Table of Contents

Forward 04
An Introduction to CSRC 06
Before The Crash 08
How Your Vehicle Can be Smarter than Fitness Tracking Tech 14
Don’t Call Them Dummies 20
A Bump In The Road To Autonomy 26
Diagnosing Driver Distraction 32
Driver’s Ed For Robots 36
Acknowledgements 44
CSRC Projects / Partners 46
And yet in 2017, the automotive industry and regulators are looking back on 2016 that was more deadly to pedestrians and drivers, not safer. The trend is going in the wrong direction, despite new technology designed to keep passengers, drivers and passengers safer.

When the Collaborative Safety Research Center (CSRC) was founded in 2011, safety was just as much of a concern, then as now. The impetus of an automaker the size of Toyota might be to try to tackle the problem internally, but CSRC by design has asked, collectively, over 200 researchers at 23 research institutions throughout the U.S., Canada, and Mexico to ask their own questions.

CSRC starts with questions that are deceptively basic: How can we make drivers, passengers and pedestrians safer? But it doesn’t presuppose it’s even asking the correct question. It wants the researchers to determine that. Because while Toyota created CSRC with over 80 years of vehicle-making history in its wake, it was clear that no single automaker, and even collectively, even every automaker, couldn’t stop vehicle crash fatalities alone. That’s not the essence of their work—it’s to make the safest vehicles they can, but they can only make vehicles safer with better science.

Rather than look inward, CSRC was founded to look outward. To embolden and enable clinicians who study the human body as a profession, data miners who look for patterns in how and why we’re hurt in crashes, and human factors scientists who study drivers to understand why we engage in risky behaviors behind the wheel. CSRC wanted those researchers to use their own knowledge as a baseline. What questions could they answer? Where would those answers lead them?

Because even though Toyota didn’t have the answer, they did know that it wasn’t that kind of challenge because just like automating a vehicle’s functions doesn’t create autonomous driving (don’t forget, there are millions of human-driven vehicles still on the road that that autonomous vehicle has to interact with), saving thousands of lives a year in myriad kinds of vehicle crashes doesn’t have a single root cause. It’s bigger than that. It requires more expansive problem solving and being open to unconventional solutions.

Throughout the following chronicle, we’ve presented a highlight reel of collective research projects funded by CSRC and, in many cases, the reader will find we end the entry with a question, not an answer because oftentimes the research opened a door into a bigger space, a broader question, a wider field of inquiry.

Yes, the target of CSRC is zero fatalities caused by vehicles. And to get there Toyota clearly believes that the research they’ve funded to the tune of $50 million so far has to be open-minded, to embrace the idea that “answers” will only come in small pieces, and that solutions will require many wider fields of research, from medicine to human factors science, to engineering, to collaborate in ways they never have in the past. For this to work, it’s going to take the broadest possible kind of thinking. And lastly, if it’s going to mean not holding any form of learning internally, and this is why Toyota’s made all of CSRC’s work public rather than proprietary. This is also while throughout this document you’ll see outtakes we’ve called “Force Multipliers.” These are tangents, epiphanies and other areas of thought from the hundreds of researchers involved in the CSRC study. One thought leads to another, to an eventual cascade of discovery. That, too, has been part of the Toyota mission with CSRC, to cause exponential growth in safety research—to literally multiply the field—because the mission isn’t just to prevent crashes caused by Toyotas. Helping save lives, no matter whether it’s those of pedestrians, cyclists, drivers of other vehicles or drivers of Toyotas, is the bottom line, and that will only happen through the broadest kind of effort with other automakers, regulators, lawmakers and the public all understanding that safety comes before commerce, ideology, and nationality. It is as humanistic a goal as possible, and the reason the CSRC exists.

There could be no more apt single-word description of CSRC than “forward.” When it was founded five years ago, CSRC’s Director, Chuck Gulash and his team couldn’t necessarily have foreseen all the technological safety innovations to come.
In January 2011, Toyota founded the Collaborative Safety Research Center (CSRC) in Ann Arbor, Michigan with the desire to enhance the safety and security of drivers and pedestrians alike, while making broader contributions to society as a whole.

A great deal of the motivation to establish the CSRC was borne from the recall issues we faced from 2009 and 2010. On February 24th, 2010, I was requested to testify during the US Congressional hearings concerning Toyota recall issues. As I took the stand, I promised myself that I would not simply blame others. As the person in charge, I must shoulder the burden of not only what is occurring with Toyota at present, but also consider the past and the future. This is what we believe contributes to a safe and reliable mobile society.

CSRC has now been in existence for over five years. Collectively we have, and will continue our resolve to contribute to a safer mobile society. Our direct experience with the recall issues of the past has fueled this desire to contribute to the future realization of a safe and reliable mobile society for all. As a result, we will continue to contribute to new avenues of safe mobility, trying not to forget the experience at the time, and make the past five years of accumulated CSRC research even more beneficial to society.

I would like to take this opportunity to thank everyone who has helped make the CSRC successful. We look forward to supporting the center as it continues to evolve as a member of American society, widening its circle of activities to help support the realization of a more safe and secure mobile society.

Let’s continue to work together to build a safe mobile society.

Akio Toyoda, President, Toyota Motor Corporation
Studying the Anatomy of Crashes is the Only Way to Help Prevent Them

What happens during a vehicle crash? The question seems strangely simple, yet the answer is anything but. What’s worse, even as vehicles are gaining more safety technology, last year was the deadliest on record since 2007 for driving in the United States, according to the National Safety Council, with 40,200 deaths, and 4.6 million injuries.

Rini Sherony, a Senior Principal Engineer at Toyota’s CSRC, knows the grim statistics, and she also understands that we cannot prevent vehicle crashes just by adding more and more technology to vehicles. A sensor that reads what’s happening on the road—or in the cockpit—is only as smart as the programming behind it. And to understand how to program the technology that will prevent the next crash from occurring, you need to first create a comprehensive science of crashes. This happens to be Sherony’s life work, and when CSRC was founded in 2011, she led multiple prongs of research partners to answer the key question: What happens seconds before a vehicle crash? And also: What might be done to change the outcomes?

This research began, in part, by looking at massive federal databases such as National Automotive Sampling System (NASS), Fatality Analysis Reporting System (FARS), and CDS (Crashworthiness Data System), to analyze what kinds of crashes were both the deadliest—and possibly the most preventable.

“The first thing we look at is as much crash data as we can,” Sherony explains. “What was the vehicle doing in that crash, the speed, the posted speed limit, the direction of the vehicle, the kind of crash, such as single vehicle or if the vehicle left the road, the lighting conditions, et cetera.”

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Sherony says that what they learned, in conjunction with Virginia Tech’s Clay Gabler, chair of the Department of Biomedical Engineering and Mechanics at Virginia Tech and a CSRC partner, is that there were about 20 kinds of crashes that her team could quantify that accounted for about 90 percent of severe crashes. Remember: To reduce all vehicle crashes you have to first understand what most of them look like. Typifying crashes by type is a strong first step, because then you can begin to crack the code of the events themselves. And that’s just what happened.

Sherony and Gabler saw that one of the deadliest types of crashes is when a vehicle leaves the road—which comprises about 10 percent of all occupants involved in crashes, but accounts for 31 percent of annual fatalities. Then they wondered what would happen if all of the crashes that were caused by vehicles leaving the road (481 samples pulled from the NASS-CDS database in 2012) were preventable. What if those vehicles had, for example, lane departure warning systems (LDW) that told drivers when the system determined their vehicle was drifting off the road, so they could correct their steering angle and help prevent the wreck in the first place? Gabler’s team set about computer modeling the crashes as they happened, adding and subtracting variables derived from real-world events, as well as real-world challenges such as driver reaction time, shoulder width, and whether outside lanes were painted or unpainted (because lane detection largely depends on markings to signal the driver).

What Sherony and Gabler found is that the addition of LDW technology to all cars might be able to help prevent approximately 30 percent of all of those drift-out-of-lane crash types, resulting in about a 24-percent drop in the severity of driver injuries in this type of crash, potentially saving hundreds of lives annually.
Saving Pedestrians with A Bigger Variety of Fake Pedestrians

Yet another type of driver aid that could save lives is pedestrian detection. Concurrent with the LDW study, CSRC wanted to also look at these kinds of radar systems and how they’re deployed—and if they’re actually capable of detecting both pedestrians and other vehicles.

