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INTEGRATING IN-VEHICLE, VEHICLE-TO-VEHICLE, AND INTELLIGENT ROADWAY SYSTEMS

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ABSTRACT

With the inexorable push toward autonomous road vehicles by companies such as Tesla Motors and Google, there is an urgent need to make roadways ‘smart’ and to connect vehicles’ computer systems to one another and to their surroundings, infrastructure, and ecosystem. The effective integration of these systems is a major challenge for companies and government agencies. We examine the state of current and evolving systems and communications with respect to in-vehicle (IV), vehicle-to-vehicle (V2V), vehicle-to-surroundings (V2S), vehicle-to-infrastructure (V2I), and vehicle-to-ecosystem (V2E). We define the term ‘surroundings’ as the immediate vicinity of a vehicle; ‘infrastructure’ as the local area, such as a municipality or nearby countryside; and ‘ecosystem’ as distant facilities, such as the Internet, the Cloud, and call centers. We postulate that, for self-driving road vehicles to be fully effective, these efforts must progress together, and selected approaches must be standardized, preferably globally, so that diverse systems can be readily integrated into systems-of-systems. Failure to make such advances across the board will hamper the design, development, and deployment of the many safety-critical systems in need of integration. We suggest how to introduce such technologies, taking into consideration the latest advances and the cost and ease of implementation and support.

Keywords: adaptive, autonomous, complex, complicated, driverless, in-vehicle, self-driving, self-organizing, systems-of-systems, vehicle and traffic control systems, vehicle-to-infrastructure, vehicle-to-vehicle.

1 INTRODUCTION

Ground vehicle manufacturers and software builders are pushing the capabilities of in-vehicle (IV) autonomous systems to their limits in anticipation of enormous profits to be derived from self-driving vehicles [1]. However, system malfunctions and failures have already led to some serious and fatal accidents. We cannot expect to achieve death-proof motoring, as expressed by Volvo in [2], with our current complicated and unintelligent infrastructure [3] and with any residual human element. Human driver involvement cannot be eliminated unless virtually all vehicles are autonomous, can communicate with one another, operate on infrastructures that communicate with vehicles, and are managed by overarching integrated vehicle and traffic control systems. Until these goals are accomplished, the need for human intervention will continue.

The evolution of IV, driver-assist and vehicle-control technologies is fast and furious. Software companies, such as Google, and vehicle manufacturers, notably Tesla Motors, General Motors, Audi, and Volvo, are expanding frontiers with respect to IV technologies. However, until recently, auto manufacturers and government agencies have generally ignored vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications. There are a few exceptions to this assertion, such as a large-scale test of V2V and V2I communications for more than 3,000 cars in Ann Arbor, Michigan, and the introduction of external vehicle communications in some 2017 Audi and Cadillac automobiles, as described in [4]. The paucity of such tests is largely because no single entity establishes, maintains, and enforces interoperability standards among in-vehicle and ex-vehicle systems, which are being developed by vehicle and software manufacturers, and traffic control systems that are being developed by third parties and implemented by government agencies, although some agencies have

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made attempts to come up with standards [5, 6]. There is a critical need for collaboration and coordination among all involved in developing related systems to avoid inconsistencies and incompatibilities.

While IV detection and response technologies are effective over a wide range of traffic situations and under many road conditions, they are limited in scope because, first, vehicles incorporating these technologies currently represent only a small fraction of total vehicles in service and, second, present-day driver-assist and vehicle-control systems are necessarily conservative to allow for deficiencies in the infrastructure and in the preponderance of traditional non-autonomous vehicles. We must consider what will be the outcome when autonomous-vehicle technologies become pervasive and the likelihood of errors, malfunctions, and failures of these highly complex systems increases. Such luminaries as Elon Musk, the founder of Tesla Motors, and such government agencies as the U.S. Government Accountability Office [7], believe that self-driving technologies will greatly reduce the number and seriousness of road accidents, as do some government agencies. While this is clearly a good goal for the automotive industry, there remain many liability, ethical, and moral issues that still need to be resolved.

