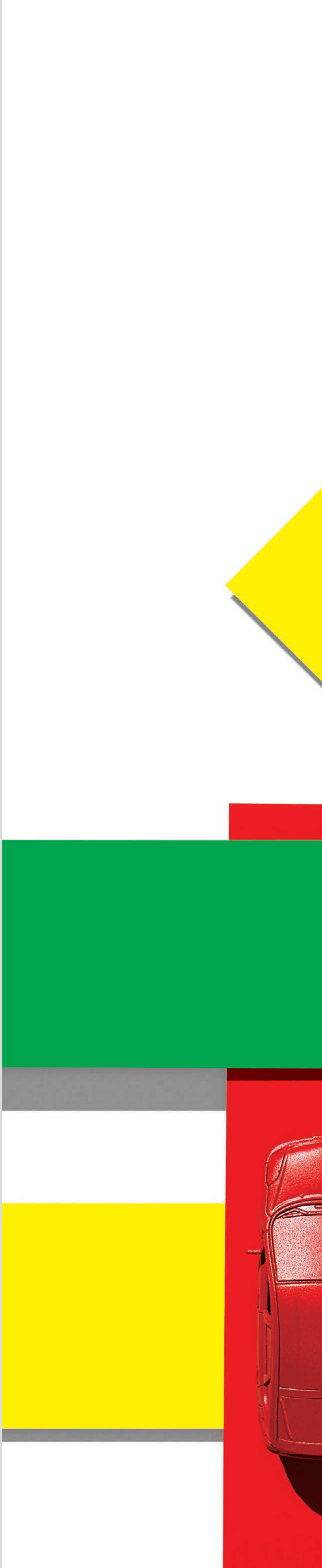
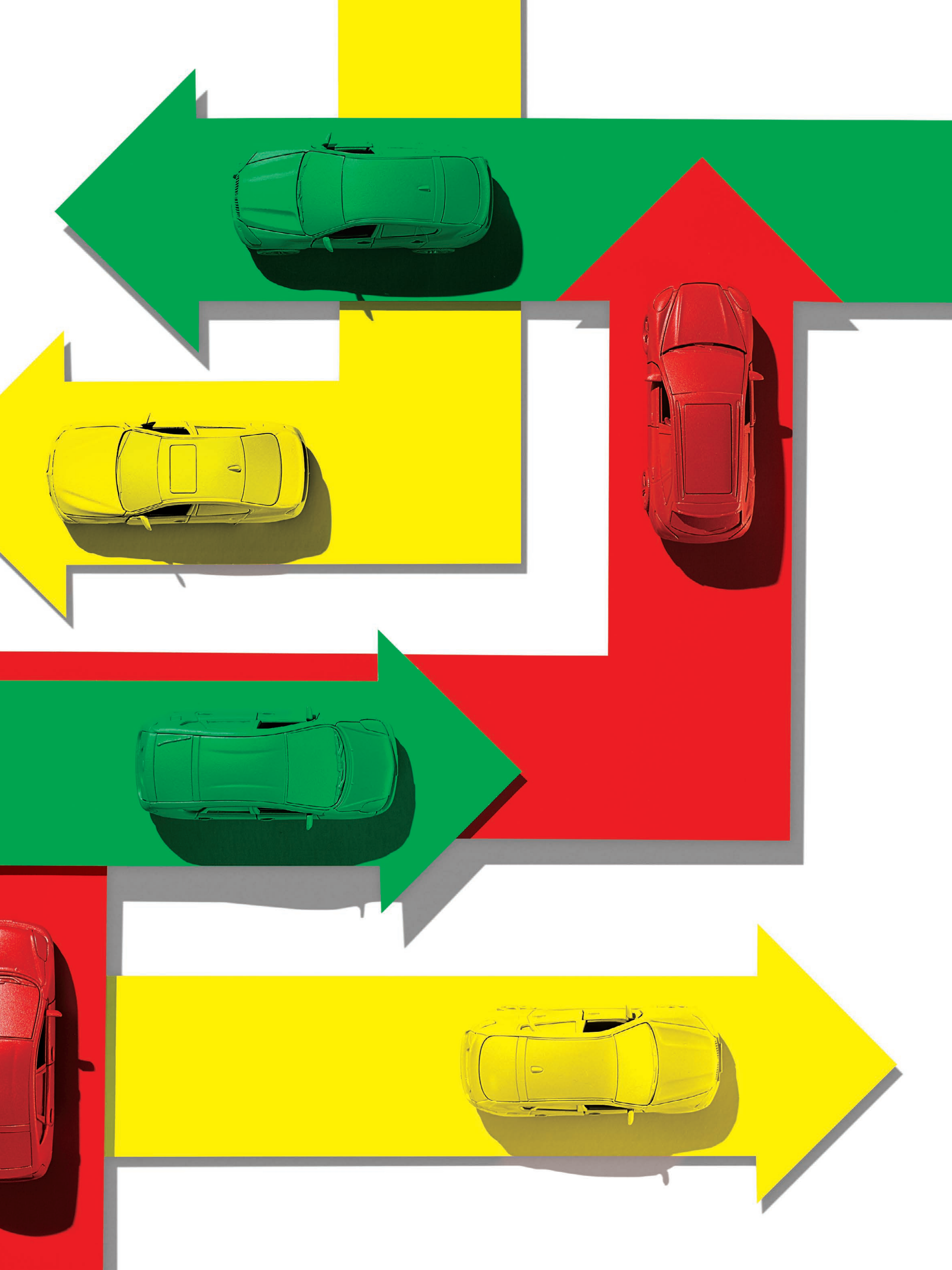
RED LIGHT, GREEN LIGHT—NO LIGHT