Working with researchers at Ohio State, Sherony asked another basic question: What should a vehicle’s radar see, and what is it actually seeing? So in the lab at Ohio State, researchers scanned different people of multiple shapes and sizes, and significantly, looked at their state of dress, “because,” Sherony explains, “skin reflectivity isn’t as strong as most clothing, and some radar frequencies go right through skin.”

The radar scanning of people led to the creation of a different kind of skin for surrogates that more accurately emulate real human skin’s radar reflectivity, and also led to the creation of a dummy cyclist. “This study yielded a learning, which was that while cyclist fatalities are, like pedestrian rates, on the rise, pedestrian detection systems weren’t helping to reduce these because, like radar transmitting right through pedestrians, detecting cyclists’ distance from vehicles wasn’t especially accurate. But a minor tweak in their algorithm, which would account for the doppler effect of cyclist’s legs as they pedal, would help create a earlier, more accurate warning.”

The effect of the entire study wasn’t just to create improved surrogates, but to prove that merely adding radar to vehicles isn’t the final solution to protecting pedestrians. Simply put, improved dummies combined with improving radar technology is expected to help save even more lives.

Human Beings Come in Many Shapes and Sizes!

CSRC partner Matt Reed, Head of the Biosciences Group of the University of Michigan Transportation Research Institute (UMTRI), sought a better understanding of the entire population of crash victims. This is versus a population of crash test dummies used industry-wide that, on average, is both lighter than the average male or female driver or passenger today, and designed to emulate a younger than average driving population that exists in most of the world’s developed economies.

Then Reed’s team (after scanning both elderly and heavier BMI, or body-mass-index, volunteers) found that the heavier a driver or passenger, the more likely they were to not wear their seat belts properly, with the lap belt higher than where safety experts intend. The net effect is it can introduce slack in the restraint system, and that means occupants might be flung further forward during frontal crashes. That might result in greater whiplash or a harder impact with an airbag than is being emulated in NHTSA’s own studies of crashes, or those of the Insurance Institute for Highway Safety. The upshot of which isn’t just theoretical.

“If a 25-year-old cracks a few ribs, he or she is likely to recover,” Reed says. “If someone’s 85, or obese or in poor health, we’re looking at complications they may not recover from.”
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Stop Texts, Stop Your Teenager’s Wrecks

There’s an old adage in parenting: Do as I say, not as I do. Turns out, that just doesn’t work when it comes to distracted driving. So while CSRC’s earliest work looked at pre-collision safety, augmented safety systems like lane-departure warnings, and pedestrian safety, there was another key thread Toyota wanted to pursue — our behavior behind the wheel. Tina Sayer, a principal engineer at CSRC explains that a phone survey of teens and their parents revealed a startling result, which is that kids who perceived their parents engaged in distracted driving behavior more frequently self-reported engaging in more of it themselves. This doesn’t mean the parents actually engaged in this risky behavior as frequently as the teens thought they did. It means that teens who perceived that exaggeration of distracted behavior by their parents (texting while driving, or taking eyes off the road to pay attention to another passenger) modeled the risky behavior, because it was normalized within their family.

Sayer says while this isn’t necessarily predictive of actual crashes, Toyota’s Teen Drive 365 (toyota.com/teendrive365) initiative contains three simple steps to change the cycle of misperception. First, it contains documentation for the parents to understand the risks of their own behaviors—and the profound impact these have in the minds of teens, who grossly over-estimate incidents of distracted driving by their parents. Then it contains a pledge that both parents and their children agree to and sign. This re-normalizes appropriate behavior.

“Every family creates conventions of what’s normal, but parents set the tone,” Sayer explains.

She also says being open about why something like texting and driving is dangerous is key. And finally, she says it’s important to revisit the document, on good or not-so-good occasions, such as on a teen’s birthday, or after a fender bender.

“Sometimes the parent doesn’t even know they’ve influenced their child,” she says. Just the thought of violating a promised-to pact is enough to change driving behavior.

Force Multipliers

• One of the cheapest things municipalities can do to help prevent vehicle crashes is to paint outside lane strips on roads. That’s because even as the Sherony-Gabler LDW study was only five years ago, lane warning/lane keeping technology has greatly increased, so that far more vehicles have these assistance systems. However, they rely on cameras that “read” the position of the vehicle on the road. Without painted markings, this potentially lifesaving tech isn’t as effective.

• Sayer’s research suggests that some kids who start out with risky driving habits frequently don’t know or fully comprehend the dangers. “But what we’ve seen is once you point to this behavior, some just sort it out, and then they model good behavior.” Unfortunately, she says predicting where your own child falls, and if they’re likely to revise their habits, still requires greater research.
**Why a Vehicle that Monitors Your Health is Better at Saving Your Life**

CSRC's broad mission is safety, but as with all CSRC queries to collaborators, understanding safety starts with understanding all sorts of risks to drivers. That doesn’t just mean vehicle crashes—it could mean what leads to them.

While we tend not to think of health complications directly leading to crashes, Clay Gabler’s research at Virginia Tech into lane departures revealed that, while rare, there have been instances drivers suffered cardiac or other events that caused them to veer off the road, including stroke, heart attack, blackouts and seizures.

That was one reason CSRC’s Principle Scientist Pujitha Gunaratne looked to the University of Michigan’s Kayvan Najarian, a professor of computational medicine and bioinformatics, who said, “Toyota came to me with a very simple problem: They wanted to know if we could predict a cardiac event. This is a central issue in medicine of course, predicting if someone is going to have a heart attack, and until now, people would have said it was impossible, but now we’re getting better at interpreting it.”

Najarian explains that the patients in the study were already likely to go home from the hospital wearing EKG monitors. “These are people diagnosed with cardiovascular issues, so their doctors want to monitor their clinical state,” he explained, so his study didn’t look at a broad swath of healthy people, but at people who otherwise might be at risk of another event, that could quite literally add danger to their chance of survival and put other drivers at risk.

“What we wanted to do was to see if the technology would be robust enough for driving. Not dancing the Samba behind the wheel, but if we could separate the signal from the electronic ‘noise’ of driving for a normal behavior pattern,” he said.

After eight months of study, Najarian says they did conclude that it was feasible, and in fact learned that, “In some people susceptible to these kinds of attacks, we could actually predict their onset.”

Najarian’s research is ongoing, too, to look more broadly at more types of cardiac and other health issues that make driving difficult or dangerous. “What we hope is that we can put health monitoring software to work, so that for someone who’s at risk, we could call 911 and pull the vehicle off the road, so that we’re saving lives and also not putting other drivers at risk.”

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You Are Your Blood Sugar

Dr. Matt Rizzo certainly thinks such a technological advance can’t come soon enough. Rizzo chairs the department of neurological sciences at the University of Nebraska Medical Center and says that diabetes is unfortunately increasingly prevalent. While we’re profoundly aware of the effects of lost heart function, Rizzo says we should be just as concerned about how a more subtle disease, like diabetes, which is now prevalent in 10 percent of the U.S. population, affects one’s ability to drive.

“We have a self-reporting function that normally works for most tasks. Can I do this? Am I capable?” Rizzo explains. But for diabetics, that feedback loop, which they may have had their whole life, isn’t telling them when they’re hypoglycemic, and studies show this state greatly impacts cognitive function, putting diabetics and other drivers at increased risk. Rizzo also explains that drivers who use insulin pumps can see their blood sugar fall rapidly, and this, too, can impair judgment.

“People want to do better, they want to be safer. But if they don’t know they’re being risky they can’t help themselves.”

“What we wanted to see is if we could study these effects in the real world,” Rizzo said, so his team recruited volunteers with diabetes and studied them over the course of four weeks of driving, totaling 21,252 miles. Subjects’ blood glucose, heart rate, and other biometrics were measured, and vehicles were fitted with cameras and other sensors as well. Rizzo and his team found a correlation between hypoglycemic episodes and erratic driving patterns, such as sudden braking or throttle inputs, as well as swerving and a few near-miss crashes. The study also found that drivers were poor witnesses to their own condition and didn’t restrict themselves from driving. Likely because they were unaware of the severity of their own hypoglycemia and its impact on their ability to drive.

