Synergies Between Vehicle Automation, Telematics Connectivity, and Electric Propulsion

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Abstract Vehicle automation is one of three broad categories of emerging and disruptive technologies that have the potential to fundamentally transform surface transportation. The other two are the emergence of practical and commercially viable electric vehicles, and the constellation of innovative ways to connect vehicles to the Internet, other vehicles, infrastructure, and data. Each of these new technologies taken alone represents an important advance in surface transportation. Taken and deployed together these three technologies can resolve the major objections to current vehicle technology and address the objections some have to individual components of each of the three main emerging transportation technologies.

Keywords Vehicle automation · Autonomous vehicles · Electric vehicles · Telematics · Vehicle safety · Demonstration project · Petroleum · Energy management

1 Introduction

One of the potential obstacles to large-scale and rapid deployment of self-driving vehicles in the United States is an underlying concern among policy makers that this technology will encourage more frequent use of single occupant cars, less use of alternatives and thus more urban pollution and greenhouse gas emissions.

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Center for Advanced Transportation and Energy Solutions (CATES, based in Seattle) is working in partnership with the Connected Vehicle Proving Center at the University of Michigan—and with funding from the Graham Environmental Sustainability Institute—to conduct assessment research and develop policy options that would accelerate and integrate self-driving vehicle technology with other emerging technologies in ways that also enhance the goals of federal, state, and local government livable and sustainable community initiatives [1].

This task begins with recognition that personal automobile mobility is an important part of daily life in all communities, including those making progress on encouraging more pedestrian walkability, biking, and transit. The U.S. Census Bureau reports that 86 % of trips to work in 2011 were by private vehicles [2]. Personal automobile use is likely to continue to be high. For example, the U.S. Energy Information Administration forecasts that annual miles per driver will rise from 12,000 in 2014 to 13,000 in 2032 [3], even though U.S. DOT reports that miles of driving per capita have fallen since 2006 [4].

The challenge is how to minimize or eliminate the negative aspects of personal vehicle use while also making the alternative modes safer and better integrated. This should be an essential policy priority for livable, sustainable communities in addition to any public policy efforts to reduce solo driving via land use changes, financial incentives, regulations, and other means.

In a broad overview, there are four major problems with current surface transportation systems that can be significantly reduced with a combination of connected, autonomous and electric vehicles.

1.1 Problem 1: Oil Dependence in Transportation

Oil dependence in transportation harms the economy, national security and the environment. It is not sustainable because the cost of extracting oil is rising. Oil fuels 97 % of U.S. transportation, and the cost has risen sharply to over $100 a barrel today from $20 twelve years ago. Oil use in transportation is one of largest causes of anthropogenic greenhouse gas emissions and urban air and noise pollution. Tailpipe emissions of criteria pollutants, concentrated in urban areas, kill more people than collisions [5].

Imported oil in recent years has cost the U.S. economy over a billion dollars a day. New oil supplies from tight rock formations and deep off-shore sources are costly to exploit and are ultimately finite.

A significant percentage of world oil comes from unstable and undemocratic regions, harming world and national security. The annual U.S. military cost to protect world oil supply lines exceeds $80 billion, not counting direct war costs in the Persian Gulf region [6].

Replacing oil with electricity to power urban vehicles will dramatically reduce oil consumption, improve energy efficiency, help the economy, reduce greenhouse gas emissions and reduce other tailpipe emissions and urban pollution.

1.2 Problem 2: Fatalities and Injuries from Accidents

The ongoing carnage from U.S. road accidents—33,561 fatalities in 2012, 2.4 million people injured, and billions of dollars in medical costs and property damage [7]—could be reduced by as much as 80 % through road vehicle automation. New vehicles are now available with a growing array of automated driver assistance technologies, such as adaptive cruise control and lane keeping, to reduce driver errors leading to accidents. These technology applications are the precursors to a future of self-driving cars with and without a driver in the vehicle.

1.3 Problem 3: Congested Roadways

Traffic congestion wastes time and fuel, damaging the economy and the environment. Urban pollution and greenhouse gas emissions increase dramatically in stop-and-go traffic. The estimated cost of traffic congestion is $121 billion annually, not counting the costs of the adverse health consequences of traffic related vehicle pollution [8].

