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Connected Vehicles: an Innovative Transport Technology

Khair Jadaan[a], Sana Zeater[b], Yazan Abukhalil[c,]*

[a]*Civil Engineering Department, University of Jordan, Amman, Jordan*
[b]*Civil Engineer, ARCADIS, Amman, Jordan*
[c]*SETS international company, Amman, Jordan*

Abstract

The emergence of Intelligent Transportation Systems (ITS) has paved the way to new innovative prospects for improving the safety, operation, and environmental impact of transportation networks. Connected vehicle (CV), a ground-breaking initiative of "intelligent vehicles", emerging as the next wave of technology to further empower travellers. Among other benefits, this technology will help provide for increased capacity of existing transportation networks in addition to increased roadside safety for motorists through the development of an overall Intelligent Transportation System. However, before we can even consider how to integrate the technology of CV into our transport system, professionals must understand and realize its environment and how future cities to be created. This paper outlines the various aspects of the CV concept and how it will affect the transport system and urban environments over the next decade with the aim of providing transport directors and practitioners with an insight into this innovative technology. Two main types of short-range wireless communication are discussed namely Vehicle-to-Vehicle (V2V), and Vehicle-to-Infrastructure (V2I) communication. An overview of the evolution of the CV and its operational aspects are presented together with its application. The impacts and potential operational benefits of the CV are discussed. The best practices of CV initiatives are reviewed, the broader public perception of CV applications are investigated, and the various challenges to the CV technology are identified.

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* Corresponding author.
E-mail address: yazan.abukhaleal@gmail.com

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1. Introduction: An overview on the evolution of the CV

The fundamental premise of the CV environment lies in the power of wireless connectivity among vehicles (referred to as V2V communications); vehicles and infrastructure (referred to as V2I communications); and Wireless communications for crash prevention, which improved mobility and environmental sustainability. A Connected Car may therefore be defined as “the presence of devices in an automobile that connect devices within the car/vehicles together or with devices, networks and services outside the car including other cars, home, office or infrastructure”. In the early 2000s, the U.S. Department of Transportation (DOT) developed the Vehicle-Infrastructure Integration (VII) Program as a part of its Intelligent Transportation System (ITS) Program. The main goal of VII was the development of wireless V2V and V2I communication to significantly improve safety and mobility on the nation’s roadways (ITS Joint Program Office RITA, 2010). To achieve this goal, the U.S. DOT proposed the use of dedicated short-range communications (DSRC) for V2V and V2I communications. DSRC works by using one-way or two-way short- to medium-range wireless communication radio channels tuned to the 5.9 GHz frequency (AASHTO, 2011). Since the technology of using DSRC was not yet available, the Federal Communications Commission (FCC) reserved the 5.9 GHz frequency for transportation safety applications. Since safety messages would not require the entire bandwidth, the remaining bandwidth could be used for non-safety applications like mobility (ITS Joint Program Office RITA, 2010) [1].

Currently, there are two views/approaches on the future of connected vehicles: the Google approach, where connected vehicles are viewed as fully automated, also called autonomous vehicles(AV) utilizing connectivity to drive themselves and the U.S. Vehicle Manufacturers approach, where connected vehicles still possess manual vehicle control while utilizing continuous real-time connectivity amongst vehicles and infrastructure.

V2V communications comprise a wireless network, where automobiles send messages to each other with information about what they’re doing. This data include speed, location, direction of travel, braking, and loss of stability the range is up to 300 meters or about 10 seconds at highway speeds (not 3 seconds as some reports say), so it can be referred to as an accurate and reliable communication method [2].

Traffic signals or other stationary devices are called V2I, or vehicle to infrastructure. Often they are just rolled into the V2V umbrella. Terms for V2V such as Car-to-X, “internet of cars”, “connected car” and the popular-press term “talking car.” are used but V2V seems to be the phrase that’s winning out [3].

V2V technology represents the next generation of auto safety improvements, its main benefit is crash avoidance which potentially warn drivers about dangerous situations that could lead to a crash. On the first cars, V2V warnings might come to the driver as an alert, perhaps a red light that flashes in the instrument panel. It might indicate the direction of the threat. Moreover, V2V could warn a driver that a vehicle up ahead is braking and he needs to slow down. The drivers will be able to see, hear and even feel the hazard signals through vibration of the seat [4].

2. Impacts and potential operational benefits of the CV

2.1. Impact on long range planning models

Connected vehicle technology will have a profound impact on the long range planning and land-use models used today. It will provide planners with a greater insight into each step than ever before leading possibly to more precise models and providing enhanced information for better decision making [5].