Tomorrow's communicative cars could take turns at intersections

By Ozan K. Tonguz • • • Photography by Dan Saelinger





Life is short, and it seems shorter still when you're in a traffic jam. Or sitting at a red light when there's no cross traffic at all. In Mexico City, São Paolo, Rome, Moscow, Beijing, Cairo, and Nairobi, the morning commute can, for many exurbanites, exceed 2 hours. Include the evening commute and it is not unusual to spend 3 or 4 hours on the road every day. Now suppose we could develop a system that would reduce a two-way daily commute time by a third, say, from 3 to 2 hours a day. That's enough to save 22 hours a month, which over a 35-year career comes to more than 3 years.

Take heart, beleaguered commuters, because such a system has already been designed, based on several emerging technologies. One of them is the wireless linking of vehicles. It's often called vehicle-to-vehicle (V2V) technology, although this linking can also include road signals and other infrastructure. Another emerging technology is that of the autonomous vehicle, which by its nature should minimize commuting time (while making that time more productive into the bargain). Then there's the Internet of Things, which promises to connect not merely the world's 7 billion people but also another 30 billion sensors and gadgets.

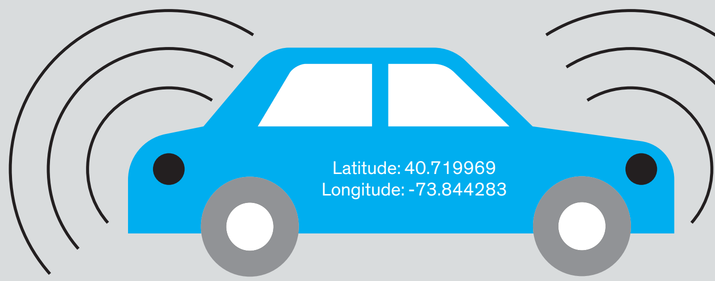
All of these technologies can be made to work together with an algorithm my colleagues and I have developed at Carnegie Mellon University, in Pittsburgh. The algorithm allows cars to collaborate, using their onboard communications capabilities, to keep traffic flowing smoothly and safely without the use of any traffic lights whatsoever. We've spun the project out as a company, called Virtual Traffic Lights (VTL), and we've tested it extensively in simulations and, since May 2017, in a private project on roads near the Carnegie Mellon campus. In July, we demonstrated VTL technology in public for the first time, in Saudi Arabia, before an audience of about 100 scientists, government officials, and representatives of private companies.

