
Franco Vairani/MIT Smart Cities

BY TOM BAMONTE [1]

# INFORMATION BECOMES INFRASTRUCTURE:

## Remaking the Highway Operating System in the Era of Smart Cars

Google's successful deployment of a car that drives itself on existing highways tells us that the process of driving and hence the highway operating system itself is being reinvented. This change is being driven by vehicle manufacturers, intelligent transportation initiatives at the federal and state levels, and a variety of research initiatives in areas such as robotics and computer science.

**THE HIGHWAY OPERATING SYSTEM HAS NOT FUNDAMENTALLY CHANGED IN OVER A CENTURY. EMERGING TECHNOLOGIES WILL ALLOW VEHICLES TO DRIVE THEMSELVES AND DRAMATICALLY INCREASE THE CAPACITY OF OUR HIGHWAYS.**

Google CEO Eric Schmidt speaks for many in this movement when he said: "Your car should drive itself. It's amazing to me that we let humans drive cars. It's a bug that cars were invented before computers." [2] Sebastian Thrun, the lead researcher on the Google self-driving car project, predicts that by 2030 driverless cars will be a commercial reality. [3] The result will be a new highway operating system that offers

**THE CURRENT HIGHWAY OPERATING SYSTEM IS BASED ON THE UNSUPPORTABLE NOTION THAT ROADS ARE "FREE."**

much improved highway efficiency and enhanced safety.

For decades, the safe bet has been against the successful implementation of technology that takes humans out of the driver's seat. [4] However, the disruptive force of technological change that has transformed so many industries, products and services over the past few decades may finally be remaking a highway operating system that was established over a century ago and has not changed much since. This article will discuss some of the challenges and opportunities facing highway authorities generally, and toll operators in particular, as a result of these changes. [5]

## THE DIGITAL WAVE FINALLY HITS THE HIGHWAY SYSTEM

The highway operating system has not changed in any fundamental way for decades. We still put human beings at the steering wheel of petroleum-fueled vehicles, just as Henry Ford did a century ago. Our physiological limitations as humans require us to maintain significant spacing between vehicles. This limits the carrying capacity of the highways, requiring costly physical expansions to meet growing traffic demand. Even with significant improvements in vehicle and roadway design that have improved highway safety, there are more than 30,000 fatal vehicle accidents annually in the U.S. alone. [6] Annual accident-related costs exceed the total federal, state and local annual capital investment in highways. [7]

The transformation of the current highway operating system is happening in three dimensions — vehicle design, intelligent vehicles and pricing. [8]

### The Shift to New Vehicle Types

Electric-powered vehicles and possibly other alternatively powered vehicles will supplement and may eventually replace petroleum-powered vehicles. The shift to electric-powered vehicles will allow a much greater range of vehicle types. Digital technology and more compact power sources allow vehicle manufacturers to strip out cumbersome control mechanisms and reduce

vehicle size and weight. Today's stubby Smart Car points the way to more innovative vehicle designs in the future.

By our standards, many of these new vehicle types will seem small, underpowered and even flimsy. However, many of our trips, especially in crowded urban areas, do not require a vehicle that weighs over a ton, takes up much parking space, and is capable of going over 100 miles an hour. Accommodating a wider variety of vehicle types on roadways designed for current vehicles will be a challenge for highway authorities.

## The Shift to Smarter Vehicles and Highways

The notion that technology will supplant you and I as drivers has been around for many decades. It appears, however, that technology has finally reached the stage where we can consider alternative models for operating vehicles on our highway system.

Vehicle manufacturers already are using digital technology in a variety of ways to make cars smarter and safer. Some of this technology works autonomously, such as adaptive cruise control, where the vehicle maintains appropriate spacing between itself and the vehicle ahead. [9] Other technology interacts with the driver, such as systems that warn drivers if they are swerving off the road or that an obstruction is ahead. [10] Driver fitness can be tested and enforced through equipment that determines if a driver is impaired as a result of intoxication. [11]

The Google cars that drove themselves on regular California streets and highways points the way to the increasingly realistic prospect of vehicles that drive themselves. [12] The Google vehicle was equipped with LIDAR sensors, GPS

technology, and standard radar sensors that already are being installed in vehicles. These technologies are no doubt susceptible to mass commercialization in the near future. Together, the technologies allow the vehicles to handle the challenges of driving without direct human intervention. The most important human intervention came, quite ironically, when a Google car was rear-ended by a vehicle driven by a human.