2.2. CV and geometric design of highways

Roads and signalized intersections are usually designed based on the behaviour and characteristics of human drivers. This human behaviour might differ vastly from the driverless vehicles’ behaviour. Unlike people, automated vehicle uses sensor systems to locate itself along the path and communicate with other vehicles and/or infrastructure along the network. This element could lead to optimize the geometric design of highways enabling the use of minimum control radii, horizontal and vertical curves.

2.3. Impacts on capacity and traffic operations

One of the major benefits of CVs and AVs is their potential to increase capacity on freeways and other uninterrupted flow facilities. AVs can improve capacity by using their equipped radars and other sensors to maintain a consistent gap to the vehicle ahead; thereby, reducing the headway between vehicles compared to human-driven vehicles.

2.4. Highway safety

Research found that deployment of connected vehicle stems and the combined use of (V2V) and (V2I) applications have the potential to address 81% of unimpaired driver crashes in all vehicle types (i.e., cars and heavy vehicles). Highway crashes can be reduced when vehicles can sense and communicate the hazards around them.

2.5. Mobility

According to the Texas Transportation Institute, U.S. highway users wasted 5.5 billion hours stuck in traffic in 2011. CV mobility applications will enable system users and system operators to make smart choices to reduce delay through providing actionable information and tools to affect the performance of transportation system in real-time.

2.6. Environmental benefits

The principal pollutants of vehicle emissions include nitrous oxides, Sulfur oxides, and Carbon monoxide, which have negative health effects. Connected vehicle technologies will generate real-time data that drivers and transportation managers can use to make green transportation choices [1].

3. Connected vehicles applications

There are different, but not necessarily separate, types of connected applications:

3.1. Safety applications

Connected vehicle safety applications that increase situational awareness and reduce or eliminate crashes include driver advisories, driver warnings, and vehicle and/or infrastructure controls; further safety applications include:

3.1.1. V2V applications

By V2V applications, drivers will be alerted to imminent crashes, such as merging trucks, cars in the driver's blind side, or when a vehicle ahead stops suddenly. They include: forward collision warning, Emergency Electronic Brake Light, blind spot/lane change warning, not pass warning, intersection movement assist and left turn assist.

3.1.2. V2I Applications

By V2I applications, drivers will be alerted when they are entering a school zone, if workers are on the roadside, and if an upcoming traffic light is about to change. They include: curve speed warning, red light violation warning, stop sign gap assist, smart roadside and transit pedestrian warning.

3.2. Mobility applications

Besides the unused DSRC bandwidth, other non-DSRC sources, such as cell phone bandwidths and current wavelengths used for wireless traffic detection equipment, can be utilized for mobility applications. To address these mobility applications. The U.S. DOT developed two mobility-centred programs in its 2010–2014 ITS Strategic

Research Plan: the Real-Time Data Capture and Management Program (RTDCMP) and the Dynamic Mobility Applications Program (DMAP). The RTDCMP focuses on the collection of real-time transportation data from CVs, mobile devices and infrastructure and the integration of all this data for use in management and performance measurement. The objective of DMAP is to develop new mobility applications that can provide more real-time data to travellers. With these two programs, traffic data collection in the future will be easier [6].

3.3. Environmental applications

Connected vehicle environmental applications might advise drivers about how to save fuel with changes in maintenance and driving style. Environmental applications can also help integrate travel by personal vehicles with public transit, or help drivers plan trips for off-peak times. In addition, connected vehicle environmental applications will give motorists the real time information they need to make “green” transportation choices [7].

4. Public perception issue of CV applications

Due to the wide range of potential applications and technologies, this section will focus on public perception issues such as privacy, security, the cost of deploying a system, data ownership, driver distraction, and equity.

4.1. Privacy

Privacy is a top concern to both public and private sectors. The public sector is concerned with the potential misuses of the data which could preclude deployment if they are perceived as threats, and once a system is deployed, misuse of data could undermine the system (Persad et al. 2007). Privacy concerns should be a central consideration in decisions about how information is collected, archived, and distributed (Briggs and Walton 2000). CV system could violate drivers’ expectations of privacy. Therefore, agencies planning to deploy ITS must address privacy concerns and may have to market the benefits of the program to gain public support (Persad et al. 2007).

The data collected through connected vehicles and other ITS applications could potentially be useful for purposes not related to the drivers themselves. For instance, the data could be used by state departments of transportation or other road managers for analysing road use patterns and planning maintenance and improvements [8].