“These are cognitive impairments, there’s no question,” Rizzo says, but he also holds out hope that there are simple correctives. If, for instance, diabetic drivers could see how their heart rate corresponds to their glycemic state, to actually see a warning in the vehicle, and know that their judgment is impaired, it might change behavior patterns. Another way to do that, a post-drive video report, Rizzo suggests, that shows diabetic drivers their incidence of erratic driving. “People want to do better, they want to be safer. But if they don’t know they’re being risky they can’t help themselves.”

Here’s Looking at Me!

Yes, video can help, says Bryan Reimer, associate Director of The New England University Transportation Center at MIT. He explains that the in-vehicle camera is probably the most powerful, most likely sensor for assessing driver health and fitness behind the wheel, despite not being as glamorous as the latest wearable fitness tracker.

Reimer says that videos are far more capable of predicting what drivers will do behind the wheel, and their state of involvement with the task of driving, than measuring other physiological factors. So you can probably tell if a driver is awake or not, but Reimer says you can also measure patterns that are unique to the vehicle’s primary drivers, and while much of his work has involved driver monitoring with far more invasive technology, such as heart rate monitors and eye trackers to measure cognitive load, he says that the future belongs to teaching the vehicle about you, and you about the vehicle.

For instance, for one study on voice control systems and dash design, “We presumed that when we allowed the driver to tell the vehicle what to do that that would free them to look at the road.” But that’s not what happened. Instead Reimer’s team found that, “It’s human nature to look somewhere for a confirmation that we were heard. You hear a bang in the hall and immediately your head turns to see what caused it.”

Reimer says that because we’re never going to change eons of evolution with different vehicle design, we have to instead look at human nature and design to take advantage of how we think, and take in information. Reimer’s study eventually contributed to the redesign of the instrumentation of the current Toyota Corolla and the forthcoming, 2018 Toyota Camry, but he says that ultimately automakers have to go even further.

“We all learn differently, we interact with our environment differently, so the vehicles have to learn how you learn, by using a camera to look at you, and to use the science we already have to understand your emotional state, your stress level, and how much you can handle,” he said.

Naturally that leads to more questions, like are we ready for such monitoring, and will we accept the benefit, or fear that being monitored is an invasion of privacy?

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Force Multipliers

• “Currently, some people with specific medical conditions are not allowed to drive, but epilepsy or other conditions aren’t considered,” Michigan’s Kayvan Najarian said. Therefore, he hopes for a day when some people who currently suffer from medical conditions that restrict them from driving might instead wear monitors that predict their condition and allow them to drive. “That way, the vehicle could come to their aid, call for help, or switch to automatic driving to help until the event passes.”

• “We found incidence of people looking at their phones or engaging in more distracted behavior during hypoglycemia, but people just aren’t aware of it,” said Nebraska’s Matt Rizzo. So he hopes that camera-monitors and possibly video-review techniques can help diabetic drivers understand their own riskiness. “We’re looking at a billion diabetics worldwide, so education has to play a part to get better, safer outcomes.”

• “Adding more technology is often fueled by the desire to deliver something new for its own sake,” says MIT’s Bryan Reimer. But he says there should be more thought about the benefit of the technology, and more effort behind education. Reimer says that especially as we begin to add updates to vehicles on the fly, like a new smartphone operating system iteration, automakers have to think about how to try to ensure the driver truly knows what the vehicle can do. “Turning the key one day and being told of a new capability can lead to over-trust,” and that might mean, he cautions, that drivers think their vehicles are suddenly more capable than they actually are.
If you’ve seen commercials that show vehicle crash tests, you’ve almost surely seen what a crash-test dummy looks like. They were originally designed several decades ago, and although they’ve evolved, they’re still limited by the fact that they were designed around the tests that governments use to validate that vehicles sold into a certain regulatory environment are up to snuff. Put another way—outside of the environment that they were designed for, they’re not really designed to provide a complete understanding of what happens to human beings.

CSRC desired to gain a more comprehensive understanding of what happens to humans in actual vehicle crashes, as opposed to dummies in a test environment.

To do that, you need smarter ways to replicate the human body, and then to use real crash data as inputs to replicate real-world crash scenarios through computer modeling (as opposed to standardized crash testing) because the variety in vehicle to vehicle real-world vehicle crashes is something that standardized crash testing is intentionally designed to avoid. And the goal was to develop a more realistic human model to test in those crashes. So CSRC worked with Wayne State University’s King Yang, Director of the Bioengineering Center, and with CSRC Steve Ham. They created biometrical accurate models of the most vulnerable population of pedestrians and passengers.

The study took nearly five years, but as Ham explains, “It’s really complicated. I began my career looking at what happens to vehicles in crashes, but that’s simple because they’re steel or maybe plastic. People are a lot more complex.”

Real people are made up of skin, bone, fat, muscle, tendon, ligaments. Ham says modeling the human body in vehicle crash included looking at the bones, the age or fragility of bone, at the internal organs. The models he helped create have all of that in simulation, including simulations of lung, heart, liver, brain, spleen, gall bladder and even skin, and of course, age-accurate skeletons, muscle, and an accurate replication of all of those elements fitting together to form a complete human body.

While much of this might seem like an interesting science experiment, it’s also personal work, because, as Ham says, “I have a son. He wasn’t large enough to stop using a booster when all of his friends stopped using them, and we really struggled with that.”

The struggle for Ham came from a place of knowledge: Both ten-year-old kids and 70-year-old women die more frequently in vehicle crashes than those in other core demographics: Children between 8 and 14 die at a rate higher than children of all other groups, while 75-year-old women are 4.2 times more likely to be injured in vehicle crashes than a 21-year-old. And as Ham points out that the crash-test dummies used to emulate these vulnerable age groups, are miniaturized versions of the original full-sized male. For instance, he says, children have longer torsos and, relative to full-sized adults, their heads have greater mass, and their necks and spinal muscles aren’t as developed. Knowing this, Yang and his CSRC colleagues set about modeling exact replicas of vulnerable people (by using hundreds of CT and other scans of various populations), then replicated what happens to the cervical spines of small children in vehicle crashes; and to elderly women during airbag deployments, validating their research.

Ham says the significance of the resulting Collaborative Human Advanced Research Models, or CHARM for short, is that these digitized dummies are the closest thing to real flesh-and-blood people in the history of crash study, creating a new way for scientists to not just look at real-world outcome studies, but to start to ask “what if” questions, and then to proof out concepts around safety far more accurately.

Smarties vs. Dummies

Human body models like those created in the CHARM study are already having a strong effect on research. Dr. Joel Stitzel, who chairs the Biomedical Engineering department at Wake Forest University, says that one study he conducted in conjunction with CSRC shows a relationship between lower spine injuries and age.
Stitzel’s study replicated real-world crashes that resulted in lumbar spine injuries for a simple reason: They’re on the rise. What’s surprising, however, is that frontal crashes, which are the most common kind of crash, aren’t obviously where you’d anticipate finding lower-spine injury. But by using virtual human body surrogates, Stitzel and his team, including Dr. Ashley Weaver, an Assistant Professor of Biomedical Engineering, found that the biggest predictor of getting hurt is age.

“We could actually validate that even in two of the top five loads we simulated, the younger you were, the less likely you were to have spinal injuries.” Weaver adds that another strong predictor is unfortunately what you’d expect—sitting farther forward in a front collision leads to greater spinal injury.

Your Life is in Your Lap

Make no mistake about it, the seatbelt is one of the most critical and best life-saving tools ever invented. But in Wayne State/CSRC’s studies for the CHARM models, Ham says they learned that a seatbelt can damage internal organs if it wraps across your belly rather than your pelvis. And as Matt Reed, Head of the Biosciences Group of the University of Michigan Transportation Research Institute, has pointed out, routing the seatbelt lap strap across your gut rather than pelvis can create slack that might reduce the system’s effectiveness.

“If you’re heavier, we’ve learned that you’re far more likely to mis-route your seatbelt across your stomach, not your pelvis,” Reed said. “And that could reduce the effectiveness of the lap belt.”

Reed wondered if he showed subjects a short video of how to wear seatbelt properly—and the risks of donning one incorrectly, as unfortunately many of us do, especially people who are heavier—if they would learn to reset their habits. He found that everyone in the study who saw this video revised their routing and wore their belts closer to the ideal way. “Those with the most to gain, people with higher BMIs, benefited the most.”

