An Evaluation Framework for an Automated Electric Transportation Network

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ABSTRACT
Automated Electric Transportation (AET) represents a new approach for surface transportation that addresses the major challenges associated with automobile dependency – energy, capacity, safety, and emissions. In dense urban environments, integrated multi-modal systems have made measurable improvements on the cost of transportation and the quality of life. Similar solutions are needed in areas that will rely on automobiles for the foreseeable future. AET does not seek to eliminate the automobile, but rather to improve it. To achieve this, AET proposes an electrified freeway system supporting in-motion energy transfer that will overcome challenges of electric vehicles (EVs), including battery weight, cost, and range. Additionally, evolution from human-guided to automated vehicles has the potential to significantly increase freeway capacity through more efficient use of available roadway surfaces and higher speeds. AET’s operational concepts will allow for reduction of recurring congestion while greatly reducing driver-related crashes that generate non-recurring congestion. Favorable speed profiles combined with lower congestion levels will reduce the energy required to power the vehicles. In order for AET to be developed into a viable concept, it is necessary for transportation and planning professionals to gain a quantitative understanding of AET benefits and costs. The goal of this paper is to introduce an evaluation framework that will serve as an integrating mechanism to help gain the necessary quantitative understanding of the costs, benefits, and challenges of AET implementation, extending the definitions of conventional highway performance in areas of energy, capacity, safety, and emissions.
INTRODUCTION
Successful economies are dependent on transportation to connect people and goods, and improvements in transportation create substantial benefits for the economy as a whole; the construction of the Interstate Highway System has been credited with creating approximately one-quarter of the national productivity gains realized over the next four decades \( (1) \). However, America’s transportation infrastructure is aging and its increasing inefficiency costs the economy over $1 trillion annually \( (2) \) and roadway capacity limitations combined with the need to import oil threaten the status quo of the US transportation system. America’s road vehicles account for over half its petroleum consumption and one-third its CO\(_2\) emissions \( (3) \). Beyond CO\(_2\), combustion engines also contribute to air-quality problems through particulate and NO\(_x\) emissions. In 2007, traffic congestion in America was responsible for, among other things, losses of $87.2 billion dollars in excess fuel costs and nearly the equivalent of a 40-hour workweek per commuter in lost time \( (4) \). Safety is another pressing concern; approximately 40,000 people are killed each year on America’s highways and total crash-related costs approach a quarter of a trillion dollars \( (5) \).

A fundamental rethinking the basic premises of mobility is necessary in order to provide a vision for the future of transportation. Some important questions include: ‘Should vehicles be powered solely by on-board stored energy?’ and, ‘Can highway efficiency and safety be improved by removing the constraints imposed by the limits of human capabilities?’

By coupling electrification with automation, AET provides an opportunity for a paradigm shift that goes beyond what either technology could achieve alone, “leapfrogging” incremental innovations in favor of a holistic transformational system that is greater than the sum of its parts. By employing technologies that integrate vehicle automation and energy transfer, AET has the potential to reform the nation’s transportation infrastructure and be a catalyst for productivity gains.

PREVIOUS AUTOMATED HIGHWAY CONCEPTS
The desire for self-driving cars stretches back to the 1939 World’s Fair, where GM’s Futurama exhibit proposed automated roadways as necessary features of the “cities of tomorrow.” In the 1990s, Automated Highway Systems (AHS) movement began, culminating in a 1997 demonstration of modified sedans traveling in formation without the input of a driver along a stretch of I-15 outside of San Diego \( (6) \). The demonstration yielded valuable insight into the potential for automation but the concept, as tested, was not deployable due to the lack of mature technologies critical to full-scale implementation, including the need for development of sufficient on-board computing power and information exchange media to support vehicle-to-vehicle and vehicle-to-infrastructure communications. Further, the technologies of the time and the anticipated operational concept generated did not indicate a favorable cost-benefit ratio. Since that trial, requisite technologies have made substantial advancements, including the progress generated by military development of automated land and air combat vehicles, cars from DARPA’s Grand Challenges and similar programs, and core features of the FHWA Intellidrive development and deployment initiative.