With no across-the-board standards and significantly different commitments by participants, bringing such diverse systems and constituencies together will be a technical, structural, and organizational challenge. We will discuss the current state of affairs and the likely evolution over short and longer terms, and suggest initiatives that would achieve safe and secure, unified, and integrated autonomous-vehicle systems within a reasonable timeframe.

2 WHERE WE ARE TODAY

We are seeing the rapid development of IV systems. Some are driver-assist systems that monitor traffic and roadway infrastructures but rely on drivers to take appropriate action, as described in [8]. For example, a recent television commercial for Audi cars shows a prototype vehicle operating without a driver, but then insists that drivers are required. Other systems, such as Tesla's Autopilot system, can operate vehicles autonomously, but require driver intervention from time to time. Following a highly publicized fatal accident on May 7, 2016, Tesla updated its Autopilot system to prevent the same occurrence in the future. Tesla was cleared of responsibility for the crash, as described in [9]. Yet others, such as Google, are developing completely autonomous vehicles in which there are no driver controls for steering, accelerating, braking, etc. Some vehicle-to-vehicle systems have already been designed and developed and are in test mode, but there needs to be greater standardization and coordination of these efforts before they can be generally accepted. Furthermore, some individual or some group must decide who will pay for vehicle-to-vehicle communications, which is an issue raised in [10]. There have been several experiments with intelligent roadways on small stretches of road [11, 12], but these are in their early stages and will likely not be widely deployed for a decade or two.

2.1 'Smart' roadways vs. intelligent traffic systems

It is important to differentiate between traditional ITSs (intelligent traffic systems) and newer so-called smart roadways. For one, while ITSs monitor and control traffic, in general, they do not currently communicate with IV systems. If there is an incident and/or congestion, human drivers are made aware through notifications on roadside message boards or are directed to tune into local radio stations for announcements rather than from IV alerts. Drivers can rely somewhat on their IV, dedicated, or smart-phone navigation systems to recommend alternative routes to avoid delays.

3 DEFINITIONS AND ACRONYMS

The terms V2V (vehicle-to-vehicle), V2I (vehicle-to-infrastructure) and V2X (vehicle-to-everything) are in common use [13], but they do not fully reflect the scope and complexity of real-world interactions. Furthermore, they do not provide the granularity needed to describe the full range of possibilities. Consequently, we subdivide and rearrange the V2I and V2X categories into more detailed groups, adding vehicle-to-surroundings (V2S) and vehicle-to-ecosystem (V2E) to reflect current and prospective local, remote, and global interactions. We also added the classifications of surroundings-to-infrastructure (S2I) and infrastructure-to-ecosystem (I2E) to include communications not with vehicles directly. The above classifications are defined and described in Table 1.

Table 1: In-vehicle, vehicle-to-other and other-to-other communications.

Term	Meaning	Description	Comments
IV	In-Vehicle	One-way communications from in-vehic le sensors and external sources.	Sources of information may be installed in the vehicle, or come from external sources.
V2V	Vehicle-to-Vehicle	Two-way communications between vehicles within a limited geographical area.	Vehicle-to-vehicle interactions cover a limited range, within, say, 300 yards.
V2S	Vehicle-to-Surroundings	One-way communication to vehicles from local sources. Will likely evolve into two-way communications.	Category is within the usual definition of V2I. Communications via wireless signals or image recognition.
V2I	Vehicle-to-Infrastructure	One-way communications to vehicles from sources within several miles. Will likely evolve into two-way communications.	Category included within the usual definition of V2I. Includes radio communications reporting incident(s) taking place beyond immediate surroundings but within several miles of a vehicle's location.
V2E	Vehicle-to-Ecosystem	One-way communications to vehicles from external sources, such as GPS. Two-way communications between vehicles and external services.	Category included in the usual definition of V2I. Covers communications with distant sources via wireless, broadband, satellite.
S2I	Surroundings-to-Infrastructure	One-way communications, e.g. weather in area. Two-way communications e.g. where infrastructure informs surroundings of activities beyond the immediate area.	Category has not received much attention to date. However, it is likely that the surroundings will inform the infrastructure of events in greater detail than vehicles might provide.
I2E	Infrastructure-to-Ecosystem	One-way communications, such as local weather. Two-way communications, e.g. infrastructure informs navigation systems of intended actions.	Category does not appear to have been addressed in the literature but municipal traffic control systems will likely communicate to and from the ecosystem.