But Reed says there’s still a lot more to be learned. “Now with better human body modeling, we can study real-world BMI subjects, but this doesn’t tell us everything about human behavior.” For something as simple as a seatbelt, he says, nobody in his studies has ever been taught how to wear one. Unfortunately, he says, the efficacy of replicating his own study for a mass audience (for instance, on television) may not result in widespread changes in how people wear their seat belts, but what about in-vehicle video, or sensor technology, or other gamification models?

Helping Save Lives After the Crash

If you’re in a vehicle crash, how does the EMS attendant know how badly you’ve been injured? For CSRC and Joel Stitzel at Wake Forest University, the question came about because one obvious way to reduce fatalities is to know the instant after a crash how likely it is you’ll need advanced care. This is crucial, because as automakers increasingly add automatic 911 calling to their vehicles, the potential now exists to relay more than crash location if the airbags are deployed. Stitzel’s research looked at an 11-year dataset of crashes to “score” the severity of sustained injuries, how time sensitive the injuries are for need of comprehensive care, as well as to look for patterns in the kinds of crashes that lead to internal injuries (which could be difficult to detect by visual observation). These target injuries were then coded to widely-occurring crash types and Stitzel also looked at corresponding hospital records (to see what kinds of crashes might have resulted in misreporting of injuries by EMS).

In addition, to strengthen this research, Stitzel and his team, including Dr. Ashley Weaver, interviewed dozens of surgeons, emergency medical physicians, and EMS officials, as well as first responders to understand the difficulties in reacting to many types of vehicle crash injuries—the worst aspect of which may be diagnosing the extent of injury at the vehicle crash scene.

All of which led Stitzel model typical highly-occurring crash scenarios that could generate a concise output report so that EMS would know the likelihood and potential type of injury before ever getting to the scene.

“Basically,” says Stitzel, of the new Advanced Automatic Crash Notification (AACN) algorithm, “we’re not just looking at the ferocity of the crash, we’re seeing for crash characteristics as well.

Still, Weaver says, “We asked clinicians and EMS what’s really hard to know in the field, and where do you err on the side of caution?” She says that for this reason, because some crashes are more likely to create complex injuries that are difficult to diagnose on the spot, the algorithm the team created uses a cautious approach. “If an injury is less predictable, they need to go to a trauma center where they can do more complex scanning,” she explains.

Stitzel says the model suggests saving 2,700 lives a year in the U.S. alone based on a fully-realized AACN algorithm, which would be incredible.

Weaver says of course one challenge is to get others to understand just how important implementing an AACN algorithm could be. “It’s not just a matter of helping save lives in Toyota vehicles. We want to see this everywhere, no matter what you drive.”
Force Multipliers

- One of the most surprising discoveries of the CHARM study, says CSRC’s Steve Ham, was that every bone and organ in the model was validated to be as lifelike as possible. That meant including bone growth plates in the skeletal structure of the ten-year-old child—and that led to a breakthrough discovery during testing. “Adults don’t have growth plates, so in pedestrian crashes their bones break differently.” But for children, fractures at their weaker growth plates (which are where the bones elongate as we age) were unfortunately found to be far more frequent, and a fracture at the growth plate can lead to lasting complications for children as they become adults. Ham says while it’s too early to draw conclusions about how automakers might change the model for pedestrian protection, but getting to know more precisely how children are injured is an important step.

- “We’re never going to tell a first-responder what to do. We don’t want to make decisions about patient care. This is about avoiding under-triage,” says Wake Forest University’s Joel Stitzel of the Advanced Automatic Crash Notification algorithm. “Sure, maybe someone looks okay, or not badly injured, but the vehicle is saying that everything we know about the characteristics of this type of crash means that this person needs to get to a trauma center.”

- “When I was finishing up grad school, one of my friends got in a very severe crash, and good triage saved her, but she has some pretty significant disability from her injuries,” says Ashley Weaver at Wake Forest. “At the time she crashed, I was at a conference banquet where our CSRC work on the mortality associated with injuries had won an award. That call the next day was ironic and sobering, and really made me connect in a new way with the people in the data that we analyze. She survived, but lost her sight because she sustained several orbital fractures. Air care just happened to be flying over the crash site on their return from dropping someone else off at another hospital, so EMS was able to get her airlifted very quickly to a Level 1 trauma center, and from what I know from my background in triage, this saved her life. This whole experience put into context the research I’ve done looking at different facets of injury (mortality, disability, time sensitivity, and so on), and how important triage is to motor vehicle crash occupant outcomes. It’s a clear example that motivates me and says that there is more to be done in automotive research to prevent injuries and the disability associated with them.”

- University of Michigan Transportation Research Institute’s Matt Reed is working on another study around seatbelts—this time around he wants to know how well they work during Automatic Emergency Braking. He says that while the technology that brakes the vehicle automatically, and under as much force as possible if the driver fails to react to conditions on the road, is getting rolled into more and more vehicles, little is understood about just what happens during these events to vehicle occupants. “It’s quite a surprise for passengers, and there’s not a lot of analysis about how much people get tossed around. In a typical crash-test model the quantities are always where you put them, but we’re not always where we’re ‘supposed’ to be when the AEB fires.” So Reed says to understand these new conditions, AEB brake force is being studied in greater detail.
The average vehicle in the U.S. is about nine years old. Even as there’s a great deal of buzz about autonomous vehicles—and many vehicles sold today already feature some level of assistance—the study of whether and how assistance systems work, especially for a population that might get five new smartphones in the span of owning any single vehicle, is in its infancy. This is important: Technology to help us drive more safely can only work if the driver can interpret the technology. And as new technology emerges, there’s a greater prevalence of misunderstanding around what the vehicle we’re driving can do, and when to rely on it.

For this reason, its Teammate Concept is the best approach to the incremental growth of driver assistance. In essence, the idea is that the driver and the vehicle are partners in keeping each other safe, and like on a team, you rely on each other to achieve that goal, but you’re also always checking on the condition of that partner, their fitness for the task, and need to understand that partner’s limitations. Heishiro Toyoda, who works as a senior principal engineer at CSRC, explains that especially as vehicles will increasingly see “over-the-air” updates, much like smartphones do now, drivers will need to both monitor systemic changes more closely and be educated on new capabilities, and they’ll need to have broader guidelines on what the technology can do—and especially what it cannot do. Toyoda uses medicine as an analogy, where a prescription tells you how to take it, how much to take, and to know that you shouldn’t over-rely on it. “Ultimately you are in control, and you can choose to disobey, but there will be consequences.”

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Clay Gabler at Virginia Tech’s Center for Injury Biomechanics studies vehicle crashes from broad datasets. While front-to-rear-end collisions in the U.S. may not lead to fatalities, they represent nearly half of all crashes, and a massive cost in injury recovery and property damage.

How do you help stop front-end collisions? Possibly, with technology. In newer vehicles, forward crash warning systems are already wide-spread, and pre-collision braking assist that “primes” the brakes before you depress the brake pedal, to deliver maximum stopping force are also increasingly widespread. Add in Automatic Emergency Braking (AEB) where in some conditions the vehicle can brake itself if the driver fails to act, and you have the combination of a warning system coupled with a form of autonomy.

Gabler’s research into the area, in conjunction with CSRC, started with a basic question: If you took the millions of front-to-rear-end collisions and boiled them down to their most typical form (of 1.1 million crashes Gabler and his team created a sub-set of 1,396 typical crashes), and then layered on the three types of collision mitigation for front-end crashes, how much change would you see? The obvious answer? A lot.

“We played a what-if game. What if you just have the warning, what if you have the warning and the pre-brake, what if you have all three?” he asks, rhetorically.

Gabler’s study suggests that if you have all three technologies, you’d see a reduction in moderately to fatally injured drivers by a range of 29 to 50 percent. But what’s partly compelling about the study as well is how we don’t necessarily react quickly enough to warnings. Gabler found only a slight, 3.2-percent probability of collision avoidance if a vehicle merely warns the driver of a potential front-end impact, and he chalks that partly up to driving habits (following too closely) and to limited reaction time, since older drivers react less quickly.