The emergence of Intellidrive (formerly Vehicle Infrastructure Integration) provides a bridge from today’s transportation system to an AET system by providing underpinning information connectivity - both vehicle to vehicle (V2V) and vehicle to infrastructure (V2I). Intellidrive related research has led to deployable concepts to support arterial transportation, and continued investment by USDOT will propel it forward, bringing the vehicle technologies to
maturity and developing dedicated short-range communications systems to support real-time V2V and V2I information sharing. Early examples of V2V successes include variable cruise control that senses other vehicles in front of and behind and alters speeds accordingly, adaptive breaking, and lane change avoidance. Near-term V2I advances can be seen in GPS devices that receive inputs on current traffic status and determine routes specifically to avoid congestion and minimize travel time. Intellidrive should lead to vehicles with a 360-degree “awareness,” enabling them to avoid obstacles that the driver is unable to see or react to, reducing the potential for the most dangerous intersection crash types. The Intellidrive initiative is bringing technologies and concepts to maturity as public and private efforts are leveraged within Intellidrive roadmaps.

AN INTRODUCTION TO AET
A transition to AET could provide the next logical step beyond Intellidrive by incorporating automation and reducing the dependency on human performance. Achievement of AET objectives requires synergistic progression in two areas: individual vehicle propulsion and automation and network-wide infrastructure electrification and information integration. Figure 1 illustrates a high-level roadmap that identifies key stages in an evolution that leads to an AET future. AET calls on technologies of the past and present, recognizing logical transition points. Synergistic maturity of technologies and concepts lead to a realization of a freeway traveled by tightly packed “platoons” of electronically coupled vehicles, Automation leads to precise lateral tracking supporting a in-motion energy via wireless, contact-free energy transfer technologies. Additionally, automation leads to the ability for AET vehicles to act in unison capitalizing on individual, and collective automation supporting optimization of the traffic stream with respect to weather, traffic, and terrain conditions.

FIGURE 1 Transition path to Automated Electric Transportation (7).
In addition to automating the roadways, AET will provide vehicle electrification superior to the current battery-predicated model. Range limitations of current EVs would evaporate, as vehicles could travel as far as the electrified highway goes. Additionally, the highways could act as a continuous charging station, so that any vehicle exiting the AET highway for traditional manual driving could do so with a fully charged battery. Recent work into EVs has increased the technical capabilities of various electrical components, so that EVs can comfortably handle any situation faced by traditional vehicles. Additionally, the recent commercialization of EVs and interest in renewable energy has made the population more aware of the benefits of moving away from non-renewable energy sources and the potential for non-fossil-fueled automobiles.

Moving from on-board energy storage systems that incur a significant weight penalty to “continuous” energy delivery requires finding an effective way to transfer energy from the roadway to the vehicle in real time and on demand. Energy transfer could take on one of many forms, ranging from the wireless technologies of magnetic induction and evanescent wave power to direct-connection options of underfoot or overhead “third rails.” The form of electrification will depend on many variables, including anticipated vehicle speed, the potential to mix publically and privately owned vehicles, and whether non-automated vehicles and automated vehicles can travel in the same lane system.

Using a network of intelligent, electrified highways and network-automated electric vehicles, as shown in Figure 2, represents a potential way of addressing many of America’s transportation challenges. AET envisions vehicles running more efficiently and with increased throughput, reducing the need for roadway expansion. As the system matures and roadway infrastructure is rebuilt, a portion of the electric grid will be merged with highway infrastructure. The transition from operator to computer-controlled vehicles on instrumented freeway sections will allow for increased mobility, improvements in passenger comfort and safety, and reduced travel times for both intra- and inter-city travel.

FIGURE 2 The integrated AET concept.
To support decisions that will lead to AET implementation, transportation professionals, planners, and technology providers need to have a framework that will support assessment of feasibility at the system component as well as the operational concept level. The evaluation framework presented in this paper provides the first steps to determine best approach moving forward. The framework will provide guidelines to quantify the costs, benefits, and challenges of the various aspects of AET, helping determine its future direction.

REVIEW OF PRIOR RESEARCH

A review of the current state of the transportation network is presented in order to provide a baseline for comparison of the AET system. This will help give an awareness of achievable impacts and will guide development of metrics that address the contributions of both energy and automation in terms of capacity, safety, energy, and emissions. This section addresses the status and capabilities of the current highway system, and is followed by an examination some of the recent technological advancements that could help AET become a reality.

