

March 17, 2021

Motional Response

Law Commission of England and Wales and Scottish Law
Commission Consultation Paper 3

Introduction

While road safety has improved dramatically over the last century, road transportation continues to claim 1.3 million lives across the world each year, an unacceptable rate.¹ Human error continues to be a critical reason in the overwhelming majority of motor vehicle collisions.²

Motional is a United States based company building Society of Automotive Engineers International (SAE) Autonomy Level 4 full-stack AV systems. Motional has operations in the US and Asia and is a joint venture between Hyundai Motor Group, one of the world's largest vehicle manufacturers, and Aptiv, a global technology leader in advanced safety, electrification, and vehicle connectivity.

Motional is committed to improving the safety of our roads; we believe that driverless technology and autonomous vehicles (AVs) will improve road safety. AVs are poised to significantly reduce the risks of distracted or impaired drivers; AVs make safe driving decisions based on detailed and precise information about their surrounding environment. In addition to critical safety benefits, broad AV deployment would lead to more efficient road and land use,³ more affordable and accessible mobility, and better use of commuting time.

¹ World Health Organization, "Global status report on road safety 2018," World Health Organization, Geneva, Switzerland, 2018.

² S. Singh, "Critical reasons for crashes investigated in the national motor vehicle crash causation survey," Report DOT HS 812 115. National Highway Traffic Safety Administration, Washington, DC, 2015.

³ K. Spieser, K. B. Treleaven, R. Zhang, E. Frazzoli, D. Morton and M. Pavone, "Toward a systematic approach to the design and evaluation of automated mobility-on-demand systems: A case study in Singapore," in Road Vehicle Automation, (Lecture Notes in Mobility), G. Meyer and S. Beiker, Eds., Springer, 2014.

The Law Commissions (“Commissions”) have raised numerous important questions about the governance of AVs and Motional is grateful for the opportunity to contribute to its deliberations and recommendations. As a global company with operations across a range of localities in the United States and Asia, Motional has a particular interest in furthering the Commissions’ interest in adapting rules of the road for AVs. Motional played an instrumental role in the creation of Singapore’s Technical Reference 68 (TR 68), which touched on some issues raised in the Consultation.⁴

In this communication, we specifically address Consultation Questions 26 and 27. Motional continues to believe that adapting rules of the road for AVs is an important topic for collaboration between public and private stakeholders and values the attention that the Commissions are focusing on this topic. With that background, we turn to a response to the consultation questions followed by an additional section with a description of Rulebooks. Rulebooks is a theoretical framework Motional has invented to address some of the underlying questions raised by the Commissions in Consultation Questions 26 and 27.

Consultation Question 26

Question

Should the UK Government establish a forum for collaboration on the application of road rules to self-driving vehicles?

Motional Response

Motional believes that the establishment of a collaborative forum for applying the rules of the road to AVs can significantly advance both the specific question of how to interpret existing laws for AVs as well as contribute to the broader task of building consensus for what is considered good driving behavior. However, it is critical that the forum ask constructive questions, expect realistic outputs, set an appropriate scope, and engage the right set of stakeholders. To this end, we share informative perspectives gleaned from Motional’s experience developing AVs to follow rules of the road to the greatest extent possible.

⁴ Singapore Standards Council, "Technical reference 68 for autonomous vehicles," ICS 03.100.70; 43.020. Enterprise Singapore, Singapore, 2019.

Perspectives on AVs and the rules of the road

The Commissions identified a number of technical and policy issues with translating rules of the road into machine-readable specifications. Our experience with translating rules of the road encountered similar issues; further details about Motional’s Rulebooks approach are contained in a later section of this response. To assist the Commissions in shaping their recommendation to establish a forum, we offer a framework which outlines the interconnection between formalizing rules of the road, resolving conflicts between rules, and capturing a holistic definition of good driving. Ultimately, these issues are deeply interwoven.

1. *Formalizing the rules of the road*

Formulating rules of the road as unambiguous mathematical statements would allow AVs to follow rules to the greatest extent possible and enable developers to build safer, more consistently driving AVs. As noted by the Commissions, many laws appeal to qualitative notions and qualifiers rather than quantitative parameters, presenting difficulties in precisely translating rules of the road for machine understanding. Rules of the road are written by humans, obeyed by humans, enforced by humans, and adjudicated by humans and consequently, fundamentally appeal to qualitative assessments and judgment. In rules of the road, qualitative judgment is often introduced through terms such as “reasonable”, “prudent”, or “proper”.

A Digital Highway Code or, set of rules of the road usable by an AV, would replace ambiguity with deterministic parameters whenever possible. For example, it is relatively straightforward to define when a vehicle is violating the speed limit. A useful traffic code for AVs would similarly define when a driver violates a law requiring it to yield the right of way; this would enable developers to more consistently build this behavior into AVs.