In addition to being able to navigate existing roadways, intelligent vehicles will communicate with each other to share their location, direction and speed in real time. When this vehicle-to-vehicle communication technology is combined with other in-vehicle technology such as adaptive cruise control, it becomes possible to reduce spacing between vehicles, thereby significantly increasing highway capacity. When aggregated, data broadcast from each vehicle will enable sophisticated trip planning and congestion management tools. [13] Before long, the "smartest" vehicle may be as coveted a designation as the "fastest" or "most fuel efficient" vehicle.

Highways are also getting smarter. Sensor equipment and cameras allow control rooms to better monitor road conditions. Traffic light control technology allows more effective use of traffic lights to manage traffic. Dynamic message signs allow targeted communications to drivers. Some forward-looking transportation agencies are making their data available to the developer community for use in smartphone apps and the like. Eventually, intelligent vehicles will be able to communicate directly with intelligent highways about pavement issues (e.g., icy patches ahead), traffic conditions and alternative routes.

A highway system that features, or at least approaches, self-driving cars and much higher levels of vehicle throughput per lane likely will be based on some blend of innovative highway and vehicle technologies. At one end of the spectrum is a smart highway/dumb car approach, where highway authorities operate the transportation network and direct the "dumb" vehicles. Under this approach, the highway network supplies the brains and vehicles are just smart enough to plug into the network. At the other end of the spectrum is a smart car/dumb highway approach, where nimble and intelligent vehicles take the

highway infrastructure as is and use sensors and vehicle-to-vehicle communications to organize themselves like a flock of birds.

Innovation is likely to be concentrated in the intelligent vehicle end of the spectrum in the near future as vehicle manufacturers use a variety of new technologies to compete for customers. Highway authorities for the most part are public monopolies offering a free product, which is not an institutional recipe for innovation. As with the rapid deployment of the automobile a century ago, while innovation is likely to happen primarily on the vehicle side at first, major changes to how we build and maintain highway infrastructure will be necessary to fully unlock the potential of these new vehicles. Together, these intelligent vehicle/intelligent highway technologies may fix the "bug" of having humans with all of our foibles and limitations in full control of large and heavy capsules of glass and steel hurtling down roads at 60 miles an hour or more and navigating complex environments filled with pedestrians, bikes and other vehicles. There is every reason to believe that these technologies will allow us to double highway capacity and reduce accidents by half.

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## The Shift to Market Pricing

The current highway operating system is based on the unsupportable notion that roads are "free." As we might have learned from the collapse of the Soviet economy, underpricing scarce commodities — in this case highway space, especially during busy periods — just leads to long and unproductive lines and poorly maintained infrastructure.

The transformation of the highway operating system through extensive use of digital technology should bring with it more market pricing. Researchers foresee intelligent cars working with their operators to identify the best routes of travel based on the operator's preferences regarding price, speed of travel and time of day. By attaching prices to routes, time of travel and speed, the highway system can be managed to maximize efficient

use of capacity. The more intelligent the highway system, the more effective the pricing of the various elements of that system. The more effective the pricing, the more efficient the highway system.

Parking, like highway facilities, will be dynamically priced and allow users to reserve spaces, identify open spaces easily and reduce the wasteful circling search for parking. Vehicle sharing services such as ZipCar may be the model for a variety of services that will allow people to spread the cost of vehicle ownership over a variety of easily available vehicles, each suited to a particular use — commuting, long-distance family trips or other specific purposes.

**THE TIME IS COMING WHEN HIGHWAY AUTHORITIES WILL NEED TO DECIDE WHETHER TO EXPAND CAPACITY BY LAYING MORE PAVEMENT OR BY INVESTING IN TECHNOLOGIES THAT MAKE MUCH BETTER USE OF EXISTING LANES.**

## THE CHALLENGES AND OPPORTUNITIES FOR HIGHWAY AUTHORITIES FROM THE SHIFT TO A NEW HIGHWAY OPERATING SYSTEM

The Google self-driving car is a wake-up call for highway authorities. Highway authorities can take a backseat role, waiting passively for vehicles to get intelligent enough to navigate on existing roadways. Alternatively, highway authorities can facilitate the transformation to a safer and more efficient highway operating system by collaborating with vehicle manufacturers and others on finding the optimum blend of in-vehicle and highway technologies. The stakes are high. Regions and societies that find the right mix of in-vehicle and highway technology will gain a competitive advantage over those that fail to do so. This section looks at some of the challenges and opportunities faced by highway authorities in the years ahead.