Information processing and wireless communications capabilities, collectively called telematics, can make travel safer and more efficient by providing real-time, hands-free information to drivers. Telematics today can calculate the most efficient travel route, provide hints on how to avoid traffic, assure that an emergency response comes quickly, identify and reserve the nearest available parking space, and provide increasingly sophisticated and detailed information on desired destinations. The era of big data and wireless communication for drivers and their cars is creating what some call the “mobility internet” [9].

Autonomous vehicles will also decrease urban congestion and reduce pollution caused by stop-and-go driving in part by providing more real-time information but also by increasing road capacity without the need to build more roads. Autonomous vehicles traveling safely at close intervals and in more narrow lanes can triple the capacity of existing highways. Autonomous vehicles will enable dynamically and temporarily dedicated road lanes that will aid public transit, emergency vehicles and other priority usage.

Finally, advanced telematics can enable future variable road pricing that will reduce peak congestion and provide a long-term sustainable and flexible method to pay for maintaining and operating urban road systems.

1.4 Problem 4: Underutilization of Public Transit

Due in part to changing work and family patterns—from one-wage earner households with set hourly schedules and one long-term employer, to two wage earners with variable hours at multiple employers—the percentage of daily work trips on public transit has declined from 6.4 % in 1980 to 5.0 % in 2011 [10]. Among other causes, commuters generally lack the flexible transit options and scheduling tools to meet their changing work patterns.

Transit applications of telematics can provide more flexible and accessible transit options into and around urban areas and help to intercept single occupant vehicles (SOVs) with easy-to-use transit options before SOVs enter core congested urban areas, increasing urban transit use and reducing pollution. This is part of what Zielinski terms the "New Mobility Grid" in which advanced telematics help make public transportation more affordable, more user friendly, and more often used than today [11]. These new technologies are beginning to enter applications that enable commuters to reserve parking places at transportation hubs, and then reserve seats on buses, car pools, van pools and company transit options.

1.5 Framework for Improvement

One goal of this chapter is to further outline the emerging and disruptive technologies that have the potential to help solve the four major problems and to advance urban livability and sustainability.

A second goal of this chapter is to provide more information to policy makers and suggestions on how to view these technologies in an integrated public policy framework. Many policy makers remain largely unaware of the pace and extent of the innovative and disruptive technologies that form the core attributes of smart, connected, autonomous electric vehicles and transportation hubs.

Unlike private sector advances in, for example, tablet computers, smart phones and their related applications, the public sector has a significant role in the application of new transportation technology through the public ownership of roads and transit systems, as well as through its broader and more compelling interests in public health, safety, national security and the environment.

Finally, we outline a proposal for a large-scale demonstration project in Western Washington State that will bring together and test a combined set of these emerging technologies in a real-time, real-world setting.

2 Electric Propulsion: Moving From Oil to Electricity in Surface Transportation

The near total dependence on oil to fuel U.S. transportation is a major and daunting challenge to the economy, national security, human health and the environment. Moving from oil to electricity in transportation is one of the most immediate and increasingly viable solutions. As former Assistant Secretary for Policy and International Affairs at the Department of Energy, David Sandalow, has said: "To reduce oil dependence, nothing would do more good more quickly that making cars that could connect to the electric grid." [12] "No technology has more promise to break the grip of oil on the U.S. transport sector than the plug-in electric vehicle" [13].

"Electrification of transportation is the best solution for dramatically reducing oil dependence. The electric power sector has substantial advantages over the current petroleum-based fuel system, and vehicles fueled by electricity are far more efficient than the conventional vehicles we drive today". Electric motors "can turn 90 % of the energy content of electricity into mechanical energy. In contrast, today's best internal combustion engines have efficiency of just 25–27 %" [14].

A study by the Pacific Northwest National Laboratory found that over 70 % of all the cars and light trucks in the United States could be powered by the existing power system by using off-peak power capacity accessible via smart charging computer applications that charged vehicles overnight [15, 16].

There are two power sources for electric vehicles: Batteries and hydrogen fuel cells. Batteries in gas-hybrid cars are charged by the gasoline engine, as in the original Toyota Prius. Plug-in electric vehicles (PHEVs), such as the Chevy Volt and the Ford C-Max Energi, have a plug for charging the battery from the electric grid and a back-up gasoline engine. In pure electric vehicles (EVs), such as the Nissan Leaf and the Tesla Model S, the batteries are charged only by a power cord connected to external electric power. Hydrogen fuel cells are seen by some as having a long-range potential to replace or augment batteries in electric vehicles [17].