2. *Resolving conflicts between rules*

Even if each rule of the road was translated into a mathematical statement, this would be insufficient to fully specify how a driver should lawfully behave in all circumstances. As the Commissions and others have noted, rules of the road can be vague and conflicting,

leaving a driver with a choice to only obey a subset of applicable rules.⁵ Therefore, even if each individual rule was written unambiguously, it is inevitable that a driver navigating complex urban scenarios will regularly need to weigh compliance with one rule against another. Since rules of the road rarely indicate their relative priority with other rules, this implies that additional information that is not currently part of the rules of the road is needed to resolve such conflicts.

Additionally, since not all violations of the same rule are equivalent (it is worse to go through a stop sign at 30 miles per hour than at one mile per hour, even though both are violations of the law), a driver might not just consider whether to violate one rule or another, but might consider whether some degree of violation of one rule is more or less important than some degree of violation of another rule. Making such judgments will require additional information not currently in the rules of the road.

3. *Capturing holistic driving considerations*

The Commissions note several examples where rule violations might be contemplated in service of goals such as allowing emergency vehicles to pass or to be able to pass through a crowded intersection. The Commissions solicited input on the proper behavior for these examples and generated sharply divided responses.

In our view, difficulty in achieving consensus on these questions is less about the inability to distill the exact requirements of the relevant rules of the road as much as it speaks to the role of human judgment in considering competing outcomes. Rules of the road frequently refer to concepts of reasonableness, safety, care, and other behavioral exhortations which are not formally defined within a rule. A human driver implicitly balances these concepts against the literal demands of any rule.

This implies the need to embed some concept of reasonable, safe, and predictable driving in an AV that would be external to a literal translation of laws. This presents its own set of policy and technical issues; particularly challenging is the need to codify how the created notions of not-explicitly-legal considerations might be weighed against the literal demands of the law.

⁵ Prakken, H. (2017). On the problem of making autonomous vehicles conform to traffic law. *Artificial Intelligence and Law*, 25(3), 341-363.

In sum, we conclude that it is almost impossible to disentangle the question of complying with rules of the road as literally written from the broader question of what constitutes reasonable, safe driving. There is considerable research across industry, academia, and government that seeks to define proper behavior for AVs across a diverse range of scenarios. Of particular note is the activity of UNECE's Working Party 29, whose regulations are beginning to include behavioral specifications.⁶ Our core finding, which informs our comments, is that not only must a comprehensive behavioral specification for AVs consider rules of the road, but that truly integrating the rules of the road into an AV requires working towards a comprehensive framework for AV behavior.

Consultation Question 27

Question

We welcome views on: (1) the issues the forum should consider; (2) the composition of the forum; and (3) its processes for public engagement.

Motional Response

Issues for the forum to consider

The scope of the forum could be construed narrowly, corresponding to the first framework element in our response to Consultation Question 26. Such an approach would seek to create more consistent methodologies for the adaptation of any single rule for an AV. Alternatively, the forum could have a broader scope, seeking to answer questions about how rules of the road interact with each other as well as implicit considerations of safety, utility, and reasonableness. Given the framing of the consultation, we understand the Commissions to consider even the narrower construction to be of challenging breadth and scope.

We believe that a forum created in line with the Commissions' recommendation could significantly enhance and harmonize the ability of AV developers to comply with the rules of the road and balance them with other driving considerations. While the original framing of the

⁶ United Nations Economic Commission for Europe (UNECE). Proposal for a New UN Regulation on Uniform Provisions Concerning the Approval of Vehicles with Regards to Automated Lane Keeping System (ECE/TRANS/WP.29/2020/81); UNECE: Geneva, Switzerland, 2020.

question is centered around translating the rules of the road in the UK into a Digital Highway Code, we suggest that the forum be organized to align with both the current state of the art in research as well as ongoing work at several standards and regulatory bodies across the world that are stakeholders to the task of translating the rules of the roads into AV behavioral specifications.

We suggest that the Commissions initially focus on the translation of rules of the road, particularly in the cases of qualitative language and interpretation, and defer dealing with conflicts between rules of the road or between rules of the road and unwritten norms which are not easily captured. These can be more effectively dealt with after the initial stage or could be addressed through other organizations and processes. We note that some of the varying responses the Commissions received to its earlier inquiries resulted from asking respondents when certain laws should be violated. Our suggestion is that focusing on the more foundational task of translating rules would be productive as it precedes the more difficult questions of tradeoffs.

A stated goal of the Commissions is to better harmonize interpretations of rules of the road. Since there are numerous jurisdictions with relatively similar rules of the road, we suggest that the Commissions recommend a forum that is more focused on building consensus for the methodologies to adapt rules of the road for AVs than on specifically translating the rules of the road in the United Kingdom. This would promote engagement by a broader range of stakeholders who are not in the UK, and the final result would still be very germane to UK stakeholders.