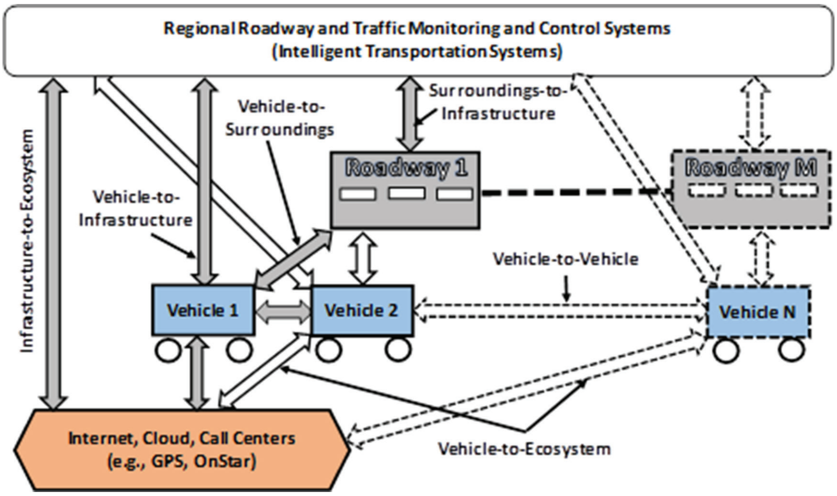

Figure 1: Communications between levels.

These categories are illustrated in Fig. 1. The diagram shows both current and future interactions. The shaded arrows to the left of the diagram show interactions between Vehicle 1 and its surroundings, as well as with the infrastructure and ultimately the broad ecosystem. As mentioned in Table 1, some of the interactions are currently one-way but will likely evolve into two-way communications. As the systems at one level expand, interconnect, and interoperate with systems at other levels, we will see systems-of-systems developing and gradually taking control across the board. This will place significant stress on current roadway operational conditions, especially as the pressure for advancing technologies varies greatly from one level to the next. We will discuss the impact of different rates of adoption and adaptation, the consequences of failing to coordinate projects, and the critical path to achieving fully automated ground transportation systems.

Figure 1 shows various levels within the overall structure and how they might communicate among themselves. The scope of systems at each level will depend greatly on the determination of where specific functions should reside. For example, IV or Internet-based navigation systems may show the speed limits along sections of roadways being travelled. Speed-limit data for Internet-based navigation will have been entered through data entry from observation, whereas IV image recognition will eventually read actual road signs and determine the appropriate speed, both types of system indicating whether the speed limit is being adhered to and, if not, alerting drivers to slow down. The former method depends for accuracy on timeliness and accuracy of data entered, whereas the latter depends on the road signs being visible and not being covered with foliage or snow, or knocked down. There should be decision rules across systems for each situation and the means of resolving any conflicts. Information about current speed and hard acceleration and braking may also be transmitted from IV systems to the ecosystem for insurance purposes, as in the case of the OnStar Smart-Driver system described below, or by law enforcement.

We now examine each of the above categories in greater detail.

3.1 In-vehicle systems

This is the field involving greatest innovation and shortest time-to-market. There are numerous companies pursuing the development of IV systems to provide driver assistance and direct vehicle control, and several government agencies are supporting research and working on standards. On the other hand, there is not much collaboration among organizations within the private sector and between them and the government sector, leading to disparities among systems that will hinder the acceptance and implementation of these technologies across the board. IV sensing and reporting systems could be proprietary if communications protocols are standardized and systems can interoperate with each other and with their environment. An excellent description of IV systems and communications and issues relating to coordination can be found in [5].

3.2 Vehicle-to-vehicle systems

When it comes to V2V systems, we can determine what information they should collect, and what they should do with it. One question that arises is whether data for traffic jams, black ice, and accidents, for example should rely on IV or V2V or V2S systems, or on a combination of, say, V2V and V2S systems. Currently, because of the deployment of notice boards, the main source is probably V2S systems, but navigation systems also announce delays along a predetermined route, presumably obtained from a representative group of vehicles using the same navigation systems, such as Google Maps with the Waze app, which report the speeds of vehicles and use those data to determine that there are delays. They then suggest alternative routes.