4.2. Security

The ability of hackers to capture data or alter records is a major security issue that must be addressed before a CV system can be successfully deployed. If the public perceives a system as being vulnerable to attacks that could affect individual users, public support for the system will suffer. Raya and Hubaux (2005) emphasize vehicle communication systems using DSRC and describe various threats to vehicle networks. These specific attacks include providing bogus information to other drivers, cheating with positioning information to avoid liability, identifying and tracking of other vehicles, using denial of service attacks to bring down the network, and masquerading as another vehicle. To protect against these attacks, the authors propose security requirements including: vehicle authentication, verification of data consistency, availability, non-repudiation, privacy, and real-time constraints. It is also suggested that authentication and data analysis be handled by separate entities [9].

4.3. Cost

An important determinant of the public perception of ITS applications is the cost associated with implementation (Sorensen et al. 2010). Public costs will stem from the specialized methods, personnel, and equipment required in deploying, operating, and maintaining a connected vehicle system. Initial deployment costs and training requirements could be significant and may require a major upgrade and overhaul of existing databases and security infrastructure. To convince drivers to use connected vehicle technology in their personal vehicles, they will have to perceive the cost of the technology as less than the benefits they accrue through the use of connected vehicle applications. Furthermore, to gain broader public acceptance from taxpayers, a connected vehicle system needs to be accessible to a broad range of drivers, who perceive benefits from the system, and it may need to offer value even to those who do not purchase in-vehicle technology. [9]

4.4. Governance and ownership of data

The organization(s) in charge of managing and protecting the data will need to be trustworthy in order to gain public acceptance. The public will also need to trust the institutional setup for collection, management, and security. Institutional separation is one design method that could be used to generate trust and support. For instance, if the activities of tracking and identifying vehicles are divided between two different organizations, it diminishes the threat of potential privacy invasion compared to a scenario where the same organization is involved with both tracking and identifying the vehicles (Briggs and Walton 2000).

There has been significant discussion as to whether ITS data ought to be collected and managed by public or private organizations. When considering the advantages and drawbacks of involving the public and private sector in the collection and management of ITS data, perhaps the most important predictor of how the data will be treated is not whether the organization is public or private, but rather what its goals and operating characteristics are (Briggs and Walton 2000).

5. The challenges to the CV technology

The challenges to the development and application of the CV may be summarized as follows:

5.1. Cars take longer to develop than Smartphones

The difference in lifecycles in the automotive and the mobile industry is a serious challenge for the future of connected cars. New features, such as operating system upgrades and new applications, are provided almost constantly for the Smartphone, whereas car manufacturers work on five-year cycles.

5.2. Carmakers need mobile partners

The automotive and mobile industries have different objectives, but they will need to find ways to collaborate in order to satisfy consumer connectivity needs. General Motors, for example, selected AT&T as its mobile partner.

5.3. Car dealers need to be tech savvy

The advent of the connected cars will dramatically change the dealership model. Salespeople must plan to spend an hour or more teaching customers how to use their car’s advanced technology.

5.4. Connected cars will likely be shared cars

Automakers agree that selling ‘just’ cars is no longer feasible. It is mobility – with required connectivity to customer services and advanced functions like power management for electric vehicles – that is needed today. That creates opportunities for new ownership models, like Zipcar’s car-sharing service.

5.5. Who will pay for connected car services?

Consumers are used to a one-off payment when purchasing a car, but with an embedded connection there is an additional bill to be paid in terms of connectivity. Will you add your car as a “device” to your existing mobile bill? Or will the added cost be rolled into your car payment? Who will pay for roaming and data usage? New business models will need to be developed.

6. Connected vehicles and public transportation future overview

Transportation mode decision making depends on many factors including safety, speed, availability and cost. This section highlights the main effects of connected vehicles and automated vehicles on public transportation future, assuming these technologies are applied to both public and private vehicles, and travellers accepted them.

Connected vehicles safety applications reduce rear end accidents, a major public transportation problem caused by their frequent stopping. On the other hand, these applications might diminish the safety advantage of public transportation resulting from their large size and highly skilled operators, since private vehicles' safety will be increased. Thus, private cars attractiveness increases. This point raises doubt about the environmental advantage of CV due to reduced vehicle routes, which will be compensated by the increase in the number of private cars. From a futuristic point of view, the application of automated vehicles in public transportation could increase their level of service, thus people acceptance, through continuous operation, more frequent trips and relatively decreased trip cost. These advantages result from trips independency from human operators and high mobility on streets. [10]

7. Connected vehicles best practice

Early research and deployment in CV system are taking place throughout the world (especially in the United States, Europe, and Asia).This section highlights major CV deployment efforts and evaluates important factors for successful deployment which will allow transportation agencies to strengthen their own CV programs. The case of USA is taken as an example and discussed in detail in this section.