The results of that trial confirmed what we had already strongly suspected: It is time to ditch the traffic light. We have nothing to lose except countless hours sitting in our cars while going nowhere.

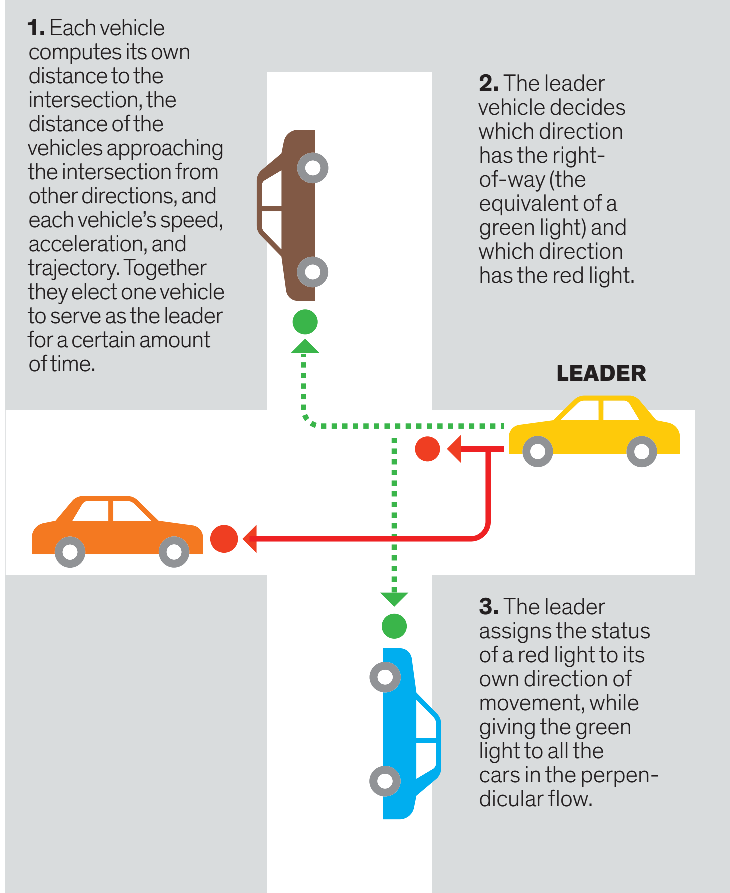
THE PRINCIPLE BEHIND THE TRAFFIC LIGHT has hardly changed since the device was invented in 1912 and deployed in Salt Lake City, and two years later, in Cleveland. It works on a timer-based approach, which is why you sometimes find

VTL Algorithm: Letting Cars Control Their Own Traffic

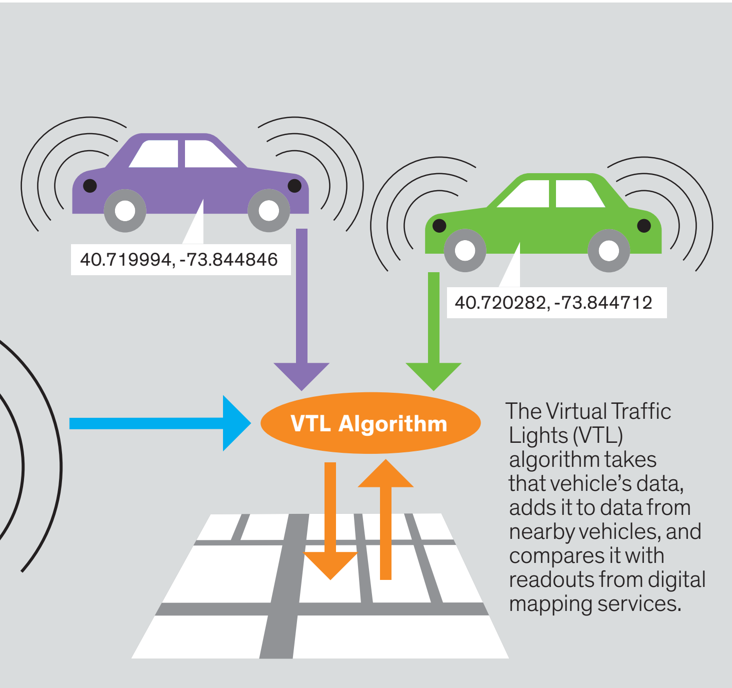
Transceivers (using IEEE Standard 802.11p) send out a basic safety message every tenth of a second. The message tells recipients where the transmitting vehicle is by latitude, longitude, and heading.