### Who Controls the Highway?

Today, highway authorities are secure in their control over the highway system. After all, it is the highway authorities that post the speed limits, place and time stoplights, and otherwise manage the traffic flow.

Flocks of smart cars equipped with technology managed by sophisticated private companies like Google could challenge the hegemony of highway authorities over the roads. The private sector could use in-vehicle technology to organize traffic flows on the highways, just as phone companies collaborate when managing traffic flow over the Internet. One can envision situations where traffic flows and speeds are actively managed by private sector operators. Subscribers to premium service plans might get preferred access to open and faster traffic lanes and queue-jumping capabilities when traffic is backed up, while regular plan subscribers or non-subscribers are held back in traffic.

Will highway authorities take a deregulatory approach and let the private sector organize and stratify traffic flows on public highways or will highway authorities assert their primacy in this regard? If highway authorities attempt to regulate use of in-vehicle technology to prevent queue jumping and other perks, can they do so without stifling the deployment of useful technologies? Do private entities own the highway-related information they harvest from smart vehicles or can public highway authorities assert a claim to such information? These and related questions go to the fundamental issue of who controls the highway network being used by intelligent vehicles.

## Changing Investment Priorities

The changing highway operating system forces highway authorities to rethink their investment priorities. The traditional approach has been to try to build out of congestion by adding new lanes. As new technologies are deployed that allow closer spacing of vehicles, thereby increasing the capacity of existing roads, highway authorities will have to face a basic question: Does it make sense to invest billions of dollars in physically expanding highways when that money might accelerate the development of in-vehicle and roadway technology that can double capacity and substantially improve the safety of existing roads.

There is no good institutional arrangement today that allows highway authorities to easily make the investment choices that will facilitate the transition to the next operating system. After all, state procurement authorities, to say nothing of the public, might look askance at highway authorities funding research and technology


deployment efforts at companies like Google or General Motors rather than pouring concrete.

Yet, as the Google self-driving car indicates, the time is coming when highway authorities will need to carefully consider whether investing in expanded capacity through the traditional means of physical expansion of the roadway is a better investment of public dollars than supporting the transition to technologies that will make much better use of existing capacity. Urban areas where further physical expansion of highways is difficult and extremely costly have a strong incentive to speed the adoption of technologies that will allow increases in capacity without physical expansion of the roadways.

The transition to electric vehicles will power the need for investment in battery charging infrastructure at homes, in parking spaces and along roadways. Range anxiety — the fear that one will be stranded in a vehicle with dead batteries — is a key impediment to consumer adoption of electric vehicles. This anxiety must be dealt with by the adequate distribution of chargers plus some provision for mobile charging of stranded vehicles, just as a H.E.L.P. truck arrives today with a gallon of gas.

Substantial investments will have to be made in the technology necessary to communicate information to and from a growing number of intelligent vehicles. The wider range of vehicle types may require investments in new signage, lane markers and other

roadway assets to accommodate vehicles that may be smaller, slower and smarter than today's vehicles.

### Information as Infrastructure

For decades the focus of highway authorities has been on the hard infrastructure — roadways and bridges. That infrastructure has communicated to vehicle operators primarily through fixed roadway signage with a static message (e.g., "curve ahead"). The new highway operating system will force highway authorities to rethink their core deliverables. Highway authorities will have to design and build highways that are capable of communicating with and supporting a growing network of intelligent vehicles. The very idea of a highway will have to be re-imagined so that its ability to sense and report on its condition is just as important as its ability to physically carry vehicles.

Smarter vehicles will place increased demands on highway authorities to increase the quantity and precision of the data generated and shared about roadway conditions. In a system that may include self-driving vehicles and much tighter spacing between vehicles, information about the location of work zones, slippery pavement, accidents, and other roadway conditions takes on new importance. Privacy and security concerns must be addressed. Information has to be accurate and accessible to different vehicle operating systems. Indeed, highway authorities conceivably could find themselves held liable for accidents that might result from absent or poor quality data.