Capacity

The Highway Capacity Manual (8) is the accepted reference for defining the achievable capacity in vehicles per hour per lane (vphpl). This number depends on a variety of factors, such as road geometry and number of lanes, but it is normally in the range of 1800 to 2200 vphpl for limited-access highways in North America, assuming limited proportions of heavy vehicles. At a capacity of 2200 vphpl, and speeds of 100 km/hr (27.8 m/s), only 11% of the longitudinal dimension of the lane will be taken up by the cars themselves, the rest being empty space between vehicles (9).

Capacity itself varies with speed, and there is a constant tension between potential for higher capacities at greater speeds, and the greater intervehicle distances that traditionally come with increasing speeds; current research indicates that maximum capacity is achieved at speeds in the vicinity of 60 mph (27 m/s) (9). Determination of the throughput per lane in either an automated or traditional system depends on a variety of different factors, including:

- Speed.
- Classes of vehicles.
- Performance of longitudinal control systems.
- Provisions for extra spacing to accommodate responses to failures.
- Considering only undisturbed “pipeline” flow between interchanges, or accommodating traffic entering and exiting at interchanges and changing lanes.

Safety

The U.S experiences about 42,000 road traffic fatalities and about 2 million injury-causing crashes per year, which equates to fatal crashes once every 2.6 million hours of vehicle travel, and injury-causing crashes every once every 54,000 hours. The total cost of American vehicular accidents in has been estimated at $230 billion per annum (5). The “critical reason” associated with 95% of the light vehicle crashes in the U.S. (from 2005 – 2007) is attributable to drivers, and the remaining 5% are equally associated with vehicle equipment faults and roadway/environmental conditions (4). Beyond vehicle damage and passenger injury, the lack of safety on the highways has numerous other less obvious deleterious effects, including higher
insurance rates, traffic congestion due to lane closings and rubbernecking, increases in highway maintenance costs, and increased reliance on police and ambulances.

**Energy and Emissions**
Internal combustion vehicles account for wholly half of the America’s petroleum usage and one-third of its carbon emissions, but the particulate and NO\textsubscript{x} emissions cannot be ignored either. These are some of the main contributors to air pollution, presenting a serious public health hazard, contributing to asthma to acid rain to emphysema for the more than half the country living in areas that do not meet Federal Clean air standards. Both particulates and NO\textsubscript{x} tend to have more localized effects than CO\textsubscript{2}, damaging air quality in population and industrial centers like Los Angeles, but as a result of topography and weather patterns, also in towns and small cities like Boise, ID and Logan, UT. Beyond causing pollution, internal combustion vehicles are inherently inefficient, failing to achieve energy conversion rates of even 25%. The energy efficiency of a vehicle, and by extension its emissions, can be fairly split into two different categories:

- Efficiency and cleanliness of conversion of fuel source or equivalent (such as wind power) to usable energy for the vehicle.
- The efficiency at which the vehicle uses energy for propulsion; an example of this metric would be how far a car can go traveling at 100 km/hr using a given number of megajoules.

**ENABLING INNOVATIONS**
Since GM’s Futurama, impressive advancements necessary for AET have been made in power electronics, electricity transmission, wireless communications, sensing, computing, and vehicle control. While AET was once merely a dream, now it is within reach of becoming reality. New technologies have been developed and many older ones have matured to the point where they are both far more reliable and less expensive than they were even 15-20 years ago. Several of these advances are detailed below.

**Wireless In-Motion Energy Transfer**
Wireless energy transfer has a number of significant advantages over direct connection to a third rail. It allows for the vehicles to be truly “trackless,” freed from any mechanical attachments to their power source, thus easing vehicle movement between lanes and creating the possibility for non-eletrified vehicles to travel along AET lanes. In addition, non-contact transfer requires much less maintenance than a direct connection system. Two technologies promise to reduce or eliminate the above issues: magnetic inductive power transfer system using a coaxial winding transformer and evanescent wave power transfer. Research by the Oak Ridge National Laboratory demonstrated bench-scale energy transfer efficiency of over 80% between moving and stationary magnetic resonance coupling antennas spaced 0.2 m apart: the approximate distance between a roadway and vehicle chassis (10,11). A significant advantage of both technologies over previous wireless energy schemes is that only objects that are tuned to the transmitter frequency draw significant power from the transmitting antenna, making them both more economical and safer for humans (12). An in-depth comparison of the two is necessary to determine which is better suited for an AET application.
General Power and Electricity
Supplying electricity is only one half of the vehicle power equation; the vehicles must also be able to convert it into mechanical force. Development of EVs and hybrid-electric vehicles has been a major impetus in advancing power electronics, and mass production has made the components significantly less expensive. Most of this technology can be readily carried over into AET-capable EVs. Of particular significance to AET are recent advances in the higher-frequency power components necessary for inductive or evanescent wave power transfer.