“What it indicates is that maybe we have to study and know the driver better, to customize alerts about following distances based on the age of the driver and their patterns of reaction ability,” he said.
In the case of a rear-end crash there’s constant monitoring needed by the driver, and even a short glance away can cause a crash.

Assistance we Can Use

Of course Gabler’s thinking presumes we’re paying attention in the first place. One of the biggest dangers of the moment, as Heishiro Toyota points out, is that we may not know what the technology in our vehicles can do, and we may over-rely on it. Or we may not heed the warnings at all.

Birsen Donmez is the Director of the Department of Mechanical and Industrial Engineering at the University of Toronto. She and her team study human factors. As she puts it, “Our training focuses on teaching us how to design systems that take people’s limitations into account, while leveraging their capabilities.”

Part of her study with CSRC has looked at human response to signals, both how we voluntarily engage with non-driving tasks (say, tuning the radio), and also how we respond to signals from the driving and non-driving environment (a cell phone buzzing in the cupholder). Donmez’s research shows that, as Gabler suggests, there are age differences to response times for warnings or changing road conditions, but also that there are many factors that contribute to our ability to pay attention to driving. Beyond general distraction, she and her team have used driver simulator studies to demonstrate that there needs to be a variety of kinds of feedback to change the way we respond to warnings.

For instance, a study of speeding showed that drivers adhere more closely to the speed limit when the current limit is displayed within the vehicle, and that feedback draws the eye back to the road (by monitoring where we’re looking), which can keep us centered on the task of driving. Still, she explains that there’s also a danger with warnings; if the driver is constantly seeing false alarms about following too closely, they might not heed a genuinely dire alarm.

“In the case of a rear-end crash there’s constant monitoring needed by the driver, and even a short glance away can cause a crash,” she said.

Assistance Makes Us Bored

We tend to fill in tasks when automation takes over. That’s at least the preliminary thought Bryan Reimer, associate Director of The New England University Transportation Center at MIT, has after studying drivers using Advanced Cruise Control (ACC). Such systems include radar-based technology, similar to what AEB uses to judge if the brakes should engage in an emergency stop, although here the brakes and throttle are modulated to manage following distances with the vehicle ahead. More advanced systems will bring the vehicle to a complete stop, and then with very minor driver engagement, allow the vehicle to resume following, which is theoretically useful in stop-and-go traffic, not just at highway speeds.

“You alleviate the driving workload and the driver is going to find something else to do.” He says this problem isn’t new, either. “We don’t think about it, but perhaps it progressed the moment we introduced the automatic transmission. As driving becomes less engaging, we find other ways to occupy ourselves.”

Still, what Reimer found is that drivers tend to let their eyes wander more frequently from the road while using these systems, and he says that’s to be expected, even if it’s clearly not ideal.

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That’s where Donmez’s research (explained in more detail in Diagnosing Distraction) comes into play. Because we’re in the infancy era of driver assistance, allowing our eyes to wander when our lives still depend on keeping them on the road ahead.
**Force Multipliers**

• “CSRC always wants us to look for unexpected outcomes. What if a new technology has a downside?” VTU’s Clay Gabler says. One result of his study of AEB systems was that the braking force is profoundly higher than most people can generate. “One possibility is that unbelted or even belted occupants are thrown out of position prior to the collision,” Gabler says that it’s possible that for AEB to have the greatest effect, it really needs to be combined with seatbelt pretensioner technology, and that this is an area that requires greater study.

• “There’s this idea that the machine will one day be perfect, but that may never happen,” says CSRC’s Heishiro Toyoda. “The machine isn’t 100 percent perfect, and we’re not 100 percent perfect, so the idea of the Mobility Teammate Concept is more like an interpersonal relationship where you build trust. Maybe you don’t have complete trust at the start of a relationship, with a new friend, a new boss, but over time you build and develop trust. If we can design the system to study the driver and the driver learns how much to trust the system you get a deeper level of trust, and the feedback changes over time, and improves. That’s how these assistance systems can work more safely and smoothly.”
We’re very distracted. Sadly, many drivers are using smartphones while driving and various studies suggest we’re either profoundly distracted or disturbingly distracted. Don’t see a real distinction there? That’s because there’s a lot of noise around distraction, but not a lot of understanding. For instance, two recent surveys that use cell phone apps to quantify in-vehicle smartphone use report very different data. One puts Vermont as the state with the most distracted drivers; another says its drivers are the least distracted. AAA says that most drivers agree that distracted behavior is dangerous and that too many admit they still engage in it.

And merely ranking how much we engage in distracting behavior or that we think it’s bad (but still do it) does little to change the pattern. What we need, as CSRC has shown with all of its research, is to engage experts who study our motivations, and once understood and codified, to explore possibilities to change them.

Teens are the Problem

Actually, teens aren’t the problem—or at least not exclusively. But allow a moment of explanation. Dan McGehee, Director of the National Advanced Driving Simulator Laboratories at the University of Iowa and a CSRC partner, says you have to understand something fundamental about today’s teen driver: “They’ve never known life without the cell phone.” McGehee says that to study not just teens, but drivers of all ages, CSRC asked that his lab first diagnose what distracted driving looks like. That is to see cause—not just mobile phone use but eating, driving, fiddling with in-vehicle technology—and effect. “A classic example of the latter,” he explains, “is the vehicle drifting out of its lane.” More worrisome is that frequently these “drifts” include into other vehicles on the road. Fortunately, these tests are done in simulators, but extrapolating these behaviors into the real-world is the natural concern.

Further, McGehee’s research on distracted behavior and teen drivers shows that as a population, they are more susceptible to group texts and group messaging apps, where they feel the need to take part in the conversation.

McGehee suggests, as others have, that better driver monitoring can lead to quicker warnings. “Simple cameras that show glancing off the road is all you need.” Still, he cautions that we still need a better handle on exactly what’s causing distracted driving crashes.

Birsen Donmez, Director of the Human Factors and Applied Statistics Lab at the University of Toronto, and her colleague Winnie Chen, a postdoctoral fellow at the department, wanted to better understand exactly what McGehee’s chasing—the characterization of actual distracted driving crashes in the real-world driving environment. To do that, through the assistance of CSRC, the lab looked at data from the Strategic Highway Safety Research Program2 (SHRP2), the largest-ever study of real-life driving using cameras. The sheer quantity of data produced by this study is nearly overwhelming. Donmez says. In sum SHRP2 created petabytes of data and 50 million miles of driving information. But it’s also a treasure trove, once sifted properly, which is what Donmez and her team set about doing—literally combing through SHRP2 for crashes or near crashes and coding each incident when it was correlated with distracting behavior.

“Distraction is a loaded word” says Donmez, so it’s put more neutrally by scientists in her field, and instead called secondary-task engagement. Eating a cheeseburger while driving, or flossing afterwards while driving, just like texting, is a secondary task.
“Crashes are rare events, but if you could examine the riskiest behaviors and warn drivers while they’re engaging in them, you might modify what they do,” she said.

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While NEST is new, the database has already yielded that compounding tasks with driving is an especially dangerous mix. That might be looking for your cell phone in your purse and then sending a text, or turning around to address another passenger. “You’re adding more mental demands,” Donmez says, and she explains that the single biggest predictor of whether or not we engage in these tasks is the speed of travel. And the second one? Age. Theoretically, the faster we drive, the less likely we are to engage in distraction (on crowded highways, but not on quiet, rural ones), in part because we perceive greater risk. And the older we are, the more we self-regulate—we know we can’t drive and do other things simultaneously.

Donmez says that future study will need to model this in simulators, to further cement the science of distraction around what happens when drivers engage in multiple tasks at once—and also to overlap that research with how to prevent the behavior whenever possible.

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Lee explains that with the simulation that was dead-straight, there was little reason not to trust the vehicle would continue to drive itself. But Lee calls the present state of autonomy “brittle,” meaning the vehicle can go from a state of perfect control to no control very quickly. He says that instead, “if you set the expectation that this is a partnership, like Toyota’s Mobility Teammate Concept, ‘you put the driver in the loop, where their trust is actually enhanced by being engaged.’” And, he says, in this critical moment in time, as automation increases, exploring how to signal trust—and whether the vehicle can trust us, not just the other way around—is going to be even more important in distraction studies.