3.3 Vehicle-to surroundings systems

Currently, most information is communicated to drivers from the immediate vicinity via human vision. Such information includes recognition of fixed road signs, such as stop, yield, direction signs, variable-message signs providing warnings (such as delays ahead), alerts (such as AMBER alerts) and information, flashing lights of police and road service vehicles, etc. A more complete list for variable-message boards, from Wikipedia, is as follows:

- Road works
- Incidents affecting normal traffic flow
- Non-recurring congestion
- Closure of an entire road
- Exit ramp closures
- Debris on roadway
- Vehicle fires
- Short-term construction
- Pavement failure alerts
- AMBER, Silver, and Blue alerts
- Travel times
- Variable speed limits
- Car park occupancy

As IV systems evolve, they will likely have increased capability to recognize signs through shape determination and word recognition. In fact, a recent video from Volvo, touting their technologies, shows roadside speed-limit sign recognition, reading, and alerting in action [14]. Such systems could potentially warn drivers to slow down for an upcoming stop sign, for example, and apply the brakes, if necessary.

At the same time, we might see roadways becoming more communicative with, for example, signs transmitting data regarding their functions. This could help address the problems of signs being knocked down or covered with tree branches, and the like. It would also reduce the need for IV systems to interpret signs from visual information. There are already prototypes of communications between vehicles and traffic signals as described further.

3.4 Vehicle-to-infrastructure systems

We are seeing some initial forays into V2I systems. It should be noted that these communications will usually be between vehicles and central control systems, such as those controlling traffic lights for a city, as described in [4] for the collaboration between Audi and Traffic Technology Services (TTS). TTS obtains data from local authorities' systems and analyzes it to predict when specific signals will change.

3.5 Vehicle-to-ecosystem systems

Communications between vehicles and distant services have been operational for some time, as with satellite-based GPS (global positioning systems) and call centers (e.g. OnStar). The services can be one-way as with GPS or two-way as with requests for navigation services. Services such as EZpass, which automates the toll payment process, are real-time one-way, in that IV sensors send details (such as location of toll, time of day) and the central system checks the validity of IV sensors and the state of account balances and the use of the service for billing purposes. In this respect, they are long-term two-way when vehicles' owners are charged for the tolls.

This category includes interchanges between vehicles and the Internet, (e.g. Google Maps), the Cloud, call centers, and the like. The services so provided include navigation services, vehicle status reporting, unlocking of doors, automatic reporting of accidents and informing of first responders, tracking and deactivating stolen vehicles, hands-free telephone service, etc. This area is characterized by rapid additions to services, such as the General Motors OnStar Smart Driver System described further, and the transfer of functions among vehicles, their immediate surroundings, and their proximate infrastructure to the Cloud, as has happened with navigation systems.

3.5.1 Traffic information systems

It is valuable for drivers to be notified of heavy traffic ahead and how to avoid the congestion via alternative routes to shorten travel time and reduce stress, fuel consumption, and the like.

When it comes to delays along the route, there are several means of notifying drivers. Local authorities will post the location of congestion and the potential duration of delays on variable-message boards along the highway and/or they will suggest to drivers, by means of flashing lights on a fixed message board, that they tune into a local radio station to obtain information about delays and the like. Notices are generated based on information from sensors and television cameras along the roadside.

Independent navigation systems, such as Google Maps, have evolved in their means of collecting and disseminating congestion data and alternative routing [15]. Earlier congestion was based upon historical data for roadways, which were obtained for time-of-day and day-of-week, as well as for holidays and various weather conditions. However, as the use of certain navigation systems has progressed, companies such as Google can obtain specific location and travel-speed information from a growing population of vehicles using their system, determine in real-time where delays are occurring, and feed that information back to drivers. Google's acquisition of Waze has provided additional driver-reported information on traffic congestion and alternative routing.