Sensing and Control
The original AHS of 1997 relied primarily on magnets to inform the vehicles of their location on the road. Much has changed since then; for example, GPS has gone from a slow, imprecise system that had only the year before been opened up to consumer use to one that is capable of handling navigation and orientation for an automated vehicle entered by Stanford University into the annual race up Pike’s Peak. Additional systems that have either come into existence or become far more viable in the ensuing 13 years are: electrically-assisted power steering, automatic steering for parallel parking, adaptive cruise control and the related obstacle avoidance (radar/lidar based), route planning hardware, and lane departure warning and keeping assistance.

Computing
As with sensing and control, computing power has dramatically increased since 1997. The computers used in the original AHS were weaker than the average (non-smart) cell phone of today. On-board computers simply were not capable of handling the tasks demanded by an effective automated system. AET vehicles must track objects, such as the vehicles ahead and behind them, steer themselves to follow a designated path, provide longitudinal (speed and braking) control to follow closely behind another vehicle while providing the occupants a smooth ride, communicate bi-directionally with the infrastructure, with other vehicles, and with the “driver,” and above all, respond quickly and appropriately in the case of emergencies.

Communications
Effective communications, both V2V and V2I, are important aspects of any automated system. Recently, many new communications technologies have become available commercially or are on the horizon, including: Dedicated Short-Range Communication radios and protocols, wireless internet connections, Bluetooth, cellular-based emergency communications systems, such as GM’s OnStar, and voice-activated command and communication systems, such as the Ford-Microsoft SYNC system.

A PROPOSED FRAMEWORK FOR AET EVALUATION
Currently, all discussions about the future path of AET are hampered by the lack of data. Implementation of AET concepts at the operational level demands investments by government agencies, companies, and individuals, but it is unlikely that any of these parties will be willing to commit unless they know the actual costs. The desires and investment decisions of these parties will inform the construction of AET, helping to establish the feasibility, location selection, suitable operational concept, and necessary public transportation policy and education development activities. The ultimate goal of this evaluation framework is to help answer these concerns and questions by establishing a guideline for the determination of the costs, benefits, technical difficulties, and parameters of AET.
High Level Questions
Ultimately, this evaluation frameworks hopes to help address/answer the fundamental issues of AET, including:

• Construction costs.
• Expected maintenance expenditures.
• Cost to the user.
• Necessary construction and/or utilization of non-highway infrastructure, such as power plants.
• Quantified benefits to both public and private stakeholders and users.
• Estimated return on investment; how long with AET take to “break-even.”
• The initial deployment and transition plan for AET.
• The necessary user adoption rate for viability, considering both user participation and connectedness of AET routes.
• Effect on and relationship with the existing transportation system.

To a large degree, these are the same questions asked regarding any major transportation investment in physical infrastructure and intelligent transportation systems. An evaluation framework recognizes the benefits of the proposed new transportation system in terms of standard measures that will support comparison of alternatives and aid development of economic analyses. Additionally, the evaluation framework will serve as the catalyst for clarification, helping to identify the weak and strong points of AET and to develop a set of specific performance measures that can be used to support objective analysis of before and after cases of various operational settings under a range of implementation and public acceptance scenarios.

This standardized measurement structure will aid in cross-cutting deployment-to-deployment comparisons, supporting monetized estimates of costs and benefits that can be used in a range of planning, transportation, and traffic operations models to assist in the consideration and deployment of AET. Besides supporting benchmark comparisons, a generalized, structured approach helps avoid the common tendency in ITS projects for stakeholders to migrate too quickly from conceptual design to component selection, deployment, and activation. The evaluation framework will aid in completing the necessary intermediate systems engineering steps, including functional requirement definition, identification of necessary system interfaces, and detailed design of the logical architecture.

