Quarterly Report for MassDOT & City of Boston

4th 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 1,500,000 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 our global headquarters, Boston is a vital part of our research, development, and testing ecosystem. We're continuing to invest in our Boston operations and are currently hiring for over 100 new positions.

In early September we made an important reveal in collaboration with Hyundai, the design of our all-electric robotaxi based on the Hyundai IONIQ 5. The IONIQ 5 robotaxi has all the IONIQ 5's consumer-centric features that wowed the industry when unveiled February 2021 - such as the neo-retro design, parametric pixel lights, auto flush door handles, low-profile interior, vehicle-to-load charging system, fast-charging capabilities, and 18.8 cubic feet of storage space - plus Motional's industry-leading AV technology package baked right into the design.

For the past decade, Motional's international R&D team has tapped into its Boston corporate headquarters, operations hub, and state of the art closed-course testing facility. In 2021, Motional committed to continuing to grow its footprint in its Boston hometown. To support the 2023 deployment of Motional's Level 4 robotaxis, we made a multimillion dollar investment to expand our Seaport operations facility at Black Falcon, conduct extensive hiring, and increase R&D testing.

The expansion of the operations facility will double the usable space and triple the available occupancy for Motional's talented teams to develop safe and smart Level 4 systems. With the added space, Motional plans to grow our local team by adding more than 100 new Boston-based positions in engineering, product, and IT functions. Along with the expansion, Motional plans on increasing testing on Boston public roads with the all-electric IONIQ 5 robotaxi in preparation of Motional's fully driverless public robotaxi service launching in Las Vegas in 2023.

Testing activity

Our testing efforts continue to focus on the Hyundai IONIQ 5 platform, which includes advanced hardware and technical capabilities compared to previous generations.

Operational Design Domain (ODD)

Our vehicles are designed to operate in low-speed, urban environments in various conditions. We validate vehicle performance in simulation environments, then in a closed-course setting before operating on public roads. To date, we have experience testing on public streets with a variety of road actors, including heavy vehicle traffic, emergency vehicles, construction, 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). This includes specialized closed-course testing and on-road data gathering in the Seaport / South Boston area.

As we continue to develop our IONIQ 5 robotaxi, we are expanding our testing methods to include more simulated environment testing.

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Takeover procedure

Motional's vehicle operators can 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 fourth 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) on 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

We continue to expand our autonomous capabilities through closed-course track tests before transitioning to public road driving. We anticipate being on public roads in both our Pacifica and IONIQ 5 vehicles in 2022.

We are also using our IONIQ 5 robotaxis to gather user experience feedback from the public. Motional's Product team will continue to get feedback from a diverse background regarding the capabilities they would like to see while riding in an autonomous vehicle.

Insights

As we execute our strategy of designing safe, cost-effective, driverless vehicles, our team has honed in on solving the problem of how to properly train its machine learning models to handle unusual or complicated driving encounters.

In essence, the challenge is providing the machine learning models with enough edge

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case data to train it to safely handle these encounters. For instance, the vehicles must be able to perceive an infinite number of road scenarios ranging from tall snow banks lining the edge of Boston's Seaport streets to pedestrians carrying surfboards in Santa Monica.

In response, the Motional team has designed a system that can be used to sift through mountains of data to train and validate the machine learning models that allow Motional robotaxis to operate safer than human drivers. We are leveraging this scenario mining approach as part of our overall continuous learning framework to improve our technology with limited human intervention. This approach allows for issues with the driverless system to be quickly detected, categorized, and curated into the problematic datasets that we can use to measure and validate its software stack.

The scenario mining approach begins with the logs generated by our AVs. For instance, the millions of data points collected in our operations facility at Black Falcon will be processed using machine learning-powered offline perception systems. We can then automatically create ground truth labels that can be used to compute attributes for every instance in the log, then store the semantic description of the environment in a searchable database of AV attributes, agent attributes, machine model errors, and custom metrics. Our team can hand pick attributes or leverage the Continuous Learning Framework to find detection and prediction errors between offline and online perception systems.

Using this mined data, Motional can create specific datasets with problematic scenarios

that can be used to train the machine learning models. It is critically important that the software changes are validated through simulation before deploying to the AVs. At the operations facility at Black Falcon, Motional engineers can run simulations using problematic scenarios to identify possible areas of regression in the AV models before any Motional AV hits the road. As a result, Motional vehicles at Black Falcon are improving automatically.

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

With the ever-evolving landscape of autonomous vehicle legislation across the world, the terminology describing the technology has emerged as an unanticipated challenge for the AV industry. Specifically, advanced driver-assistance systems (ADAS) and automated driver system (ADS) equipped vehicles have been conflated by the media, legislators, regulators and some electric vehicle manufacturers.

The two technologies are fundamentally different, with the most important distinction being that ADS-equipped vehicles are designed to entirely function without a human driver, whereas ADAS-equipped vehicles do not have that capability. The conflation of the technology is problematic because it damages the public's understanding of the capabilities of

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the two distinct technologies, which can create imminent safety risks by virtue of the misuse of ADAS technology. The unsafe use of ADAS technology could inadvertently jeopardize the future of ADS-equipped vehicle safety and mobility benefits.

As a leader in the development of autonomous vehicles equipped with ADS, Motional is focusing on consumer education to improve public understanding of AVs, AV technology, and the differences between ADAS and fully driverless vehicles. In November, Motional released its Second Annual Consumer Mobility Report and concluded that consumer trust in AV technology is improving, but there still remains confusion around autonomous vehicle technology.

As local, state, and federal legislatures look to enact autonomous vehicle legislation, we encourage policymakers to carefully draft legislation that appropriately reflects the stark differences between ADS and ADAS technology. We recommend that federal regulations around vehicle performance standards, safety, and certifications for ADS-equipped vehicles accurately reflect the benefits and limitations of the technology.

We look forward to continuing to educate the public, media, and policymakers on the intricacies of ADS technology.

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