It is noteworthy that the integration of these systems is taking place IV where the human driver can combine information from sophisticated travel-condition systems, less-advanced (and less useful) notice boards, and direct visual observation. It is to be expected that these systems will improve over time and will likely be fully automated as V2V and V2S communications become more common and either character recognition of roadside displays or transmissions from those displays become available to a central system. Whether Google owns such a system, or it is owned by a combination of Google and local authorities, or some other combination, must be worked out. However, it is likely that Google and/or other companies will own and operate such a system based on funding and on the ability to monetize the data collected.

3.5.2 OnStar regular and smart-driver systems

The OnStar system is proprietary to General Motors (GM), although other vehicle brands have either licensed the OnStar system or have developed their own equivalent systems. OnStar has many features, including the ability to unlock vehicle doors and turn off the engine if, for example, the vehicle has been reported stolen. It also automatically detects if the vehicle is involved in a serious accident and, if so, it will contact the police. However, for this analysis, we are more interested in the monitoring and reporting capabilities of the system.

The regular OnStar service collects such data as tire pressures and odometer readings (from which it calculates oil life). It also monitors vehicles' engine and transmission systems, emission system, air bag systems, stability control systems, antilock braking systems, and the OnStar system itself. All these results are reported monthly by email to the owner. It also tracks whether warranties are due to expire. Turn-by-turn navigation and hands-free telephone services are optional.

Introduced for GM vehicles of the 2015 model year and later, the OnStar Smart Driver system collects additional information including time-of-day, speed during hard braking and hard acceleration, ignition on/off, time over 80 mph (miles per hour), distance travelled, fuel level, and idle time, from which the system calculates mph and mpg (miles per gallon). Driving activity reports are provided monthly. One goal of this system is to provide lower insurance premiums, although the opposite could happen if driving habits are not exemplary. The Smart Driver system also addresses privacy issues, such as whether illegal driving activities are reported to authorities, as with traffic-light camera systems.

3.6 Surroundings-to-infrastructure systems

In one sense, the difference between surroundings and infrastructure is just a matter of distance, with surroundings limited to, say, 200–300 meters from a vehicle, whereas infrastructure can cover areas of several square miles. However, the relationships between the two will depend upon how functions are divvied up among various systems. For example, notification of traffic congestion might come from the ecosystem, such as from Google, as described in [14], or from roadside or in-road sensors, which can either alert drivers through signs or alternatively transmit the information to infrastructure systems.

3.7 Infrastructure-to-ecosystem systems

While not usually considered by researchers, communications between local (municipal) traffic control systems will undoubtedly develop and, over time, may well exceed potential communications between the ecosystem systems and vehicles or surroundings. One reason for this is that infrastructure systems will both predict and control traffic, whereas vehicles, say, are not necessarily able to predict what the traffic control systems will do. This has the potential of being able to use real-time big-data predictive analysis and AI (artificial intelligence) methods to bridge across infrastructures and to improve local systems' ability to anticipate traffic patterns, particularly for journeys that cut across many local zones.

4 DATA COLLECTION, ANALYSIS, AND ACTIONS

The attributes and capabilities of systems can be itemized according to the functions of existing and potential systems, which are as follows:

- Data collection
- Analysis and reporting
- Recommendations for action
- Driver assistance
- Vehicle control

Table 2 lists various data items collected and shows whether the systems already exist or might eventually be realized. Many of these capabilities already exist for IV and V2E systems and some are expected in V2V, V2S, and V2I systems as well. It should be noted that the lists in the following tables are not exhaustive.

In Table 3, we indicate how the results based on the analysis of data collected are reported, such as via displays, sound, vibrations, etc.

In Table 4, we recommend how drivers should respond to the alerts that they receive. If the suggested actions are not followed, then alerts and recommendations will continue.

In Table 5, we show which driver-assistance capabilities have been, or are likely to be deployed. In these circumstances, the driver remains in full control of the vehicle, but is not only alerted to various steering and braking activities that should be done in response, but may also receive nudges to steer, brake, or, in the case of blind spots, not to change lanes.

In Table 6, we indicate areas in which IV systems might take over control of the vehicle, especially when the driver does not respond to alerts quickly enough to avoid accidents.