We’re Lousy at Monitoring Robots

“If you want the best human performance, you have to engage people in activity,” while that may seem like a reductive argument from John Lee, who runs the Cognitive Systems Lab department at the University of Wisconsin-Madison, he says we’re doing just the opposite now with partially automated vehicles.

“If there’s less stuff to do, if a vehicle seems to drive by itself effortlessly, we’re just not well suited to doing nothing but being eternally vigilant,” he says.

To understand this better, Lee and his department created a simulation where they asked drivers to drive different levels of automated vehicles. The key with the simulation was that some of the models drove laser-straight down the middle of the lane, while others would wander in the roadway. Lee says that drivers of the simulators that wandered were much more aware of the conditions on the road around them, because they were actually engaged in driving—and the temptation for distraction was reduced.

“When the vehicle wandered people vicariously steered,” this reduced the lag time when an automated vehicle might have to be handed back to the driver for control. So-called “mode confusion,” when the driver isn’t sure if the automation is still engaged, is a dangerous moment; whose driving? The driver, or the machine? Lee says the reason to make a vehicle wander is to maintain engagement with the driver. “We have to communicate how much to trust in systems in different ways. You can’t have a gauge on the dash that says how much autonomy there is, you need something more intuitive.”

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Donmez says what’s interesting is that young drivers in the study improved their behavior whether in the gaming model alone or they only got the post drive report. And she also says that when we compared their scoring with how their parents scored we saw a drastic improvement.” And Chen says what they know from past work is that personality types behind the wheel don’t change with age, so an erratic younger driver is likely to stay that way. “If we can engage them early and change their behavior that goes toward reducing distraction maybe we will lead to better outcomes,” she explains.

John Lee says that part of the problem with diagnosing distraction is that most drivers rarely get into vehicle crashes. Meaning: There’s just not enough negative feedback to prevent distraction. This is of course a good thing, “but someone might be a lousy driver for years before they get in a deadly crash,” Lee explains, and that’s decidedly not good. So Biren Donmez and Winnie Chen at the University of Toronto wondered if there was a way to teach younger drivers not to engage in risky behavior—to change the feedback loop early, so that it wasn’t just a matter of time before a distracted driver crashed. “To clarify this concept, the created a co-CSRC study that turned driving into a video game model, with avatars representing drivers, with real-time feedback to reinforce good driving behavior as well as warn about dangerous driving behavior, and also layered on post-drive scoring (a report on your behavior comparing your ‘work’ behind the wheel vs. the last time you drove).

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“Technology isn’t any single thing,” says John Lee. “It can direct your attention to the road, it can reduce the task of driving.” But Lee says the 24/7 pressures for productivity “thrust most of us home.” When the vehicle is competing with the smartphone, when you’re expected to respond, we’re in trouble. “The important thing is to design so we create good habits because that has such a powerful influence on our behavior.”
Before We Get Autonomous Vehicles, We Have to Train Them to Drive on Roads with Humans

Throughout chronicle we’ve repeatedly raised the challenges of introducing automation without eroding driver attention, of adding safety features yet still seeing crash rates rise, and of constantly adding iterative layers of technology. This latter area of study is of special interest to CSRC scientists because as vehicles become equipped over the coming decade with increasingly complex technology, the concomitant perception that vehicles are in fact automated when they aren’t may lead to unintended consequences. Even now, with increasing news reports about autonomous vehicle crashes making headlines—while hundreds of human-caused crashes and fatalities daily wash by with little fanfare—recent surveys find eroding trust in autonomous capability. One obvious worry is that even as vehicles may in fact become more capable than human drivers to prevent crashes, this lack of trust may prevent progress and life-saving technology from taking hold.

Part of the challenge then will be in the proper execution of introducing life-saving technology. In theory, as more drivers and passengers experience interventions that prevent crashes, trust will build, and skepticism will decline. That cannot happen overnight, and Sherony, Senior Principal Engineer, says that one of the biggest challenges yet to be tackled is how to prevent crashes at intersections. Ninety-degree crashes (called straight-crossing path) are among the deadliest, on average leading to over 5,000 deaths each year, and finding the right formula to prevent them, Sherony says, is another step for driver assistance technology. 

Sherony and Gabler’s comprehensive study demonstrates the lifesaving potential of this kind of technology, theoretically reducing straight-crossing path injury rates by up to 80 percent, but Sherony says there’s still a great deal of research that’s necessary. For instance, their co-researcher on part of the study, John Scanlon, a biomedical engineer at Virginia Tech, explained that while many drivers braked and steered prior to these ninety degree crashes (based on analysis of event-data recorders), most actually steered toward the direction of the oncoming vehicle. That could or could not help mitigate the crash force, but Scanlon explains that this information will be critical for designers of I-ADAS systems. That is, you have to “teach” the systems the most likely response of the driver, perhaps to prevent the driver’s inputs in some cases. More directly, a minority of drivers did nothing at all prior to a crash. A warning system may help these drivers avoid impacts, and Scanlon says it’s very likely many of these drivers are older, with slower response times.

“If you can add back 1/100ths of a second in response time you’re giving back more braking force, more time to react, reducing the severity,” he explained. Scanlon says the single most important thing these systems can do in the near term is to add more reaction time—to see what we fail to see more quickly, and give us a chance to react.
Time is on Our Side

While the science of optimizing I-ADAS requires a better model of predicting human tendencies behind the wheel at slow-speeds, Mohan M. Trivedi, head of the Laboratory for Intelligent and Safe Automobiles at the University of California, San Diego, in partnership with Pujitha Gunaratne at Toyota’s CSRC, have been working on a way to predict our driving behavior at much faster, Interstate speeds. This requires much more sensor technology, to monitor the full surrounding of the vehicle, which is becoming more feasible with increasing sensor deployment in emerging vehicles. First, you have to know what the subject vehicle, the so-called ego vehicle, is doing—you need to know more precisely where the vehicle is on the road. To do that, Trivedi used higher quality GPS sensing, gyroscopic sensing, and accelerometer sensing together with lane tracking in an instrumented test vehicle. GPS aids location accuracy and the latter sensors and lane information help predict where the ego vehicle will be. Then, the roof of the test (ego) vehicle was armed with eight high resolution cameras, and hidden inside the vehicle body were six lidar units and five radar units, giving a rich, wider, and longer-range full surround field of view of the ego vehicle, so that testing on multilane highways would allow the test vehicle to “look” in every direction at once. The goal: Don’t just enable what we have today, which is cars with reasonably accurate advanced cruise control (they can follow the car ahead and accelerate and decelerate in kind with that car). Rather, go further, by building a smarter, artificially intelligent system that can model passing vehicle, following vehicle, and changing vehicle behavior. Trivedi and Gunaratne’s new system, called RefineNet, just like Gabler and Sherony’s work on I-ADAS, is publicly available. And the findings are that with enough data you can in fact model human-driven, on-the-highway passing, lane-keeping, acceleration and deceleration behavior. The dataset crucially builds in more time by detecting near vehicles sooner, and that enables the ego vehicle to “understand” its position relative to other cars on the road. From here, the algorithm can be built upon by other carmakers to understand how to make their own vehicles’ autonomous systems smarter, so they can go beyond cruise control, toward a more “aware” model that protects passengers in what otherwise seems like chaotic, unpredictable circumstances.

The Subtle Art of Us

Both Bryan Reimer at MIT and John Lee at University of Wisconsin say that even with all of the human behavior modeling work done to this point, there’s a great deal yet to be done around trust. This is trust between the driver and the vehicle—and the vehicle and the driver. As part of studying adaptive cruise control Reimer says subjects who tested the system would look away from the road more frequently, as they assessed how reliable the system was at managing driving. Going forward Reimer wants to study how automation starts to overlap with human interaction. He wants to test how human beings manage non-verbal interaction, for instance, eye contact between a driver and a pedestrian or another driver at an intersection. If we’re compelled to look away from the road more frequently, because assistive tech is doing the driving work for us, how do we then emulate something like eye contact by the machine? “How does a pedestrian know if a vehicle will stop? First we have to understand how we interpret the vehicle’s intent.” Reimer says. “And maybe we need to augment the vehicle’s ability to communicate in some way.”

