference on Biomedical Systems and Technologies (BIOSTEC 2019)*, vol 5: HEALTHINF, pp 123–34.