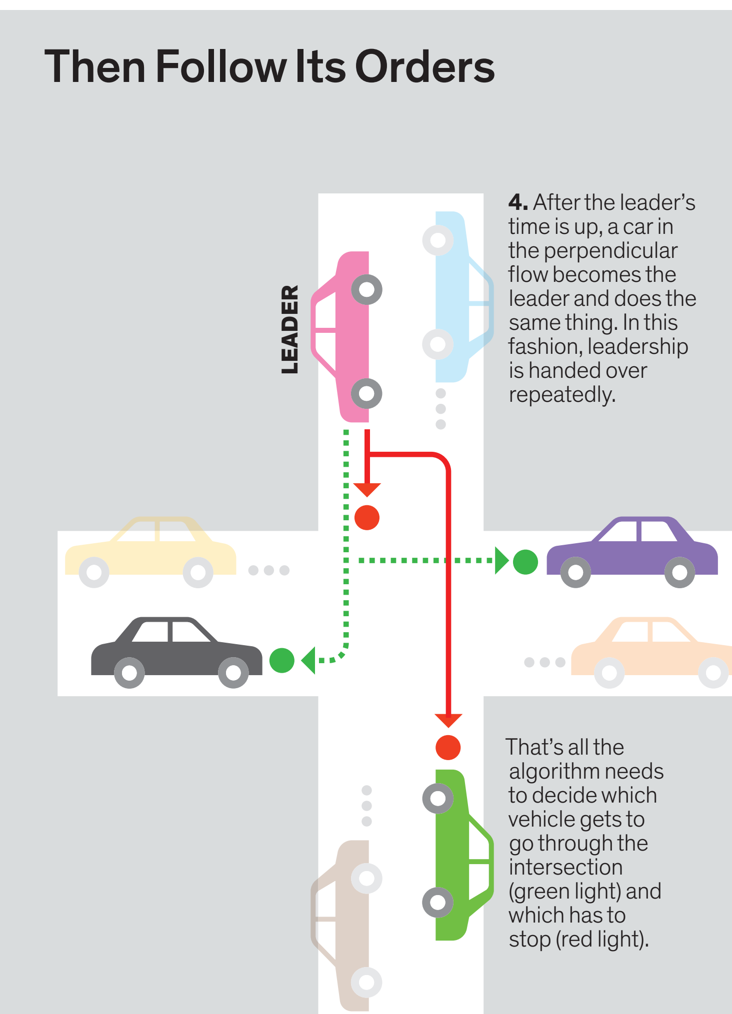


Cars "Elect" a Leader—



ILLUSTRATIONS BY Anders Wenngren





yourself sitting behind a red light at an intersection when there are no other cars in sight. The timing can be adjusted to match traffic patterns at different points in the commuting cycle, but that is about all the fine-tuning you can do, and it's not much. As a result, a lot of people waste a lot of time. Every day.

Instead, imagine a number of cars approaching an intersection and communicating among themselves with V2V technology. Together they vote, as it were, and then elect one vehicle to serve as the leader for a certain period, during which it decides which direction is to be yielded the right-of-way–the equivalent of a green light–and which direction has the red light.

So who has the right-of-way? It's very simple, and deferential. The leader assigns the status of a red light to its own direction of movement while giving the green light to all the cars in the perpendicular flow. After, say, 30 seconds, another car–in the perpendicular flow–becomes the leader and does the same thing. Thus, leadership is handed over repeatedly, in a round-robin fashion, to fairly share the responsibility and burden–because being the leader does involve sacrificing immediate self-interest for the common good.

With this approach, there is no need at all for traffic lights. The work of regulating traffic melts invisibly into the wireless infrastructure. You would never find yourself sitting at a red light when there was no cross traffic to contend with.

