Quarterly Report for MassDOT & City of Boston

2nd Quarter 2021

Background

Motional is committed to designing for people: for families that need to get their children to school safely; for elderly passengers who need continued access to mobility; and for urbanites who, more than ever, have a choice in how they get around cities. We know that self-driving vehicles have the potential to bring vast benefits to humanity: increased mobility, fewer traffic-related deaths, and a greener planet. But the only way to fulfill these promises of tomorrow is to build trust in the technology today. We believe that when we demonstrate openness and collaboration, trust follows.

Our team's expertise in autonomous driving can be traced from our R&D roots at MIT and Carnegie Mellon University, where we showcased our autonomous technology in the DARPA Grand Challenge and DARPA Urban Challenge, to our present-day commercial operation in Las Vegas, which has safely provided more than 100,000 self-driving rides to members of the public. We are proud to report that our attention to safety has extended into our real-world operations. We have driven over 1,000,000 miles in complex city environments worldwide while maintaining a record of zero at-fault incidents.

Today, our global team—spanning the U.S. and Asia—is dedicated to delivering safe and reliable production-ready SAE Level 4 robotaxis that will make roads safer and improve mobility worldwide. As we advance the technology, our people-first ethos will ensure that safety, security, and privacy are embedded in every step.

Motional has made the most of the first year since it was established as a joint venture

between Hyundai Motor Group and Aptiv in March 2020. We've made significant strides in advancing our driverless product. Motional has concluded over 100,000 hours of safety evaluations, built processes for actively identifying cybersecurity threats, and pursued inclusive User Experience (UX) research to ensure our vehicles will ultimately be accessible to disabled riders. After a rigorous review by a third party assessor, we began testing our Pacifica in driverless mode on the public roads around Las Vegas in early 2021. In March 2021, we announced that we'll be migrating to an all-electric Hyundai platform, the IONIQ 5, for our AV testing. We also have launched our nuPlan benchmark to provide a dataset for autonomous vehicle planners, while working to safely resume passenger service in Las Vegas in line with the easing of COVID-19 restrictions.

Testing activity

Motional has started to broaden the scope of its autonomous capabilities by continuing to work on suburban elements as well as taking aim on more urban dense driving. For example, by utilizing our closed course tracks we are working on traffic light environments and ensuring consistent perception and reaction to changing traffic lights.

Our work on the Safety Steward role is continuing to grow and develop. This individual will sit in the front passenger seat to oversee driverless testing. We are refining the protocols for Safety Stewards, including when and how they intervene with the emergency stop buttons.

Operational Design Domain (ODD)

Our vehicles are designed to operate in low-speed (<35 MPH), urban environments in various conditions. We continuously validate all vehicle performance and behavior changes to our AVs in simulation, then in a closed-course setting before operating them on public roads. To date, we have experience testing on public streets with a variety of road actors, including heavy vehicle traffic, cyclists, and pedestrians. Additionally, we have operated our AVs safely in daytime and nighttime and windy, rainy, and snowy conditions in closed-course and public road environments.

Amount of testing

Our testing occurs primarily during regular business hours (Monday through Friday, 9AM-5PM). As mentioned above, this testing includes specialized testing in closed-course and data gathering in the Seaport / South Boston area.

As we continue to develop and build out our Generation 2 Ioniq platform we are exploring multiple avenues for more efficient testing methods. Such methods include finding better ways to verify the basic autonomous capabilities of the vehicle before doing significant real world testing. These new practices involve multiple stakeholders within Motional to ensure that our approach is not only safe but also allowing ourselves to be more time effective.

Takeover procedure

Vehicle Operators take over manual control in any situation in which they feel uncomfortable or unsafe. Planned takeovers are also done when finishing a mission or approaching situations that are not within the outlined ODD. We are also refreshing our Fault Injection training with all Vehicle Operators where intentional system errors are introduced to make sure our operators takeover in the proper fashion before returning to public roads.

During the Second Quarter, our vehicle operators took over manual control of our AVs in the following situations:

- When emergency vehicles were in active operation (e.g., sirens and lights activated) in the roadway;
- When law enforcement officers were manually directing traffic in intersections through which our AVs were traveling;
- When construction vehicles were obstructing our lane of travel;
- When oncoming vehicles or bicycles violated lane boundaries;
- When weather conditions deteriorated rapidly; and,
- When other vehicles were exhibiting erratic behavior near our AVs.

A vehicle operator's decision to take over manual control in a given situation does not necessarily indicate that continued autonomous operation in those situations would be unsafe. Because we instruct our vehicle operators to err on the side of caution, we expect that takeovers will occur in many cases in which the AV would have handled the situation without incident.

Description of ADS System failures

We did not experience any unanticipated failures or disruptions while driving in autonomous mode. As we explain above in greater detail, in specific traffic scenarios, our vehicle operators take over manual control because of known limitations of the current state of AV software.