**THE PRICING INCENTIVES OF ALL-ELECTRONIC TOLLING WILL SPUR THE TRANSITION TO THE NEXT HIGHWAY OPERATING SYSTEM.**

Information gathering and sharing will become as important as planning and constructing roads and bridges. Information will become infrastructure in the new highway operating system. [14]

### Market Participation

Highway authorities will also have to decide whether to continue to rely on the "free" highway model or extend pricing to more highways. As discussed in the first subsection above, the private sector may be able to squeeze value and hence revenue out of the


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highway system by using in-vehicle technology to offer their subscribers premium transportation services. By extending tolling systems and using dynamic pricing techniques, highway authorities could capture for themselves some of the value being generated by a more intelligent highway system. The tolling industry provides highway authorities with tools to capture some of this value. The utility of current tolling tools is somewhat limited, however. Tolling costs, even in all-electronic environments, are relatively high. The existing electronic tolling systems are based on proprietary technologies zealously guarded by private entities. This means that there is no national interoperability and costs are high. The maddening proliferation of license plate types and the uneven quality of vehicle registration and vehicle owner information maintained by state departments of motor vehicles reduce the effectiveness of toll collection systems.

Nonetheless, there is the opportunity for expanded use of tolling, not just on limited access interstates but also on a greater variety of roads and bridges. [15] Tolling should look ever more attractive as gas tax receipts decrease with the rise of more efficient vehicles and vehicles fueled by petroleum alternatives.

## Organization

The transformation of the highway operating system will require highway authorities to revamp their organization. In a word, the primacy of the Chief Engineer is over. Information technology and customer service must be on par with building and maintaining roadways and hard infrastructure.

Highway authorities will have to invest heavily in information technology to keep up with the innovations in both in-vehicle and highway technology. Investment in information technology means more than back office server farms and dynamic message signs that communicate road condition information to passing vehicles. It also means investing in tools that directly enhance customer service, such as making it easier for people to pay for travel either in advance or immediately after travel through means such as smartphone apps. It means making system data readily available to the developer community for use in travel time and trip planning apps.

The IT and customer service sections will require more staffing and executive attention. IT project management skills will become as important to highway authorities as good engineering skills. Running a "smart" highway system will put a premium on an intelligent workforce that is capable of envisioning and implementing IT and associated hard infrastructure investments.

## Economic Development

The transformation of the highway operating system will have profound economic effects. The contrast between existing highways and future "smart" highways may be as profound as the contrast a century ago between a dirt road and a paved highway. Highway authorities, and especially those that are tax supported, have a vested interest in making sure their regions transition to the new highway operating system in a timely and cost-effective manner. Just as the towns linked to the national economy by dirt roads did not fare as well as towns connected to the economy through paved roads, metropolitan regions today will differentiate themselves by their deployment of the new highway operating system.

The new highway system will also generate new industries and employment opportunities. Highway authorities could facilitate the development of those industries by partnering with researchers and companies in

their service areas that are developing new products and services. Highway authorities can do this by sharing data, making their facilities available for testing of new products, and helping to underwrite research and new products. One can envision public-private partnerships between highway authorities, auto manufacturers and firms like Google that are interested in speeding the deployment of intelligent vehicle technology.

**PUBLIC-PRIVATE PARTNERSHIPS BETWEEN HIGHWAY AUTHORITIES AND FIRMS LIKE GOOGLE WILL SPEED DEPLOYMENT OF INTELLIGENT VEHICLE TECHNOLOGY.**

It is worth noting that the new highway operating system may provide a competitive edge to dense and built-out urban areas compared to relatively new and expanding urban areas. When the solution to congestion is expanding lane mileage, highway authorities can do so more easily in areas where land is cheap and undeveloped. Thus, over the past 50 years, the rapidly growing urban areas in the South and Southwest had an advantage over the more developed urban areas, especially in the Northeast, as the interstate system was being built out. The new highway operating system uses technology to increase the capacity of existing roadways. This will put developed urban areas on par with other regions because no new land will be required to increase highway capacity.

## THE ROLE OF TOLL OPERATORS

Toll operators have an advantage over the highway authorities in charge of "free" roads, namely, a revenue stream based on usage rather than fuel consumption. Toll operators have some flexibility in dedicating a portion of that revenue stream to make the IT and other investments necessary to build an intelligent vehicle/intelligent highway system.