Our company's VTL algorithm elects leaders by consulting such parameters as the distance of the front vehicle in each approach from the center of the intersection, the vehicles' speed, the number of vehicles in each approach, and so on. When all else is equal, the algorithm elects the vehicle that's farthest from the intersection, so it will have ample time to decelerate. This policy ensures that the vehicle that's closest to the intersection gets the right-of-way–that is, the virtual green light.

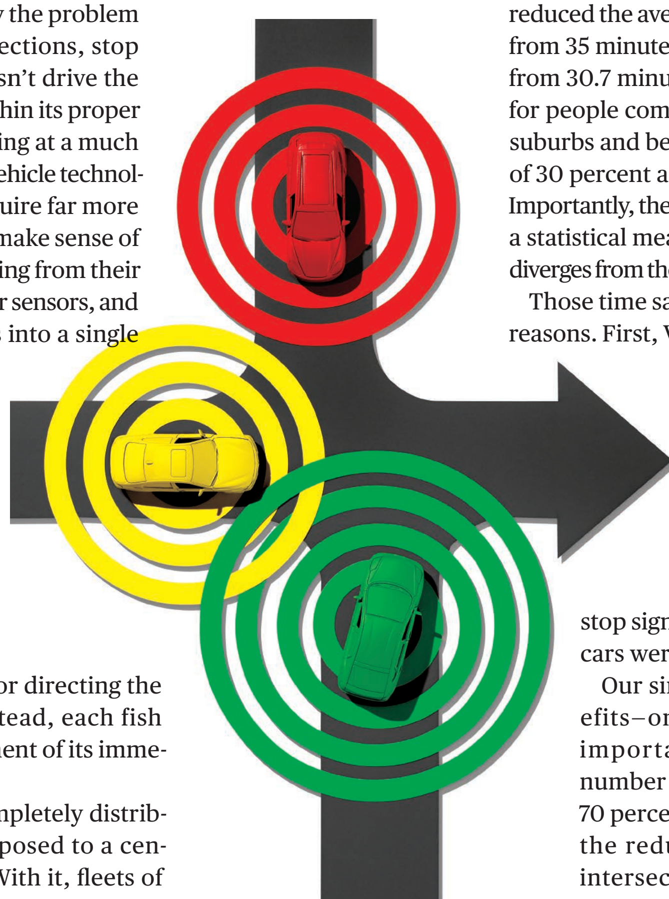
It's important to note that VTL technology needs no camera, radar, or lidar. It gets all the orientation it needs from a wireless system called dedicated short-range communications. DSRC refers to radio schemes, including dedicated bandwidth, that were developed in the United States, Europe, and Japan between 1999 and 2008 to let nearby cars communicate wirelessly. DSRC developers envisioned various uses, including electronic toll collection and cooperative adaptive cruise control–and also precisely the function we are using it for, intersection collision avoidance.

Very few production cars are now equipped with DSRC transceivers (and it's possible that emerging 5G wireless technology will supersede DSRC). But such transceivers are readily available, and they provide all the functionality we need. These transceivers, designed to make use of IEEE Standard 802.11p, must each send out a basic safety message every tenth of a second. The message tells recipients where the transmitting vehicle is by latitude, longitude, and heading. Running on a processor in a vehicle, our VTL algorithm takes the data from that vehicle, throws in whatever it is receiving from neighboring vehicles, and overlays the result onto readouts from such digital mapping services as Google Maps, Apple Maps, or OpenStreetMap. In this way, each vehicle can compute its own distance to the intersection as well as the distance

of the vehicles approaching the intersection from the other directions. It can also compute each vehicle's speed, acceleration, and trajectory. That's all the algorithm needs to decide who gets to go through the intersection (green light) and who has to stop (red light). And once the decision has been made, a head-up display in each car displays the light to the driver from a normal viewing position. Of course, the VTL algorithm solves only the problem of managing traffic at intersections, stop signs, and yield signs. It doesn't drive the car. But when functioning within its proper domain, VTL can do everything at a much lower cost than autonomous vehicle technology can. Self-driving cars require far more computing capability just to make sense of the individual data feeds coming from their lidar, radar, cameras, and other sensors, and more still to fuse those feeds into a single view of the surroundings.