The above tables show that, for all five functions, many of the capabilities span several systems. It is here that decisions must be made as to where the capabilities should reside and, if they exist in more than one system, developers must determine which system is primary. For example, we show in Table 6 that automatic braking has already been deployed for IV systems, but that we can expect V2V and V2S systems to be able to communicate with vehicles' automatic-braking systems. The question arises as to which system decides if there are differences between the IV system, which gets its information from on-board sensors, and (say) V2V systems that base their decisions on the relative location and speed of two or more vehicles. From scanning the above tables, one can identify many such cases where system designers must resolve such conflicts unambiguously.

Table 2: Data-collection capabilities for existing and anticipated systems.

		Existing (X) & Potential (P) Systems				
Function	Attribute/Capability/Metric	IV	V2V	V2S	V2I	V2E
Collecting data	Time of day	**X**				**X**
	Speed	**X**	**P**		**P**	**X**
	Speed limits	**P**	**P**		**P**	**P**
	Speed over 80 mph	**X**				**X**
	Total idle time	**X**				**X**
	Mileage	**X**				**X**
	Steering	**X**		**P**	**P**	**X**
	Lane keeping	**X**		**P**	**P**	**X**
	GearForward, reverse	**X**				
	Hard braking, hard acceleration	**X**				**X**
	Ignition on/off	**X**				**X**
	Late night driving	**X**				**X**
	Battery voltage	**X**				
	Tire pressure	**X**				**X**
	Distance to objects in front	**X**				
	Engine fluid levels (gas, oil)	**X**				**X**
	Fuel use in MPG (miles/gallon)	**X**				
	Engine temperature	**X**				
	RPM (revolutions per minute)	**X**				
	Outside temperature	**X**		**X**		
	Rear view camera	**X**				
	Front camera (built-in, dash cam)	**X**				
	Total distance travelled	**X**				
	Trip distance travelled	**X**				
	Distance with remaining fuel	**X**				
	Vehicle location					**X**
	Central oversight and monitoring					**X**
	Possibility of ice	**X**			**X**	
	Upcoming traffic jams				**X**	**X**
	Possibility of upcoming collision	**X**	**P**			

5 PHASING OF SYSTEMS

Looking at historical and current efforts, we see that IV systems are generally well ahead of systems relating to surroundings, infrastructure, and the ecosystem. Due to such initiatives as the DARPA Grand Challenge [16], which began in 2004, the design and development of IV systems have been proven viable in many cases and vehicle manufacturers and software developers have already introduced subsystems, such as adaptive cruise control, into current models.

Table 3: Methods for reporting results of analyses.

		Display (D), Sound (S), Radio (R), Vibration (V), Wireless (W), Email (E), Existing (X) and Potential (P) Systems				
Function	Attribute/Capability/Metric	IV	V2V	V2S	V2I	V2E
Analysis and reporting of data	Navigation system					
	• Current location	**D**		**P**		**W**
	• Current direction	**D**		**P**		**W**
	• Distance to destination	**D**				**W**
	• Time to destination	**D**			**D**	**W**
	• Traffic congestion	**D**		**P**	**D R**	**W**
	• Time to location	**D**			**D**	**W**
	Time – Clock	**D**				
	Speed – Speedometer	**D**				**W**
	Need to obey speed limit	**D P**	**P**			
	Need to avoid collision	**D S X**				
	RPM – Tachometer	**D**				
	Total/trip mileage – Odometer	**D**				
	Moving outside of lane	**D S V**				
	Too close to vehicle in front	**D S**	**P**			
	Vehicle behind is too close	**D S**	**P**			
	Vehicle in blind spot	**D S**	**P**			
	Vehicle/person approaching when reversing	**D S**	**P**			
	Gears	**D**				
	Ignition	**D**				
	Battery:					
	• Voltage level (unless fully discharged)	**D**				**E**
	• Battery low (flashing side lights)	**D**				**E**
	Low tire pressure warning	**D S**				**E**
	Engine fluids and fuel:					
	• Current level	**D**				
	• Low fluid and fuel levels	**D S**				**E**
	• Fuel rate of use	**D**				
	• Estimated distance on remaining fuel	**D**				
	Temperature:					
	• Engine overheating	**D S**				
	• Outside temperature	**D S**				

(Continued)

Table 3: *(Continued)*

		Display (D), Sound (S), Radio (R), Vibration (V), Wireless (W), Email (E), Existing (X) and Potential (P) Systems				
Function	Attribute/Capability/Metric	IV	V2V	V2S	V2I	V2E
	In-vehicle warnings:					
	• ABS (automatic braking system) problem	**D** **D S**				**E** **E**
	• Engine service needed	**D S**				**E**
	• Other services needed	**D S**				**E**

Table 4: Recommended actions in response to alerts.