Lee will also be looking ahead at these non-verbal interchanges at intersections. He highlights his own recent bike ride in Madison, Wisconsin, where he trusted a driver would stop—and how upon leaving the intersection he realized he had probably been in the wrong. “Put automation in the place of that human driver and I don’t know what would have happened.” Lee uses an example of how human drivers approach a crosswalk vs. what a robot driver might do. “A human driver will approach the crosswalk and stop, smoothly, about 20 feet before the intersection. That’s not the law, that’s a signal to the pedestrian to make it unambiguous that they’ve seen them. That’s signaling intention. Do we make that part of driverless vehicles’ repertoire of skills?”

Just this one bit of programming opens up all sorts of challenges, Lee says. The driverless vehicle now isn’t obeying the law, but is obeying convention instead. How do we model that more broadly? Can we?

For Toyota’s Mobility Teammate Concept to work, Lee thinks we need more intuitive ways for the vehicle and the driver to communicate. He says one implication of one of his department’s automated vehicle studies with CSRC, was that even if you have subjects read the instruction manual of how a system in a vehicle works, it’s truly the experience of use that builds trust.
One struggle with teaching automated systems is how to train their artificial intelligence, not just to recognize patterns of how we drive, but to enable the extrapolation of likely outcomes based on those patterns. It’s what human beings do all the time. You’re driving into an intersection after coming to a stop, and you use an approaching vehicle stop, then begin to go before suddenly stopping. You know that means they’ve seen you; you’ve assessed they won’t proceed. But if that driver never saw you, then what?

During their study of Intersection Advanced Driver Assistance Systems, CSRC’s Gabler and Scobion, looked at how drivers accelerate away from an intersection stop. If they accelerate aggressively, they sometimes change lane, or for automatic braking to engage. And this study did find a predictive correlation between abrupt accelerations and more crashes. “We just didn’t realize there’s such a large difference in acceleration patterns between drivers.” Scobion says this is important because it likely means I-ADAS systems will need to be adaptable—they’ll need to pattern driver behaviors and create flexible warning structures so they “know” to warn aggressive accelerators earlier. This kind of artificial intelligence is one way autonomous systems can take hold, feeding into a broader database of likely outcomes. And this kind of artificial intelligence can be bridged. The driver and the system have to be analyzed in real time, or the steps to autonomy won’t be bridged.

But Toyota says what’s important about the idea of video monitoring is to adapt the vehicle’s feedback based on the video—comparing your present state to your “normal” state. “We tend to think of this like an alert, but it has to be better than that,” Toyota says. “The trouble with technology now is that it just crashes, without warning.” For the Toyota Mobility Teammate Concept to work, Lee says, there has to be enough overlap in trust. The driver and the system have to be bridged. The driver has to trust the system, and the system has to trust the driver. We need to teach automated systems more about how human beings trust technology, “It moves from being a simple tool to being a reliable teammate. We trust it’s giving us the correct information...”

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Dear Colleagues –

We have shared some of the stories of CSRC’s first five years in this chronicle. Overall, CSRC and our partners have completed 44 projects with 23 North American institutions and shared the output globally. There are a number of other interesting stories that are not included.

More than 200 graduate and post-doctoral students have contributed to CSRC research. Some of these students have gone on to jobs in automotive, mobility, technology, insurance and start-up companies. Others have joined universities as faculty.

CSRC is thankful to the government agencies, industry committees and academic community that have contributed to defining our research themes. Toyota is continuing our desire to serve as a catalyst advancing automotive safety research not just for the benefit of Toyota, but for the entire industry – and society as a whole.

We look forward to additional research partners in the coming years and collaboratively sharing the outcomes for a safe transition to future mobility.

Kiyotaka Ise, Chief Safety Technology Officer, Toyota Motor Corporation

Chuck Gulash, Director, Toyota Collaborative Safety Research Center
We are incredibly grateful for each of our dedicated partners who have helped advance over the past five years critical safety research.

**Human Factors**

**Virginia Tech Transportation Institute**

Brain Fitness Training for Older Drivers

A three-year project that examines and tests the belief that with brain appropriate training, older drivers can increase their driving safety with improved speed of processing and useful field of view – two physical factors which shrink with aging.

**University of Michigan Transportation Research Institute**

Teen Driver Distraction Study

Research that developed a computational technique for noise-tolerant robust detection and prediction of severe cardiac events, including Myocardial Infarction and Myocardial ischemia (MI), inside a vehicle. The ECG data collected from in-hospital and in-vehicle subjects will be trained with machine learning models to detect and predict the in-vehicle occurrence of cardiac events. The models developed can be robust to the specific in-vehicle noise sources and tailored to driver cardiac monitoring.

**MIT AgeLab**

Demands of In-Vehicle Voice Interfaces (Phase I)

A two-year study to learn how the use of an in-vehicle voice command system affects driver behavior, in order to provide the NHTSA with findings to help inform future research and the development of voluntary guidelines.

**MIT AgeLab**

Demands of In-Vehicle Voice Interfaces (Phase II)

A program to extend previous research on the relationship between the use of in-vehicle voice command systems and driver behavior to additional production vehicles and provide understanding of the ability of standardization of Phase I findings.

**University of Toronto**

Designing Feedback to Help Induce Safer Driving Behaviors

A three-year study to determine what types of feedback are most effective in helping inhibit risky behaviors, as well as when feedback can become a potential distraction, what types of individuals are more susceptible to feedback, how drivers adapt to feedback over time and whether the safety benefits of feedback persist even when it is no longer available.

**Wayne State Medical School**

Driver Distraction: Cognitive Model & Validation

Combining research in the fields of driver behavior, cognitive psychology, and cognitive neuroscience, this three-year study will advance the auto industry’s understanding of the cognitive aspect of driver distraction and how to measure cognitive load related to various secondary tasks.

**University of Iowa, University of Wisconsin**

Driver Model for Crash Avoidance Technology (Phase I and II)

A study aimed at developing driver response models for crash avoidance behavior in PCS (Pre-Collision Safety), pedestrian PCS and Lane Departure scenarios, with a goal of designing testing scenarios for Advanced Driver Assistance Systems; simulator modules for testing PCS, Ped-PCS and LD scenarios; extension of study to crash avoidance driver response models when takeover control is granted in automated driving. Validating the models with Naturalistic Driving data.

**Stanford University**

Driver Vehicle Interface for Partially Intelligent Vehicles

A three-year project to develop a set of psychological principles that will guide the design of a driver vehicle interface that provides effective, real-time support for drivers of a partially intelligent vehicle.

**University of Iowa Medical School**

Measuring Use and Impact of In-Vehicle Technologies on Older Driver Safety

A three-year study to determine how some older drivers may have declining abilities relative to driving, potentially increasing driving risk, and how they may use in-vehicle technologies.

**Virginia Tech Transportation Institute**

Teen Driver Coaching

This project is intended to develop a system of feedback and coaching to help teenage drivers reduce unsafe driving acts and lower their rate of auto-related injuries and death.

**University of Iowa, University of Washington**

Task Analytics and Time-Series Analysis of Driver Behavior

A comprehensive three-year study of pre-drive behavior such as where the feet are placed prior to beginning the drive, to determine its influence on driver-vehicle interactions.

**University of Wisconsin**

Enhancing Human-Automation Coordination

An analysis into how human factors coexist with automated driving. This holistic view of human-automation interaction emphasizes a novel use for the vehicle behavior level of an algorithm. A driving simulator study validated the findings.
University of Michigan Emergency Medical Dept.
Feasibility Study for Developing an In-Vehicle Emergency Medical Detection System
A research that developed a computational technique for noise-tolerant robust detection and prediction of severe cardiac events, including Myocardial Infarction and Myocardial Ischemia (MI), inside a vehicle. The ECG data collected from in-hospital and in-vehicle subjects will be trained with machine learning models to detect and predict the in-vehicle occurrence of cardiac events. The models developed can be robust to the specific in-vehicle noise sources and tailored to driver cardiac monitoring.

University of Nebraska Medical Center
Driving Safety and Real-Time Glucose Monitoring in Insulin-Dependent Diabetics
A study of drivers with insulin-dependent Diabetes Mellitus to investigate a system for real-time monitoring of glucose level while driving to improve safety. The research looked at the feasibility and means to quantify real-world driving behavior and determine the level and patterns of glucose control needed.