The framework is aimed at clarification and generation of quantitative data that will serve to underpin the transition from basic research to applied research to AET implementation. To achieve this, and to be able to answer the high-level questions posited earlier, the framework is split into three sections on the parameters, costs, and benefits of AET. The current framework is the best current working model for evaluation, as new technologies and challenges are realized they can be added to the framework.

Parameters
This section will discuss the actual functioning of the AET system. The macro questions that must be answered are what will be the roadway requirements, lane capacity, and vehicle speeds, both average and maximum. In addition to being an important statistic in its own right, vehicle speed is also a factor that affects both lane capacity and energy use. Figure 3 shows the four areas for AET evaluation, and below that are some of the factors that will effect those parameters.
FIGURE 3 The parameters for AET evaluation.

**Energy**
- Electrical load: precisely how much electricity will each lane need to deliver to the vehicles, both in total and to individual vehicles?
- What is the efficiency of the power transfer?
- Turns and Hills: how will power transfer be affected by deviations from straight, flat roads?

**Capacity**
- Minimum separation between independent vehicles and/or platoons.
- Minimum separation between vehicles within a platoon.
- Length of each vehicle.
- Number of vehicles in a platoon.
- Capacity derating factor to merging and diverging within the traffic stream.

**Safety and Roadway Characteristics**
- Smoothness: how will different roadway surfaces affect AET performance?
- Lane width: existing freeway lanes are at least 12’ wide lanes, while cars average 6’. If AET were to allow for a reduction in lane width and thus increased capacity per road width, precisely how much narrower could the lanes be?
- Road strength: would the roads reinforcement be necessary to handle the additional weight of the electrification infrastructure and/or increased number of vehicles per lane-mile due to increased capacity?
- Emergency and maintenance vehicle access: would anything new be required?

**Emissions**
- Can renewable energy be used for AET?
- Will the production of electricity be cleaner than petroleum usage?
- What will the effect of the system be on the carbon footprint of transportation?

**Costs**
One of the large advantages of AET over other new transportation technologies, such as Personal Rapid Transit or high-speed rail, is its reliance on virtual, as opposed to physical, infrastructure. The ability to utilize existing roadways greatly decreases the costs of construction and implementation. Additionally, just as with computer software updates, AET’s virtual infrastructure could be easily and inexpensively improved over time. However, there still are numerous hardware and implementation costs of AET that must be considered as shown in
Figure 4. FIGURE 4 Diagram of potential AET costs.

Electrification
Much work has already been done on comparisons of energy costs between EVs and traditional vehicles, but it is necessary to form a determination specific to AET. Of particular importance is an investigation of the relative costs and requirements of providing electricity through the roadways itself. The potential for electrical losses exist both on the roadway, such as through degradation over distance, and in the connection between the roadway and the vehicle. Furthermore, the capacity of the existing electrical system to handle the needs of AET must be addressed. As with any system that depends on electricity, the cost could vary both with time of day and with type of production.

Freeway Capital and Maintenance Costs
Construction costs of AET will vary greatly depending on a number of variables, especially on whether the AET will go along existing roadways or will demand new construction. Assuming existing roadways, the amount of improvements necessary to make the lanes AET-compatible will also play a large role. One of the biggest expenses for AET construction promises to the electrification of the roadway, and different methods, such as induction vs. direct connection, will likely have far different costs.

Any highway system demands a certain amount of upkeep, and it is necessary to determine exactly how much this will cost for an AET system and how that number might vary
from traditional highways. Some additional costs could include running the automation system (both in terms of human and mechanical capital) and maintenance of the system governing electricity delivery to the vehicles.

*Vehicle Systems*
While AET could allow for some areas of reduction in vehicle construction cost, it will present some added costs as well, most notably in the instillation of the mechanisms/technologies to control automation and allow for electrical power transfer. The possibility also exists for the addition of some features necessary for and particular to AET travel, such as different, low rolling resistance tires and specialized bumpers for platoon travel.

*Environmental*
Though AET promises to be far “greener” than the existing model, that does not mean its environmental costs are non-existing. The generation of electricity has significant costs that highly dependent on the form of production, both in terms of carbon footprint and beyond. For example, while hydroelectric power has near-zero carbon emissions, the damming of rivers present serious ecological costs. Additionally, energy transmission, both along the roadway and to the vehicle, could present environmental costs due to land use and electrical “leakage.” Lastly, the costs of the hardware must be considered, including environmental damages resulting from roadway and vehicle construction and waste management, especially for batteries.