The advantages of moving from oil to electricity are in five main areas: (1) Reduction of greenhouse gas emissions; (2) reduction of other criteria pollutants; (3) improvement to the national economy through greater efficiency and a reduced trade deficit; (4) national security improvements through reduced world oil dependence and less reliance on unstable regimes; and (5) reduction of water and noise pollution.

2.1 Reduction of Greenhouse Gas Emissions

Burning oil for transportation produces significant quantities of anthropogenic GHG emissions. In the Seattle area, for example, oil-based transportation causes over half of all such GHG emissions. A 2013 National Research Council study, *Transitions to Alternative Vehicles and Fuels*, found that EVs and other alternative fuel vehicles could reduce petroleum use and GHG emissions in light duty vehicles 80 % below 2005 levels by 2050 [17].

The *Transitions* report recommended keeping the price of petroleum-based fuels from dropping below a floor level in order to assure "a profitable market for alternative fuels, and encourage consumers to reduce their use of petroleum-based fuels" [17]. It also called for low-carbon generation of electricity—less coal and more solar, wind and nuclear power. Recent advances in nuclear power generation technology may lead to much safer and more affordable non-carbon power [18].

2.2 Reduction of Criteria Pollutants

There are six criteria emissions—particulate matter, ozone, sulfur dioxide, nitrogen dioxide, carbon monoxide, and lead—which are regulated under the Clean Air Act [19]. Although catalytic convertors and more efficient engines have reduced these emissions, research now shows that tailpipe emissions are killing more people than car crashes, as noted earlier. Electric vehicles have no tailpipe emissions, and the electric power generating plants that provide EVs their electricity are increasingly clean or are located far from urban areas.

2.3 Improvement to the National Economy Through Greater Efficiency and a Reduced Trade Deficit

In recent years, the U.S. has spent over a billion dollars a day to buy foreign oil. Henry Kissinger has called this the greatest transfer of wealth in human history [20]. The cost to the U.S. economy from oil dependence over the last two decades is in the trillions of dollars [21]. As President Obama has said, paying for foreign oil "stifles innovation and sets back our ability to compete" [22].

In the last few years, the U.S. has reduced its oil imports from nearly two-thirds to just under half due to decreased demand and increased domestic production from new sources including hydraulic fracturing of tight rock formations and deeper and more remote off-shore oil drilling.

"Technology and high prices are opening up new oil resources, but this does not mean the world is on the verge of an era of oil abundance," according to the International Energy Agency [23]. The most troublesome long-term factor is increasing demand from emerging countries that threatens to exceed global oil production capability. The world is using oil at a pace that is hard to visualize: "The world produces nearly 1,000 barrels of oil every second. If those barrels were physically stacked up, the pile would grow taller at 2,000 miles per hour" [24].

2.4 National Security Improvements Through Reduced World Oil Dependence and Reliance on Unstable Regimes

As President Obama has said, "No single issue is as fundamental to our future as energy. America's dependence on oil is one of the most serious threats that our nation has faced. It bankrolls dictators, pays for nuclear proliferation, and funds both sides of our struggle against terrorism" [22]. The harm to national security from dependence on foreign oil is a major reason to accelerate the transition from oil to electricity and other alternatives in transportation. The added risk arises from the concentration of oil in the Middle East and the domination of those resources by OPEC countries—most of which are unstable, undemocratic or both; and some of which are openly hostile to our interests [25].

2.5 *Reduction of Water and Noise Pollution*

An underappreciated benefit of moving from oil to electricity is the reduction of water and noise pollution. Oil dripping from vehicles on roads and parking lots carried by storm water runoff is a significant non-point pollution source in many areas of the U.S., such as the Puget Sound region in Washington State [26]. Copper shavings from brake linings, which are sharply reduced by regenerative brake technology in EVs, are also becoming a significant threat to aquatic life [27]. Urban noise pollution is reduced as EVs run as quietly as bicycles—increasing the need for autonomous vehicles with their collision avoidance capabilities.

3 Synergies Between the Three Emerging Vehicle Technologies

There are significant synergies in combining autonomous vehicles, electric vehicles, and connected vehicle technology.

First, moving from oil to electricity in vehicles addresses the concern of policy makers and segments of the public that autonomous vehicle technology will result in more vehicle miles traveled and thus more greenhouse gas emissions and other pollution produced by conventional gasoline and diesel powered vehicles.