Active Safety
Virginia Tech Transportation Institute (VTTI), and Michigan Tech Research Institute (MTRI)
An analysis of existing crash and naturalistic driving data to investigate the factors associated with crashes and non-crashes at intersections, as well as to estimate the benefits of a system that could detect and warn in such scenarios.

University of Michigan Transportation Research Institute and Michigan Tech Research Institute
Vehicle Pre-Collision (PCS) System Test Procedures
A multidisciplinary project to develop test procedures for vehicle pre-collision systems in order to help consumers and the government compare technologies across the automotive industry.

Virginia Tech Transportation Institute (VTTI), and Michigan Tech Research Institute (MTRI)
Animal Pre-Collision (PCS) System Test Scenarios
A study to develop testing protocols for automotive PCS designs to prevent and mitigate animal-related vehicle crashes by examining crash data, collecting and analyzing naturalistic driving data, and radar scanning deer in order to better establish test parameters.

Virginia Tech
Brake Time to Collision Investigation
An analysis of the average time to Collision (TTC) following the application of the brake, based on naturalistic driving data in forward-collision scenarios, in order to help establish the necessary distances and warning timings for Forward Collision Warning systems.

Virginia Tech
Intersection Advanced Driver Assistance System (I-ADAS)
An analysis of existing crash and naturalistic driving data to investigate the factors associated with crashes and non-crashes at intersections, as well as to estimate the benefits of a system that could detect and warn in such scenarios.

Passive Safety
Virginia Tech
Abdominal Injury Study
A study that examines the relationship between age and abdominal injuries from automobile crashes to find new ways to better protect vulnerable populations of drivers and passengers.

Wayne State University
Finite Element Model Development for Vulnerable Populations (CHARM10 and CHARM70)
A four-and-a-half-year study to develop human body finite element (FE) models for children and older people (two vulnerable populations) so that engineers can account for differences in their body characteristics when designing vehicle safety systems and ultimately reduce injuries to all occupants regardless of age.

University of Virginia
Evaluation of Vehicle Kinematics and Occupant Response During Rollover Crashes
A study designed to establish an accurate simulation of rollover crash events that can establish realistic vehicle and occupant positions and kinematics at the time of first impact.

University of Virginia
Injury Simulation of Pedestrian Impacts
A study of the capabilities of Toyota’s pedestrian THUMS modeling system in accurately modeling the injuries suffered by pedestrians in various vehicle/pedestrian collision scenarios.

University of Michigan Transportation Institute
Parametric Human Body Modeling
A study to go beyond traditional Finite Element Models to create parametric Human Body Modeling techniques for auto safety research that will allow engineers to simulate injuries to a wide range of vehicle occupants, including specific individuals, by semi-automating changes to the models' body shape and posture.

Wake Forest
THUMS Simulation of Real-World Collision Events
A five-year project to combine collision reconstruction data with Finite Element Modeling to better understand how to reduce injuries caused by vehicle collisions, allowing researchers to pinpoint which changes to vehicle design could have prevented the actual injuries suffered by vehicle occupants.

University of Virginia
Whole Body THUMS Validation
A project that is aimed to learn more about how Toyota's Total Human Model for Safety (THUMS) models perform in crash tests at a "whole body" level.

University of Michigan Transportation Research Institute
Research Institute
Posture, Body Shape, and Seatbelt Fit in Older Drivers
This project is a study of the relationship between age and how the occupant sits in, and interacts with, the vehicle due to posture and body shape changes in order to find new ways to protect older drivers and passengers.

University of Michigan – International Center for Automotive Medicine
Research of Child Body Anatomy Feature Relationships
A one and half year project to develop digital 3D geometry data of 3-year-old and 6-year-old children from medical scan images to create human body Finite Element (FE) models. The research also analyzed anatomical features of children with respect to age.

University of Michigan Transportation Research Institute
Research Institute
Driver Belt Fit Behavior Study
A research project to measure the impact of novel messaging and instruction on proper seat belt placement for better crash protection. While seat belt use continues to increase due in part to consistent “buckle up” messages to, they do not describe the best way to position a seat belt over the body.

University of Virginia
Driver Nationality Body Study
A continuation of "Posture, Body Shape, and Seatbelt fit in Older Drivers," this project studied if body shape and vehicle interaction varies based on a person’s country of origin. The data collected in the previous study is further analyzed to probe potential differences in North America and other countries around the world.

University of Michigan Transportation Research Institute
Seat Belt Assurance System
A project investigating unbelted driving, looking at where drivers are more likely to travel unbelted and different types of unbelted driving. Further, the study presented a Seat Belt Assurance System concept to drivers and measured reactions to the system.

Wake Forest Medical School
Advanced Automatic Crash Notification (Phase II and III)
This project is developing vehicle computer systems that not only notify first responders in the event of a crash, but also predicts them the likelihood and severity of occupant and driver injuries.

Washtenaw County Crash Data Archive
This project is working to develop a detailed crash data archive to help better understand crash mechanisms and improve in-vehicle safety countermeasures.

University of California San Diego
Automated Tools for NDS Data Analysis for Driving Assessment
This study is focused on developing systematic and automated tools for monitoring and analyzing driver behavior in full context, including the vehicle and environment, to better understand dangerous situations and to inform the design of effective counter-measures.

Virginia Tech Transportation Institute
Distraction Data Collection
A three-year study aimed at using the SHRP2 Naturalistic Driving Study to develop a re-identified database of distracted and baseline driving events that can be used to support in-depth studies of driver distraction.

Children's Hospital of Philadelphia
Child Injury Database
This project studies the effective ways to establish a new National Child Occupant Special Study database in order to improve how we keep children safe in vehicles.
The Ohio State University

Ohio State University is one of the nation’s 15 colleges, Ohio State University is one of the nation's key leaders in research, preparing and educating students for leadership since its opening in 1891. Research (CAR), OSU strives to make our roads and vehicles safe.

* List of Partners

The Children's Hospital of Philadelphia

The Center for Injury Research and Prevention (CIRP) is a comprehensive, interdisciplinary pediatric trauma research center at The Children's Hospital of Philadelphia dedicated to preventing injury, the leading cause of death for children and adolescents.

* University of California San Diego

The University of California, San Diego Laboratory for Intelligent and Safe Automobiles (LISA) is a multidisciplinary effort to explore innovative approaches to making future automobiles safer and “intelligent”. Research includes computer vision and intelligent systems with synergistic contributions from cognitive sciences, psychology and decision theory.

* Michigan Tech Research Institute

The Michigan Tech Research Institute (MTRI), a research center of Michigan Technological University, is a recognized leader in the research, development and application of sensor and information technology. The center works to solve critical problems in national security as well as protecting and evaluating critical infrastructure, bioinformatics, earth sciences and environmental processes.

* Stanford University

As one of the world’s leading teaching and research universities, Stanford University has been dedicated to preparing and educating students for leadership since its opening in 1891.

* University of Iowa

The University of Iowa Hospitals and Clinics, which recognized as one of the best hospitals in the United States, is Iowa's only comprehensive academic medical center and a regional referral center. UI Hospitals and Clinics and UI Stead Family Children's Hospital together deliver quality care in collaboration with University of Iowa Physicians; the state's largest multi-specialty medical and surgical group practice composed of faculty physicians of the UI Roy J. and Lucille A. Carver College of Medicine.

* Virginia Tech

The Virginia Tech Transportation Institute (VTTI) serves as Virginia Tech's largest university-level research center. It is dedicated to conducting research to save lives, time and money in the transportation field by developing and using state-of-the-art tools, techniques, and technologies to solve transportation challenges.

* Wake Forest University School of Medicine

The Wake Forest University School of Medicine is among the top 33 schools in the country in research funding awarded by the National Institutes of Health, and is dedicated to teaching excellence in clinical medicine, promoting strong clinical and basic research, in addition to its work with the CSRC’s Finite Element Modeling project.

* Wayne State University

Wayne State University School of Medicine’s Office of Research utilizes a multidisciplinary approach to research and education with the goal of improving the quality of life and safety for everyone who shares the road. The Bioengineering Center of Wayne State University is a leading laboratory, doing research work in the areas of impact trauma, low back pain and orthopedic biomaterials.

* List of Partners