*Benefits*
The following section details anticipated AET benefits. These benefit categories are shown in Figure 5.
Environmental: Reduction in Energy Use and Pollution and Increased Vehicle Efficiency
The reduction energy use and pollution is highly correlated; the lower the energy consumption, the lower the pollution, whether in the form of vehicle emissions, or in the case of electricity, point-source pollution from the power plants or equivalent. However, since with electricity, the pollution per unit energy varies greatly with the form of generation, determining the actual pollution of an AET system (or any EV system) is a difficult proposition. The following are some of the different ways that the AET could reduce energy usage over traditional vehicles and roadways.

Electrification Even the most efficient internal combustion engines struggle to reach conversion rates of 50%, and traditional automobile engines are closer to 25%. By comparison, electric motors can convert electricity to power at near 100% efficiency. Additionally, electricity can be provided at a far lower cost per KJ than gasoline, and it has the potential to be both clean and renewable, such as through wind farms, solar arrays, or nuclear power. It allows freedom from dependence on oil, and can be generated from numerous different fuel sources. Even if generated from fossil fuels, the point source nature of power plants allows much cleaner and more efficient combustion.

Vehicle Design AET vehicles have the potential to be lighter and more efficient than both traditional automobiles and battery-powered EVs. As with any EV, AET vehicles can do away with the weight and expense of internal combustion engines, but since they have an external power source while on the electrified roadway, they could be constructed with much smaller batteries than traditional EVs. This process of subtraction will provide cost savings during construction, but also during use; since an AET vehicle will be lighter, it will be more energy
efficient than either it’s traditional V-6 or EV counterpart. Additionally, vehicle design could be tailored to maximize efficiency while on the AET; this is of significant potential importance for vehicles that will spend most if not all of their time on the AET.

**Platooning** One of the largest advantages of automation is that it would allow for much smaller longitudinal separation between vehicles than is currently possible during manual driving. In addition to increased highway capacity that would come with platoons, the vehicles could “draft” each other, where the lead vehicle would assume the same amount of aerodynamic drag as if it were traveling individually, but the following cars would experience much lower aerodynamic resistance, using less energy for the same rate of travel. The potential to reduce aerodynamic drag is of special importance for higher speed travel, as air resistance becomes an increasingly larger proportional consumer of a vehicle’s energy output as velocity increases.

**Automation** Platooning would not be possible without automation, but automation itself has the potential to yield significant energy savings. Most basically, computers can be smarter than people, at least when it comes to the most efficient driving, reducing the energy sapping acceleration and deceleration of manual operation and ensuring that the vehicle is functioning in a way that minimizes energy consumption. More efficient travel could also be gained through traffic reduction, one of the key desires of any AET system. The grossly inefficient rhythms of stop-and-go traffic could be replaced by smooth, steady speed travel.

**Improvements in Roadway Operations**

**Congestion** Beyond simply reducing energy consumption, a reduction/elimination of congestion would provide other substantial advantages to the users, including faster and more predictable travel times. The benefits of speed are obvious, but those of travel time reliability cannot be understated. If a trip averaged 40 minutes, ranging from 20 to 60, the driver must set aside the full hour to avoid being late, so he/she would prefer taking a route guaranteed to take 45 minutes even if on average that is longer than the original. By reducing congestion, the AET would allow its users to predict precisely how long the voyage will take, and the presence of intelligent infrastructure would allow that information to be accessed from almost anywhere.

**Lane Throughput Capacity** An AET system should be able to yield significant improvements over existing freeways’ approximately 2000 vphpl. The combination of traffic reduction and decreasing distances between vehicles should allow each lane to handle far more vehicles than they currently do, which of supreme importance as numerous roadways across America continue to approach and exceed their designed capacity. Additionally, whereas on traditional roadways average speeds decrease rapidly once the highway load reaches a certain point, AETs have the potential to continue to function smoothly as they approach their capacity. The potential of high speeds on AET roadways could increase that highway capacity even more.