Think of our method as the substitution of a rule of thumb for true intelligence. The VTL algorithm lets the cars control their own traffic much as colonies of insects and schools of fish do. A school of fish shifts direction all at once, without any master conductor directing the members of the school; instead, each fish takes its cue from the movement of its immediate neighbors.

This is an example of a completely distributed system behavior as opposed to a centralized network behavior. With it, fleets of vehicles in a city can manage traffic flow by themselves without a centralized control mechanism and without any human intervention—no police, no traffic lights, no stop signs, and no yield signs.



WE DIDN'T INVENT THE CONCEPT OF intelligent intersections, which dates back decades. One early idea was to place a magnetic coil under the asphalt surface of a road to detect the approach of vehicles along a single route to an intersection and then adjust the duration of the green and red phases accordingly. Similarly, cameras placed at intersections can be used to count the vehicles in each approach and compute how best to time the lights at an intersection. But both technologies are expensive to install and maintain and therefore only a few intersections have been fitted out with them.

We started by running our VTL algorithm on a virtual model for two cities: Pittsburgh and Porto, Portugal. We took traffic data from the U.S. Census Bureau and the corresponding Portuguese agency, added map data from Google Maps, and fed it all into SUMO, the Simulation of Urban Mobility, an open-source software package developed by the German Aerospace Center.

SUMO simulated the rush-hour commuting time under two scenarios, one using the existing traffic lights, the other using our VTL algorithm. It found that VTL reduced the average commute to 21.3 minutes from 35 minutes in Porto and to 18.3 minutes from 30.7 minutes in Pittsburgh. Reductions for people commuting into the city from the suburbs and beyond were cut by a minimum of 30 percent and a maximum of 60 percent. Importantly, the variance of the commute time—a statistical measure of how much a quantity diverges from the mean value—was also reduced.

Those time savings came primarily for two reasons. First, VTL eliminated the time spent waiting at a red light when there were no cars crossing at right angles. Second, VTL introduced traffic control to every intersection, not just those that have active signals. So it was not necessary for cars to stop at a stop sign, for example, when no other cars were around.

Our simulations showed other benefits—ones that are arguably more important than saving time. The number of accidents was reduced by 70 percent, and—no surprise—most of the reduction was centered at the intersections, stop signs, and other interchanges. Also, by minimizing the time spent dawdling at intersections and accelerating and decelerating, VTL measurably reduces the average car's carbon footprint.

So, what would it take to get VTL technology out of the lab and into the world? To begin with, we'd have to get DSRC into production cars. In 2014, the U.S. National Highway Traffic Safety Administration proposed the adoption of the technology, but the Trump administration hasn't yet implemented the regulation, and it's not clear what the final decision will be. So U.S. manufacturers may now be reluctant to install DSRC transceivers, given that they'd add cost to a car and they'd be useful only if other cars carry them, too—the familiar chicken-and-egg problem. And until enough cars begin to carry the devices, the scale of manufacturing will remain low and the unit cost high. In the United States, only General Motors has begun to put DSRC radios into cars, all of them high-end Cadillacs. However, in Europe and Japan the outlook is a lot more favorable. A number of European automakers have committed to putting the transceivers in their

PHOTOGRAPH BY Dan Saelinger

cars, and earlier this year in Japan, where the government strongly supports the technology, auto giant Toyota reiterated its commitment.

And even if DSRC fails entirely, our VTL algorithm can be implemented with other wireless technologies, such as 5G or Wi-Fi.

The concept of incomplete penetration of DSRC transceivers brings up one of the biggest potential obstacles to adoption of our VTL technology. Could it still work even if only a certain percentage of vehicles is equipped with DSRC? The answer is yes, provided that governments equip existing traffic signals with DSRC technology.