		Display (D), Sound (S), Radio (R), Vibration (V), Wireless (W), Email (E), User Manual (M)				
Function	Attribute/Capability/Metric	IV	V2V	V2S	V2I	V2E
Actions suggested to drivers	Navigation system:					
	Take preferred route, e.g. shortest distance	**D S**				**W**
	Make turn after a specific distance	**D S**				**W**
	Respond to revised instructions	**D S**				**W**
	Engine fluids and fuel:					
	Add fluids and fuel when levels are low	**D S**				**E**
	Replace fluids when recommended life met	**D S**				**E**
	Recharge or replace battery	**D S**				**E**
	Increase tire pressure	**D S**				**E**
	Reduce speed to limit	**D S**				
	Drive cautiously on ice	**D S**				
	Take vehicle for service	**D S**				**E**
	Engine overheated:	**D S**				
	Switch off engine	**M**				
	Add coolant	**M**				
	Check for coolant leaks	**M**				
	Return to lane	**D S V**	**P**			
	Reduce speed if too close to vehicle or obstacle in front	**D S**	**P**			
	Accelerate if vehicle to the rear is approaching too fast	**D S**	**P**			
	Do not switch lanes	**D S V**	**P**			
	Stop if vehicle/person approaching when reversing	**D S V**	**P**			
	Accelerate or brake if traffic lights about to change	**D**		**P**		

Table 5: Various driver-assistance methods in response to alerts.

		Existing (X) & Potential (P) Systems				
Function	Attribute/Capability/Metric	IV	V2V	V2S	V2I	V2E
Driver assistance	Aided steering to stay in lane	**X**	**P**			**P**
	Aided braking for obstacle ahead	**X**	**P**			
	Aided steering around obstacles	**X**	**P**	**P**		
	Aided response to vehicles in blind spots	**X**	**P**			
	Accelerating/decelerating – adaptive cruise control	**X**	**P**			
	Braking to obey speed limit	**P**				

Table 6: Existing and potential control systems.

		Existing (X) & Potential (P) Systems				
Function	Attribute/Capability/Metric	IV	V2V	V2S	V2I	V2E
Vehicle control	Steering	**X**				**P**
	Automatic braking	**X**	**P**	**P**		
	Accelerating/decelerating – adaptive cruise control, obeying speed-limit signs and the like	**X P**				**P**
	Turning off engine	**X**				**X**
	Keeping in lane	**X**				
	Unlocking doors remotely	**X**				**X**

On the other hand, infrastructure-related systems are mostly at the initial stages of development and are being tested in select areas.

Since there will be many interdependencies among all levels of systems, we must ask whether the IV system implementers are in a ‘hurry-up-and-wait’ situation. What appears to be happening is that vehicle manufacturers and software development companies are building overly complex IV systems to compensate for the lack of progress in external systems. While it may be acceptable to some players to rely totally on IV systems today, we are clearly heading towards a situation in which further progress will be stymied by limitations and deficiencies in V2V, V2S, V2I and V2E systems.

While there is general agreement that there are significant issues relating to the deployment of systems other than IV systems, many such systems face major challenges, as described in the following text.