**Safety** Though AET, like any mode of transportation, cannot pretend to be capable of achieving 100% accident avoidance, by removing the human factor it can drastically improve the safety of the nation’s highways. Unlike people, the AET system will not get fatigued or impaired, nor get distracted by the scenery or cell phones. Additionally, a reduction in accidents promises to further reduce traffic, both in terms of lane shutdowns and rubbernecking. Examining local and
regional realized crash rates by class, typical lane closure, and incident duration will support the evaluation of the safety impact for both primary and secondary crashes as well as the impact of AET on non-recurring congestion.

**Improvements in Passenger Experience**

**Increased Productivity/Freedom** Whereas technology has allowed for the reduction, if not elimination, of many repetitive manual tasks such as laundry and water gathering, people actually are spending an increasing amount of time behind the wheel: 614 hours/year per capita in America (4). Automated driving would free people to do whatever they wanted while their cars were navigating themselves: read, text, make calls, use the internet, catch up on work, etc. Admittedly, these benefits are somewhat more difficult to quantify than something like increased energy efficiency, but they need to be at least considered as important improvements in passenger experience promised by the AET.

**High Speeds** Another difficult to quantify advantage of AETs is the potential for high-speed travel. Automated control could allow for vehicles traveling along an AET lane separated from manually-driven vehicles to achieve far higher speeds than the highway average. High speeds would create additional costs and difficulties, such as by increasing aerodynamic drag and creating the necessity for more rapid response times. However, in addition to the aforementioned potential of increasing lane capacity, high speeds could allow for AET to be far more attractive to the consumer, providing incentives like halving commuting time, and could even allow AET to be a viable alternative to high-speed rail and short distance plane travel. High speeds will not necessarily be a feature of AET, but the possibility exists, and a determination of the costs of such a system is necessary to arrive at any conclusion.

**DATA COLLECTION**

Identifying data requirements and developing collection strategies are critical steps in generating a valid evaluation of AET. It is expected that each study will contribute to a body of knowledge enabling a higher degree both of data collection efficiency and of understanding on how the data will fit into simulation and empirical assessment methods. It is necessary to ensure that data collection for the before and after cases will generally follow the same structure and methods, except where new measurement capabilities become available in the after case. For example, the technologies enabling AET will have some event-record generation capabilities, which may replace or supplement some field collection elements. Until automated methods become more widely available, an AET evaluation will require a field collection component to ensures that no operational and/or safety issues are overlooked. Data will be obtained with the intermediate goal of constructing a simulation program to evaluate different aspects of AET function; this is a necessary preliminary step before initiating field operating tests.

**CONCLUSION**

Over the past twenty years, significant research has been conducted into vehicle automation and electrification. Automated guidance systems and related components have advanced substantially to field level trials, and in some instances beyond. Intellidrive has provided a valuable framework for development and implementation of both V2V and V2I communications technologies. This previous work have provided insight into the potential benefits that will arise as technology reduces dependency on fallible human actors for vehicle control, in areas as
disparate as highway function, energy consumption, passenger safety and comfort, and travel speeds. In the area of transportation electrification, the emergence of various types of EVs have proven the advantages of moving away from petroleum products and towards domestically produced electricity, including reductions in both emissions and energy usage. AET promises significant improvements over traditional EVs by electrifying the roadway itself as opposed to requiring vehicles to carry their electrical source in the form of heavy, expensive batteries.

Network automation and electrification promise will work tandem, with the electrical transfer system doubling as platform for V2V and V2I communication. By abandoning a piecemeal approach to surface transportation improvement, AET hopes to provide cars and highways for the 21st century. The vast majority of America consists of areas where the development structure creates a dependence on the automobile, and AET does not seek to eliminate the car, nor does it pretend that to be possible. Rather, it hopes to make personal transportation better: faster, cleaner, safer, more efficient, and less expensive than what came before it.

An evaluation framework is a prerequisite for AET to become a reality, as it will allow decision makers committing resources to research efforts, infrastructure upgrades and vehicle development to assess the potential for AET in operational settings in current and future travel demand and energy availability scenarios. Results of such assessments help provide an AET roadmap in which incremental and breakthrough opportunities will be identified and prioritized based on cost and contribution. This research provides the initial direction for generating the evaluation framework by identifying the parameters of interest, and the various areas where the costs and benefits can be compared both internally and with the existing highway system. These will help make reliable forecasts of AET performance, supporting benefit and investment assessment. Ultimately, this evaluation framework will provide a roadmap for AET, helping to shepherd it from concept to reality.
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