Toll operators should have an existing customer service orientation. They need to take the next step and re-imagine themselves as electronic commerce organizations similar to major online retailers and financial institutions, offering a safe

and efficient transportation service. Scrimping on investments of money and talent in the IT and customer service sectors of the business will just create an opening for the Googles of the world to use in-vehicle technology to take over more control of the highways. Conversion to all-electronic tolling may become a business imperative. Toll operators that continue to invest heavily in toll collection by hand will fall behind toll operators that build up their IT resources and expertise by focusing toll collection efforts on all-electronic tolling. Agencies with substantial legacy workforces will face difficult challenges in making this transition in a fair and cost-effective manner.

All-electronic tolling allows toll operators to more easily use pricing incentives to help spur the transition to the next highway operating system. These incentives include price breaks for vehicles using alternative fuels and technology such as adaptive cruise control that demonstrably increase safety. Such price incentives also have environmental benefits because they encourage the transition to more fuel-efficient vehicles.

Toll operators as a group can do two things to facilitate the transition to the next highway operating system. First, they need to make tolling systems interoperable so tolling has an immediate national scale. Second,

they need to work zealously to drive down the cost of collection, both by transitioning to all-electronic tolling and pressing vendors for more efficient electronic systems. By modeling the benefits of pricing and delivering superior service, toll operators will make it easier for more elements of the transportation system to become priced.

## CONCLUSION

Roughly a century ago, those who managed the dusty roads filled with horse-drawn carriages glimpsed the first horseless carriage chugging down the road and wondered if that invention would change everything. It did, as we see from the interstates and the development patterns spawned by the mass-produced automobile. Self-driving cars are the horseless carriages of our era. They will jump-start a new highway operating system featuring intelligent vehicles and infrastructure and greater reliance on market pricing. The transition to that new system presents major challenges and opportunities for highway authorities and toll operators.

**— TOM BAMONTE** is general counsel, Illinois State Toll Highway Authority. He may be reached at tbamonte@getipass.com.

1 The views in this article are the author's alone and are not necessarily shared by the Authority or the Illinois Attorney General.
2 http://techcrunch.com/2010/09/28/schmidt-on-future/
3 http://www.timesonline.co.uk/tol/news/science/article1403715.ece
4 http://www.nytimes.com/2007/12/04/science/04tier.html
5 "Highway authorities" refer to all entities responsible for building and operating highway while "toll operators" refer to the subset of highway authorities that charge tolls.
6 http://www.gao.gov/new.items/d04802.pdf
7 http://www.gao.gov/new.items/d04802.pdf
8 This section was especially informed by W. Mitchell, C. Borroni-Bird & L. Burns, *Reinventing the Automobile: Personal Urban Mobility for the 21st Century* (MIT Press 2010)
9 http://www.wired.com/cars/coolwheels/magazine/17-08/pl_motor
10 http://www.fmcsa.dot.gov/facts-research/systems-technology/product-guides/lane-departure.htm
11 http://www.dadss.org/
12 There are other intelligent vehicle initiatives in addition to the Google car. *See, e.g.,* http://ec.europa.eu/information_society/activities/intelligentcar/icar/index_en.htm (European Commission); http://vislab.it/ (Italian research company); http://autonomos.inf.fu-berlin.de/ (Freie Universitat Berlin); http://english.anhuinews.com/system/2010/10/28/003410092.shtml (Hefei Institutes of Physical Sciences). These initiatives have resulted in prototypes of driverless taxis summoned by iPhone Apps (http://reviews.cnet.com/8301-13746_7-20019613-48.html?tag=mncol;23n) and an 8,000 mile trip by a driverless vehicle from Italy to China (http://link.baia-network.org/profiles/blogs/italian-driverless-car-beats). Driverless vehicles are already in operation a Heathrow Airport, albeit on a dedicated roadway (http://www.engadget.com/2009/08/18/heathrow-taxi-pods-become-a-glorious-driverless-reality/)
13 Already companies are using data harvested from cell phones and other electronic devices traveling in vehicles to provide travel time and route recommendations to their customers. http://travel.nytimes.com/2010/11/14/travel/14practraffic.html; http://blogs.strategyanalytics.com/auto/?p=210
14 http://www.govtech.com/transportation/Smart-Highways-Smarter-Drivers.html
15 The U.S. 35 project in West Virginia is a good example of extending tolling to non-interstate highways. http://www.transportation.wv.gov/turnpike/Pages/Route35.aspx