USDOT goal of zero fatalities is one of the driving forces behind the connected vehicle research effort. Statistics show that over 80% of avoidable collisions could be prevented with the inclusion of connected vehicle technology.

In February 3, 2014, (NHTSA) started taking steps to enable (V2V) communication technology for light vehicles. NHTSA explained that the agency will begin working on a regulatory proposal to require V2V devices in new vehicles in a future year. NHTSA focus now on two important applications: "intersection movement assist" (IMA) and "left turn assist" (LTA). The two safety applications for V2V technology may be able to prevent up to 592,000 collisions and save 1,083 lives per year. The Intersection Movement Assist (IMA) application warns the driver of a vehicle when it is not safe to enter an intersection. USDOT research results show that over 25% of all U.S. intersection-related collisions are attributed to left turns made against oncoming traffic, so LTA is an important application. According to the NHTSA report, the new technology would cost consumers $329/vehicle in 2020 [11].

USDOT and eight major automotive manufacturers are working together to conduct a collaborative research to better understand V2V systems and the effectiveness of applying this system in real word. Major part of this collaborative report program is "The CV safe pilot program" which is designed to determine the effectiveness of applying V2V safety applications in reducing crashes in real word driving scenarios. What distinguished this program that testing has been done using inexperienced drivers, who were not familiar with connected vehicles unlike most connected vehicle testing, which has been done using trained drivers and experimenters [6].

The Safety Pilot program consists of two phases

Phase 1: driver acceptance clinics

In August 2011, The Department began a small-scale driver clinics to obtain driver acceptance data in cars equipped with "V2V" safety systems in six different locations. Each clinic involved four days of testing, 112 drivers, and 24 vehicles equipped with connected vehicle technology. A representative sample consisting of a range of driver characteristics was taken. The vehicles, during testing, recorded information such as brake status, Global Positioning System (GPS) location, rate of acceleration, speed, and steering-wheel angle ten time each second. Drivers tested several scenarios that involved applications of several connected vehicle, after which, drivers would pull over and be interviewed by answering a series of questions to find out which features seemed useful [11].

After the information were gathered, the results showed that 9 out of 10 drivers agreed they would like to have V2V safety features in their vehicles and believe the technology would be useful in improving driver safety [12].

Phase 2: model deployment

On August 21, 2012 the project began its second phase to further test connected vehicle technology in a year-long effort (later extended to 18 months). Around 3,000 vehicles in the north-western part of Ann Arbor, Michigan were set up with (V2V) communications devices. The model deployment will include a mix of cars, trucks, and buses.

These vehicles translate and send electronic data to other equipped vehicles at the site when risk occur. By the end of the project, 200 terabytes of data were collected. This data support USDOT efforts and help them to decide whether to proceed with additional V2V communication activities, including possible future rulemakings.

As a result of the successful results of the Safety Pilot activities, the agency at this time (2015) solicit applications for the first wave of pilot deployments and the second wave of applications will occur in early 2017. All pilot deployments will be completed by September 2020. USDOT literature recommended for the country, which is interested in hosting one of the pilots to learn more about the program, form partnerships, identify needs, and assess connected vehicle technologies and applications [13].

8. Conclusions

This paper shows how intelligent vehicle technologies can improve operational performance on road links and intersections leading to increased mobility and improved operations. Many simulations have been run showing that CVs and AVs can improve roadway capacity, stabilize traffic flows during congestion periods, and reduce delays at signalized intersections. However, more research is needed on AVs to determine the trade-off between capacity improvement and occupant comfort, and in order to fully comprehend mobility data needs and requirements.

CV technology will provide increased capacity of existing transportation networks, in addition to increased roadside safety for motorists through the development of an overall Intelligent Transportation System (ITS) preliminary trials, and implementation of these communication technologies amongst vehicles and infrastructure has proven to provide greater benefits that will only improve as time progresses. These concepts will help to improve roadside safety through communicating with other vehicles, and also relaying this information through the roadway network allowing an opportunity for communication between a centralized traffic management system and motorists. The future of this technology will help to revolutionize the automotive world, traffic engineering design and management practices in the near future. Based on its initial effectiveness, it is a viable alternative to help solve transportation problems faced by the US currently and in future. The benefits of CVs on the safety, operation and the environment of transportation networks are evident. The necessity for assimilation of connected vehicles and long range planning has moved itself to the forefront of significance, especially since there is now a greater need for catering infrastructure upgrades to connected vehicle technologies for the future. If long range planners will start incorporating connected vehicles and the associated infrastructure, we will be prepared for better transportation systems on the horizon. The implementation effort, replacement of classical vehicles for connected vehicles and required infrastructure will not be an overnight occurrence, but as they say, "Rome wasn't built in a day.

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