Article for Thinking Highways

Vehicle Automation Challenges

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For a researcher who has been working on road vehicle automation systems for 40 years, it is exciting to witness the high level of attention this topic is receiving now. The general interest media, as well as the trade press, seem to be publishing stories almost every day and the Internet is overflowing with commentaries about automated driving. Unfortunately, the vast majority of what is being written and said is naive, uninformed speculation that seriously underestimates the technical challenges that must be overcome before fully automated driving can become reality.

Most of this upsurge of interest in automated driving can be credited to Google and their highly publicized work on "self-driving cars", but so can a good portion of the unrealistic expectations that have been raised. A large part of the problem is that many different concepts for driving automation have been tossed together indiscriminately without recognition of their large differences. The problem is compounded by widespread mis-use of the term "autonomous" (which simply means independent and self sufficient) as a synonym for "fully automated" (which means using a machine to replace a human function). It is important to clarify the contrasts among the diverse automated driving operational concepts so that they can be considered independently.

The most important discriminant among concepts is the level of driving automation that a system provides. The German Federal Highway Research Institute, BASt, has done an excellent job of classifying these levels of automation as:

1. Driver only – Human driver executes manual driving task.
2. Driver assistance – The driver permanently controls <u>either</u> longitudinal <u>or</u> lateral control. The other task can be automated <u>to a certain extent</u> by the assistance system.
3. Partial automation – The system takes over longitudinal <u>and</u> lateral control; the driver shall <u>permanently monitor</u> the system and shall be prepared to take over control at any time.
4. High automation – The system takes over longitudinal and lateral control; the driver must <u>no longer permanently monitor</u> the system. In case of a take-over request, the driver must <u>take over</u> control <u>with a certain time buffer</u>.
5. Full automation – The system takes over longitudinal and lateral control completely and permanently. In case of a take-over request that is not followed, the system will <u>return to the minimal risk condition by itself</u>.

Level 2 automation is already commercially available quite widely in adaptive cruise control systems. Level 3 automation is available in vehicles that combine adaptive cruise control with lane keeping assistance, but since these are still relatively rare there is not yet a significant body of evidence about the ability and willingness of drivers to maintain the permanent monitoring that is required. If drivers relinquish that monitoring responsibility in favor of more interesting activities such as text messaging, reading or web surfing, the safety consequences are likely to be severe when the system encounters conditions that it cannot handle safely.

Many automotive companies and first-tier suppliers are now developing systems aimed at Level 4 automation for driving, but only under the simplest subset of driving conditions, on limited-access highways, especially in low-speed congested traffic conditions. Nobody, including Google, is seriously tackling the significantly more complicated challenges of operating in urban and suburban traffic conditions, where the traffic pattern complexity is compounded by the presence of pedestrians, bicyclists, pets, children, officers directing traffic, blind driveways, opening doors on parked cars, etc. The big challenge for the Level 4 systems is how to re-engage the driver's attention to take back responsibility for controlling the vehicle within the "certain time buffer" after the driver has disengaged to read, eat, web surf, or maybe even sleep. The length of that time buffer is not yet clearly specified, but will probably need to be within a very small number of seconds after a failure has occurred (or the system has encountered a road hazard that it cannot manage) in order to prevent a crash. This, in turn, means that the driver probably needs to be precluded from falling asleep or doing other highly distracting activities while the system is active. Unfortunately, those are likely to be precisely the things the driver would most like to do, and the biggest incentives for a driver to desire a Level 4 system. If the system has to nag the driver to keep him or her available to resume control when needed, it is likely to be perceived as more of a nuisance than a convenience.

The technological leap from Level 4 to Level 5 automation is vast, because at Level 5 the system needs to take over complete responsibility for the vehicle operation and its safety under all possible traffic conditions. This is the vision that captures the public imagination ("driverless" or "self driving" cars that can take a blind person to a fast food restaurant or chauffeur a seven year old child to school), but is also unlikely to be achievable on the general public road network for many decades, probably not even within this century. What makes this so hard technically? Many things:

- To be acceptable to the public and society at large, as well as to be insurable, the vehicles will need to be safer than today's driving. Based on recent road safety statistics in the U.S., this means that they would need to have less than one fatal crash per 3 million vehicle hours of travel and less than one injury crash per 60 thousand vehicle hours of travel. That is orders of magnitude longer than the mean times between failures for modern software-intensive consumer products such as laptop computers and mobile phones, and many orders of magnitude longer than any automated vehicle has ever driven *continuously*, in *real traffic*, and *without human intervention*.
- The vehicles need to be able to respond safely to essentially ALL hazard scenarios they may encounter on the road, without benefit of the learning that good defensive drivers acquire over years of experience, and without benefit of the often subtle human interactions that generally prevent hazardous conditions from becoming crashes today (eye contact with other drivers, hand gestures, verbal interactions, etc.).

- The vehicle sensor, control and actuation systems will need to be self-diagnosing, self-healing and functionally redundant in order to prevent their own failures of hardware or software from causing crashes. This will require extensive development and testing beyond the current state of the art for consumer systems, and is likely to be very expensive.
- The system software will be compelled to make decisions in morally ambiguous situations even if the vehicles were to have "perfect" sensor information (such as deciding whether to kill a motorcyclist on one side or crash into a large truck on the other side, severely injuring the occupants of the automated vehicle). Who is going to write the code that makes such a decision, and who is going to certify it?
- The vehicles will need to be tested extensively to prove (to regulatory authorities, insurers and customers) that they are indeed safe. Since the hazards that will be of concern are by their nature rare and unpredictable combinations of events, it is not clear whether a realistic accelerated testing program can be designed to prove operational safety without accumulating huge numbers of hours of testing.
- The performance requirements are multiple orders of magnitude more difficult than they are for commercial aircraft autopilot systems, but at the same time the system needs to be multiple orders of magnitude cheaper (and cannot be guaranteed to receive the prescribed preventive maintenance). Compared to an autopilot, the automated road vehicle will need to track an order of magnitude more targets, with tracking accuracy for each target a couple of orders of magnitude higher, and the system needs to detect and respond to new threats a couple of orders of magnitude faster as well in order to provide safety.

Since this is so difficult, what should we be doing about it now? That depends on what goals we are trying to achieve.

If the primary goal is improving driving safety, attention should be focused on improving the current generation of collision warning and control assistance systems, and augmenting these sensor-based systems with enhanced data available from V2V and I2V connected vehicle technology. *Combining* the sensor and communication data with the driver's own vigilance is a much surer path to improving safety than *removing* the driver from the equation and shifting the entire burden of hazard detection and response to an automated system.

If the primary goals are associated with mobility and the environment, there are great opportunities to apply automation technology to heavy vehicles operating in dedicated rights of way. Automated buses on a dedicated transitway can provide the service quality of rail transit at a much lower cost, enabling high quality transit service to be extended to much more of the population. Automated trucks on a dedicated truck roadway can provide dramatically increased capacity per lane while saving significant energy. In each of these cases, full automation should be technically achievable within a decade because the physical separation from the rest of the traffic network excludes external hazards and restricting access to properly equipped vehicles enables the vehicles to exchange knowledge of their own condition so that internal faults can be identified quickly enough that they can be managed safely without human intervention.