Second, autonomous vehicles support electric propulsion by better managing acceleration, cruising, slowing, and stopping. Automatic computation of driving profiles for power and brake application assists drivers to maximize efficiency and range. EVs are already software intensive; today's Chevrolet Volt extended range EV incorporates more computer code than the Boeing 787 [28].

Third, the need to make EVs as lightweight as possible to achieve more efficiency and longer range fits well with the capability of automated cars to avoid collisions. Smaller, electric urban vehicles are safer to the degree that they can be made more crash proof via automation. Automated cars over time may be able to substitute crash avoidance software for heavy structural elements that mitigate collision damage when crashes occur. Equally as important will be EVs that can avoid collisions with pedestrians, bike riders and other urban vehicles. The goal of livable, sustainable communities will be enhanced when walkers and bike riders are safer. Car companies are already working on this [29].

Fourth, wireless connectivity will provide data to vehicles connected to the cloud and to other vehicles. This helps EV drivers to know the shortest or most efficient path to a destination including the nearest charging station. Strong mapping and routing capabilities will be critical for increasingly automated vehicles.

Fifth, wireless connectivity is important for updating software and data in the car while in the owner's garage, and for the car reporting its status to maintenance providers.

Finally, wireless connectivity supports vehicle-to-vehicle and vehicle-to-roadside communications that is important for safety and smooth traffic flow. The reduction of stop-and-go traffic congestion allows EVs to go longer between recharging the battery or otherwise refueling. Wireless communications to and from points beyond the range of in-vehicle sensors are likely to be important in automated driving to avoid collisions at blind intersections. Furthermore, the efficient interaction of EVs with the charging or refueling infrastructure – finding where it is and getting there efficiently—is already a part of dashboard displays installed in the EVs being sold as of this writing. In the long-run, EVs in a driverless mode may be able to go to a charging/refueling point on their own.

4 The Interface of Cars with Livability and Smart Growth

Reducing the environmental, health and safety impacts of vehicles should be an essential policy priority for livable, sustainable communities.

Some predict and are concerned that automated driving will encourage more vehicle miles traveled (VMT). To mitigate the risk of adverse environmental impacts of more driving in and around cities, it is important that automated cars employ safe, low-emission, non-oil, energy-efficient, and quiet means of propulsion.

Turning the argument around, EVs with lower environment impacts and low operating costs may themselves encourage growth in VMT. In that case, higher levels of vehicle automation reducing collisions and allowing closer vehicle spacing can reduce congestion. Car parking without drivers at the wheel can also lower the space requirements of parking lots and will mitigate that growth in driving. These mitigation dynamics are important for livability and sustainability.

Parking and charging by automated, driverless access can also be done in less-prime, peripheral locations that do not impinge on walkable, pedestrian-friendly residential and commercial zones.

Furthermore, if public transit—a key element of livable communities—is to remain viable in competition with private autos and advanced taxis, then public transit will require innovative formats that are more energy efficient and more effective in attracting customers. Better transit is likely to require both electric motors for propulsion and information technologies for flexible, dynamic routing.

At the same time, road-vehicle automation could enhance the financial sustainability of transit by reducing the expenditures needed for professional vehicle operators. This cost component is about one dollar per passenger mile for buses, amounting to 45 % of direct operating costs in 2011. But with driver salaries not needed, that same cost for vanpools with eight paying passengers and one doing the driving is only 10 cents per passenger mile [30].

In the short run, starting with today's fixed-route van pools, organized ride sharing and car sharing, CATES envisions a step-by-step evolutionary potential for vastly expanded small-vehicle, electric transit, where in effect, passengers do the driving. Eventually they can travel door-to-door on driverless robotic vehicles.

Automation in the long run facilitates a step-by-step movement toward more sustainable public transit across all the dimensions of sustainability—environment, economics, and equity. By equity, we mean the ability to cover urban geography much more completely than fixed route buses can, and at an affordable cost.

As an immediate example of lowered environmental impact, small EVs with 50 % or greater load factors provide an opportunity to vastly reduce energy consumption and greenhouse gas emissions per passenger mile. In Seattle, for example, fixed route diesel buses average 44 passenger miles per gallon. At the same time, the transit agency has deployed four-passenger shared ride pool vehicles using Nissan Leaf EVs, with an efficiency rating of 396 passenger miles per gallon fuel equivalent [30].

To the degree that some bus and train services to urban centers carry high passenger loads and yield low fuel consumption and GHG generation as a result, there are opportunities in the long run for driverless, energy efficient electric shuttle vehicles in low-density environments to move customers from scattered residential locations to train stations and bus transit depots. Kornhauser has modeled such a future system for the entire State of New Jersey [31].