6 CHALLENGES TO IMPLEMENTATION

There are many technical, structural, economic, and political challenges to implementing the various systems described earlier. High on the list is the determination of who is responsible for developing the systems and their interfaces and who is liable when something goes wrong. Appendix III of [7] shows the ratings by 21 experts of the challenges facing the deployment of V2V technologies. The biggest challenges were shown (in rough order of significance) to be:

- Establishment of a system management framework, with roles and responsibilities
- Technical challenges of developing V2V devices, driver–vehicle interfaces, and (especially) V2V safety applications
- Technical development of a data security system
- Accepted use of DRSC (dedicated short-range communications)
- Potential need for roadside equipment
- Public acceptance
- Human factors
- Liability issues relating to legal responsibility for crashes
- Deployment of devices and applications across enough vehicles and infrastructures to realize significant benefits
- Standardization to ensure interoperability among systems
- Acceptable end-user privacy
- Costs of deploying interconnected systems-of-systems

The results in [7] are heavily biased toward system security, which is a very valid concern and is being addressed by this researcher elsewhere. However, systems and their interfaces must first be designed for appropriate security controls to be established. Indeed, security requirements must be explicitly included in the general requirements, as recommended in [17]. Therefore, for the purposes of this article, systems challenges are mostly generalized to overall systems-of-systems.

It is interesting to note the predominance of concerns about establishing a structure that will govern the deployment of systems and assign roles and responsibilities, and various technical challenges. Standardization, privacy, and costs are seemingly less challenging. However, when it comes to surroundings and infrastructure, costs may be one of the more difficult issues to resolve since funding will likely come from government sources, which are not profit-driven. With respect to liabilities, the ruling on the above-mentioned case sided with Tesla Motors, which was not found to be liable [9]. This may indicate how such cases will be resolved in the future.

7 COMPLICATED AND COMPLEX SYSTEMS

Current and future IV systems, which are presented very well in [18] are, and will be, complicated, in that they may be difficult to comprehend taken together, but can generally be broken down into more understandable pieces. To quote from [19]: ‘A car is not complex, just complicated’. However, as vehicles interconnect with one another, the resulting systems-of-systems will become complex since the behavior of combinations of these systems, which will be combined into vast systems-of-systems, will no longer be predictable, especially since they do not presently adhere to any predetermined standards across the automotive industry.

8 ADAPTIVE AND SELF-ORGANIZING SYSTEMS

Current intelligent transportation systems are essentially deterministic, even if they are interconnected and interoperate. They are more appropriately called ‘expert systems’. They perform in predictable ways, which have been preprogrammed into the systems.

Looking forward, there is great interest in building systems that are truly adaptive, which is the basic requirement for AI systems. An excellent overview of the current status of self-driving cars and an interesting preview of what we might expect in the near future are given in [20]. With respect to training a vehicle to anticipate the unexpected, it is suggested in [20] that there are two ways to achieve this – either program in every possible eventuality, which is impossible with the current infrastructure, or teach a vehicle to learn and think for itself, which raises its own set of issues. Also in [20], Professor Philip Koopman of the National Robotics Engineering Center (NREC) at Carnegie Mellon University says that 'he worries the [automotive] industry is seriously underestimating how hard it will be to build innate safety features into artificially intelligent cars'.

In [21], there is a chapter on 'self-organizing traffic lights", which is particularly relevant to the situations discussed in this article. Gershenson [21] states that, as of 2007, mathematical and computational methods for controlling traffic lights did not consider the state of traffic in real time and were 'blind to "abnormal" situations, such as many vehicles arriving or leaving a certain place at the same time, such as a stadium after a match …' While optimization methods might give the best solution for a given configuration, it is asserted in [21] that an adaptive mechanism would perform better than optimization and that while each traffic light is 'unaware of the state of other intersections … [they] still manage to achieve global coordination'.

9 CONCLUSIONS

While the case for system integration among vehicles and their environment has been vehemently argued by many researchers and journalists, the mission to design and implement such complex systems-of-systems is fraught with technical and structural issues. There is clearly a need to bring diverse efforts together and encourage collaboration among players.

We have described the complex systems and interactions making up the current autonomous-vehicle situation and have indicated how that situation might develop over the short term. However, we are facing many challenges for developing and deploying long-term systems-of-systems and these must be addressed if we are to achieve the goal of completely safe and reliable autonomous ground vehicles and road systems. It is strongly recommended that a global facilitating group be created, made up of all interested parties, and that this group develop a generally accepted design that will result in safe and secure intelligent automotive systems-of-systems.

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