Governments may well be willing to do that, if only because they would rather not do away with hundreds of billions of dollars' worth of existing signal infrastructure. To address this problem, we've fitted out our Virtual Traffic Lights technology with a short-term solution: We can upgrade existing traffic lights so that they can detect the presence of DSRC-equipped vehicles in each approach and decide the green-red phases accordingly. The beauty of this scheme is that all vehicles could make use of the same roads and intersections, whether or not they are equipped with DSRC. This approach may not reduce commute time as much as the ideal VTL solution, but even so it is at least 23 percent better than the current traffic control systems, according to both our simulations and to field trials in Pittsburgh.

VTL REDUCED THE AVERAGE COMMUTE TO 21.3 MINUTES FROM 35 MINUTES IN PORTO AND TO 18.3 MINUTES FROM 30.7 MINUTES IN PITTSBURGH

Yet another challenge is how to handle pedestrians and bicyclists. Even in a regime mandating DSRC transceivers for all cars and trucks, we couldn't reasonably expect cyclists to install the devices or pedestrians to carry them. That might make it hard for those people to cross busy intersections safely.

Our solution for the short term, while physical traffic signals still coexist with the VTL system, is to provide pedestrians a way to give themselves the right-of-way. Ever since January of this year, our pilot program in Pittsburgh has provided a button to push that actuates a red light—real for the pedestrians, and virtual for the cars—at all four approaches to the intersection. It has worked every time.

In the longer term, the bicyclist and pedestrian challenge might be solved with Internet of Things technology. As the IoT expands, the day will finally come when everyone carries a DSRC-capable device at all times.

Meanwhile, under ideal conditions, with no physical signals at all, we have demonstrated that the vehicles voting on how to assign right-of-way can allot a portion of the signaling cycle to pedestrians. During these interludes, a virtual red light shines in all the vehicles at all four approaches, lasting long enough for any pedestrians there to cross safely. This preliminary solution wouldn't be optimal for traffic flow, and so we are also working on a method using cheap dashboard-mounted cameras to spot pedestrians and give them the right-of-way.

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ULTIMATELY, WHAT MAKES VIRTUAL TRAFFIC SIGNALS so promising is the advent of self-driving vehicles. As envisioned today, such vehicles would do everything human drivers now do—stopping at traffic lights, yielding at yield signs, and so forth. But why automate transportation halfway? It would be far better to make such vehicles fully autonomous, managing traffic without any conventional signs or signals. The key in achieving this goal is V2V and vehicle-to-infrastructure communications.

This matters because today's self-driving cars are often unable to negotiate their way into and out of busy intersections. This is one of the hardest technical problems, and it continues to challenge even industry leader Waymo (a subsidiary of Google's parent company, Alphabet).

In our simulations and field trials, we have found that autonomous vehicles equipped with VTL can manage intersections without traffic lights or signs. Not needing to identify such objects greatly simplifies the computer-vision algorithms that today's experimental self-driving cars rely on as well as the computational hardware that runs those algorithms. These elements, together with the sensors (especially lidar), constitute the single costliest part of the package.

Because VTL has a largely modular software architecture, it would be easy to integrate it into the rest of an autonomous car's software. Furthermore, VTL can solve most, if not all, of the hard problems related to computer vision—say, when the sun shines straight into a camera, or when rain, snow, sandstorms, or a curving road obscure the view. To be clear, VTL is not really competing with the technology of self-driving cars; it is complementing it. And that alone would help to speed up the robocar rollout.

Well before then, we hope to have our system up and running for human-driven cars. Just this past July we staged our first public demonstration, in Riyadh, Saudi Arabia, in heat topping 43 °C (100 °F), with devices installed in the test vehicles. Representatives from government, academia, and corporations—including Uber—boarded a Mercedes-Benz bus and drove through the campus of the King Abdulaziz City for Science and Technology, crossing three intersections, two of which had no traffic lights. The bus, together with a GMC truck, Hyundai SUV, and a Citroën car, engaged the intersections in every possible way, and the VTL system worked every time. When one driver deliberately disobeyed the virtual red light and attempted to cross, our safety feature kicked in right away, setting off a flashing red light for all four approaches, heading off an accident.

I hope and believe that this was a turning point in transportation. Traffic lights have had their day. Indeed, they lasted over a century. Now it's time to move on. ■

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