5 A Large-Scale Integrated Demonstration Project at Joint Base Lewis McChord

As this chapter has outlined, there are valuable synergies in combining the emerging technologies into smart, connected, autonomous, electric vehicles. There is a resulting need for large-scale, real-world testing to work out the integration of the technologies and to build public confidence. In seeking an environment to do this testing, CATES is inspired by the history of U.S. military involvement to date.

The U.S. Department of Defense (DOD) through its Defense Advanced Research Project Agency (DARPA) carried out a series of "Grand Challenge" autonomous vehicle competitions in order to develop driverless vehicles for use on battlefields. The DARPA competition produced successful prototypes which led to the more rapid development of autonomous vehicle technology for civilian use [32].

The DOD and the Department of Energy (DOE) have more recently signed a Memorandum of Understanding to use the purchasing power of the DOD (and its capability to do large-scale controlled experiments) in order to test technologies that hold the promise to save energy in both the military and civilian applications [33].

One of the largest military bases in the U.S. is Joint Base Lewis McChord (JBLM), located along both sides of Interstate 5 near Seattle, Tacoma and Olympia in Washington State. JBLM is the equivalent of a small city (it would rank 7th among Washington State cities) and ranks second in the number of employees in Washington State [34].

JBLM has unique and favorable attributes for testing the emerging vehicle technologies and associated systems:

(1) The power supplied to the base by Tacoma Power is over 95 % carbon-free hydroelectric, wind, solar and nuclear power;
(2) JBLM is adjacent to two project areas receiving livable community grants coordinated by the U.S. Department of Housing and Urban Development, Environmental Protection Agency, and Department of Transportation;
(3) The portion of the Interstate 5 highway running through the base is the most congested road segments on the West Coast and needs cost-effective solutions;
(4) JBLM has an existing vanpool program that can be expanded and used for experiments in smart, connected, increasingly autonomous, electric vehicles;
(5) JBLM is an award winning leader among U.S. military bases for its strong commitment to environmental sustainability as well as livable community design;
(6) It has strong civilian support at the local and state level through the South Sound Military & Communities Partnership and through new state level initiatives;
(7) Private sector companies located nearby are leaders in different aspects of the emerging technologies outlined in this chapter, including Google, Microsoft, INRIX, Airbiquty, VoiceBox, Amazon, PACCAR, and Boeing;
(8) Public officials frequently demonstrate leadership on technical and environmental issues;
(9) Residents of Western Washington have historically been early adopters of technology that improves the environment and the sustainability of communities.

The integrated, large-scale testing at JBLM would include the following elements:

(1) Incorporation of a new petroleum and CO_2 reduction goal into the existing Department of Defense program of Net Zero energy;
(2) Implementation of smart, connected electric vanpools for troops as well as contractors for commuting to and from the base—perhaps flexible versions of what Microsoft calls microtransit;
(3) Implementation of an on-base EV shuttle system to move transit commuters inside the base;
(4) Testing of driverless EV shuttles initially in limited numbers, then with expansion to all on-base shuttles;
(5) Testing of driverless and platooned vehicles along I-5 and I-90 from JBLM to the Yakima Firing Range in central Washington State;
(6) Testing of information protocols and standards in applications linking vehicles to infrastructure and data;
(7) Creation of connected transportation hubs north and south of the base to allow for reserved parking, flexible car pools and vanpools;
(8) Creation of incentives for military and civilian base employees to purchase EVs or to use transit;
(9) Testing of used vehicle batteries as back-up power sources for mission critical circuits;
(10) Testing of bi-directional power supplies for EVs that are capable of providing back up power and ancillary power services.

Planning effort is underway to detail the design of project components and muster resources for this large-scale demonstration of electric, automated mobility on and around Joint Base Lewis McChord.

6 Conclusion

Significant media and popular attention is focused on new technology applications in automobiles. Often stemming from a writer's informal understanding, problems and benefits are frequently mischaracterized. Based on research, we at CATES have now outlined an effective way to educate our region and nation about the benefits, costs, and barriers of these technologies applied in the integrated way we describe in this chapter. Our action plan is to facilitate a pilot implementation in a mixed military-civilian environment with careful measurement of resource inputs and performance outputs. We believe the result will be more accurate public perceptions of how a growing number of automated, connected, electric vehicles can support and influence sustainability and livability.

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