Goals for future testing

Continue to expand our autonomous capabilities through proven closed course track tests before transitioning to public road driving. We anticipate being on public roads in both our Pacifica and Ioniq platforms this year.

When looking at future testing we are keeping an eye on ride-hail abilities and much of that comes down to pick up and drop off scenarios. While our Product team is exploring the various interactions members of the public would have with a fully driverless car in their own User Experience testing, the Operations team will be working on the physical practice of autonomously doing pullovers in challenging scenarios that we see in the Boston area.

Insights

Motional's autonomous vehicles make rule-based decisions derived from the vast streams of data that they receive from advanced LiDAR remote sensing technology, cameras and radar. Terabytes of data, some of it extraneous, some of it critical to safe driving,

are broken down by our software using deep learning. Data from all of our sites is constantly broken down and analyzed in an ongoing iterative process that directly informs our on-the-road testing in Boston. Our vehicles are thus not encountering the world anew each time they travel from the testing lot along our routes throughout the Seaport area. The production of detailed, high-definition mapping is a key part of our development process, as we develop and annotate maps which provide a firm foundation for our vehicles as they navigate through their Operational Design Domains (ODDs). Our publicly released nuScenes dataset, which has been cited more than 220 times and includes many annotated images from our mapping of Boston, gives insight into how we interpret data from Massachusetts.

Motional's testing is getting smarter, as we trial new ways of connecting our vehicles to even richer sources of real-time data. Our relationship with the predictive analytics platform Derq has facilitated a vehicle-to-everything (V2X) pilot in Las Vegas with important implications for the future development of connected and autonomous vehicles. Cameras located atop roadside intersections feed data to Derq's roadside computers, which can communicate an entirely new view (a birds-eye view) to Motional's vehicles that complements the onboard sensors. Real-time analysis of intersections gives an unobstructed view of traffic to the autonomous vehicles, including information not just about other cars in the intersection but also vulnerable road users and physical objects. The pilot program starts with offline comparisons of the perspectives from the two sets of cameras and was designed to transition to real-time transmission of data from the Derq computers to the vehicles. This technology is especially promising for extremely complex intersections where even human drivers struggle to predict the activity of massed vehicles going in multiple directions. In the long term, this kind of technology could reduce accidents at problem intersections like Columbia Road and the Southeast Expressway in Dorchester.

V2X technology is an important pillar of the future integration of autonomous vehicles with a connected environment that includes the Internet of Things. Given the recent federal reallocation of a significant fraction of the mid-band DSRC (Dedicated Short Range Communications) spectrum previously reserved for connected vehicles to unrestricted commercial use, autonomous vehicle companies have had to move quickly to turn to V2X and long-term evolution (LTE). Innovations like the Las Vegas roadside camera pilot program speak to the power of V2X to enable smarter driving by autonomous vehicles maneuvering in complex intersections. Motional is closely tracking a number of ongoing V2X studies underway in the Boston area and the Commonwealth as a whole.

Eventually, V2X can not only support safe driving, but also lead to more smooth and comfortable rides for passengers by enabling

the vehicle to make earlier decisions. Connected vehicles could be alerted to the presence of objects out of their direct line of sight. Fleet and traffic management will both benefit from this technology, which will enable operators and urban planners to make smart, real-time decisions about where to put resources. While the pilot program in Las Vegas is an incremental step towards the connected infrastructure of the future, it speaks to the disruptive potential of V2X technology in Boston and globally.

Feedback for municipal and state transportation engineers, planners, and policymakers

Disengagement reports from autonomous vehicle companies are attractive metrics for state and local policymakers given the seemingly clear insight they provide into the reliability of driverless systems. The autonomous vehicle industry has raised a number of issues with disengagement reports, including that the degree of discretion afforded to operators in defining disengagements means that true company-to-company comparisons are impossible. First-order consequences of overreliance on disengagement reports in a locality can include an incentive for operators to conduct less public road testing volume overall as well as less difficult testing, as well as more testing on private tracks. The result is less investment in local testing operations, hiring of fewer vehicle operators and reduced public exposure to innovative AV technology.

Other consequences of overreliance on imprecise and non-uniform disengagement reporting include the generation of datasets which produce research that then informs public policy. For example, a study on vehicle operator reaction times during disengagements in California was produced at a time when seven companies were conducting driverless testing in the state. But because only two companies reported precise reaction times for disengagements, while the others chose to report reaction times in terms of upper bounds (e.g., <1 second), the study's reaction time dataset was limited to those two operators. However, the industry as a whole is affected by the policy recommendations that are drawn from this kind of study, even though the most meaningful data speaks only to the best practices and state of the technology at two companies in a field where resources, strategy, and technical proficiency diverge widely.

In considering whether and how to utilize disengagement metrics, localities should consider the precision with which disengagements are defined as well as how even incomplete disengagement data will be publicized and used by the media, the business community, academic researchers, and ultimately policymakers.