Composition of the forum and public engagement

A potential successful outcome of the forum would be to create more harmonized methodologies for translating traffic laws into AV behavioral specifications. A partial set of relevant stakeholders includes: developers of automated driving systems, researchers specializing in logical behavioral specifications in automation, law enforcement and road user safety advocacy groups to provide perspectives on interpreting rules of the road, experts in traffic safety engineering, experts in the intersection of emerging technology and law, standards organizations such as SAE, ISO, and IEEE, and representatives of regulatory bodies at the international and national levels.

In our experience, the essence of adapting a rule of the road for AVs is to take the legal text of an individual rule and fully specify it using mathematical and logical statements. If formulated

well, these statements could be used to determine, given hypothetical actions by a driver and other road actors, whether the driver is complying with the law. A well-adapted rule of the road would give a clear and objective binary answer.

Based on our earlier comments, we view ongoing efforts to develop safety models⁷ and AV behavioral regulations as closely related to this effort, but believe they should be kept distinct at this stage. Ultimately, safety models will be required to better understand how to incorporate safety judgments that are in tension with the literal requirements of rules of the road. We would recommend working closely with developers and bodies responsible for determining acceptable AV behaviors that do not arise explicitly from rules of the road, with the goal of eventually harmonizing safety models and rules of the road into a comprehensive behavioral specification. Key entities that work on behavioral specifications include the UNECE, the Society of Automotive Engineers (SAE), and the Institute of Electrical and Electronics Engineers (IEEE).

Rulebooks

A framework for integrating rules of the road into AV behavior

Motional, in collaboration with leading academic scientists, has invented and published Rulebooks, a framework for ensuring maximal AV compliance with rules of the road while considering concepts of safety, comfort, and utility.⁸ The Rulebooks framework is a methodology to integrate behavioral specifications derived from multiple sources, including safety analysis, rules of the road, real-world driving data, and utility (e.g. getting to the destination). Behavioral specifications are encoded as formal rules, where each formal rule is a precise mathematical and logical statement about how a good driver behaves (i.e. don't go through a red light, maintain appropriate clearance with other vehicles, drive in a manner comfortable for passengers).

Motional continues to publish advances in the development and application of the Rulebooks framework. Rulebooks can be used in conjunction with industry standard safety processes to

⁷ IEEE (2021). *P2846 - Assumptions for Models in Safety-Related Automated Vehicle Behavior*, accessed March 16, 2021, <<https://standards.ieee.org/project/2846.html>>

⁸ Censi, A., Slutsky, K., Wongpiromsarn, T., Yershov, D., Pendleton, S., Fu, J., & Frazzoli, E. (2019, May). Liability, ethics, and culture-aware behavior specification using rulebooks. In *2019 International Conference on Robotics and Automation (ICRA)* (pp. 8536-8542). IEEE.

develop safe AVs,⁹ serve as the basis for selecting the optimal trajectory in a complex scenario,¹⁰ and provide surrogate metrics for accelerated evaluation of safe driving.¹¹ Rulebooks is a promising framework, in part because it is applicable in all driving scenarios. This eliminates the need to classify a given driving situation as belonging to a specific scenario type and only then applying the behavior developed for that specific scenario.

Core to the Rulebooks framework is the notion that a reasonable driver will, with some regularity, violate some behavioral specifications. To select the most reasonable and safe trade-off, Rulebooks creates a priority structure that codifies the relative importance of different behavioral specifications. For example, the framework might encode that uncomfortably hard braking - which should be minimized - is preferable to running a stop sign or driving too close to another vehicle. The Rulebooks framework is specifically designed to address considerations for balancing rules of the road with each other and implicit concepts such as safety and utility. Our experience developing the Rulebooks framework and working across the United States and Asia informs our responses to the consultation questions.

⁹ Collin, A., Bilka, A., Pendleton, S., & Duintjer Tebbens, R. (2020). Safety of the Intended Driving Behavior Using Rulebooks. In *2020 IEEE Intelligent Vehicles Symposium (IV)* (pp. 136-143). IEEE.

¹⁰ Xiao, W., Mehdipour, N., Collin, A., Bin-Nun, A., Frazzoli, E., Duintjer Tebbens, R., & Belta, C. (2021). Rule-based Optimal Control for Autonomous Driving. *arXiv preprint arXiv:2101.05709*.

¹¹ Bin-Nun, A. Y., Panasci, A., & Duintjer Tebbens, R. (2020, January). Heinrich's Triangle Heavy-Tailed Distributions and Autonomous Vehicle Safety. In *Transportation Research Board Annual Meeting, Washington, DC*.

Conclusion

Motional deeply appreciates the engagement of the Commissions on the important topics raised in their consultations and looks forward to continued engagement. Please do not hesitate to reach out to us if we can be of further assistance.

A handwritten signature in black ink, appearing to read 'A. Bin-Nun'.

Amitai Bin-Nun, Ph.D.
Senior Research Scientist
Motional

A handwritten signature in black ink, appearing to read 'R. Duintjer Tebbens'.

Radboud Duintjer Tebbens, Ph.D.
Principal Data Scientist
Motional

