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Introduction to CV-Based ITS Infrastructure

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Abstract:

ITS infrastructure encompasses hardware and software components designed to manage and optimise transportation systems. This system incorporates various field equipment that collaborates to collect, process, and disseminate traffic information. The current ITS infrastructure heavily relies on field ITS devices and fibre optic networks, which are pivotal in delivering communication connectivity. However, this infrastructure entails significant costs associated with installing and maintaining traffic sensors, communication networks, and ITS devices.

This paper introduces a game-changer in traffic management: the Connected Vehicle-Based (CV-based) ITS infrastructure. This innovative approach reduces the costs of installing and maintaining field traffic sensors and enhances traffic management efficiency using smart infrastructure. Directly notifying vehicle drivers through virtual signs displayed inside their vehicles minimises the overall costs associated with the current ITS installations, paving the way for a more efficient traffic management system.

Keywords:

Connected and Automated Vehicles, CV-based ITS Infrastructure

Traffic Data Flow

Traffic data flow, the movement information of the traffic conditions within a transportation system, is a crucial element of Intelligent Transportation Systems (ITS). It involves data collection, processing, transmission, and utilisation to monitor and manage various aspects of traffic. The key components of traffic data flow, including data collection, processing, communication and transmission, Traffic Management Centre (TMC), and notification signs for drivers, such as Variable Speed Limit Signs (VSLS), Variable Message Signs (VMS) and Dynamic Message Signs (DMS), play a vital role in enhancing efficiency, safety, and overall management of the system.

Understanding the critical parameters in traffic flow data, such as speed, density, and occupancy, is crucial. These metrics are not just important; they are indispensable for comprehending and analysing traffic dynamics on roadways and ensuring that our audience is well-informed about the critical factors in traffic management. The successful development of effective real-time traffic management and information systems hinges on the availability of high-quality traffic information in real-time.

Vehicle as a Traffic Probe Data

Currently, vehicle probe technology stands out as a highly efficient method but is not highly utilised for monitoring traffic, eliminating the need for extensive equipment deployment and maintenance. This strategy involves leveraging vehicles as probes to collect information about traffic conditions by observing their movements and behaviours on the road. These vehicles act as continuous data collectors, offering valuable insights into the current state of the transportation network. As defined by the National Transport Commission in Australia [8], vehicle-generated data encompasses information produced by the vehicle itself, including details about the car, the road environment, or the vehicle's usage. Categories of vehicle-generated data encompass movement/location data, events/actions, driving behaviour, crash analysis, crash response, asset sensing, and V2X (Vehicle to everything) messages. This wealth of information significantly enhances our understanding of traffic dynamics and vehicle-related aspects.

Researchers have extensively employed vehicle probe data for diverse purposes, such as travel time estimation, speed evaluation, and traffic state estimation. For example, Ramezani and Nikolas [9] utilised vehicle probe data to estimate queue profiles in congested urban networks. Cathey and Dailey [6] determined time series data of vehicle location and speed using transit vehicles as probe vehicles.

Torfeh Nejad and Jalali [11 & 12] utilised autocorrelation factors of density and flow extracted from GPS data for traffic conditions and incident detection. Torfeh Nejad and Adamnejad [13] have also developed algorithms for predicting traffic flow or dynamic speed management in segmented freeways based on vehicle probe data. This comprehensive utilisation of vehicle probe data underscores its critical role in advancing our understanding of traffic dynamics and developing effective traffic management and incident detection solutions.

Connected Vehicles

The deployment of advanced sensor networks and real-time data processing platforms is improving the diagnostic capabilities of connected vehicles, allowing for predictive maintenance and enhanced operational reliability [15]. Integrating 5G and decentralised networks significantly enhances vehicle-to-everything (V2X) communication. This technology allows vehicles to interact in near real-time with each other, infrastructure, and other devices, improving safety and operational efficiency [14].

Austroads (AP-R654-21) [3] research report has introduced two categories for connected vehicles:

- Category C1 refers to vehicles equipped with standards-based interoperable Cooperative Intelligent Transport Systems (C-ITS).
- Category C2 pertains to vehicles with embedded mobile data connectivity to a cloud.

These categorisations provide a framework for understanding the different levels of connectivity and technology integration in vehicles, emphasising the growing importance of connected and intelligent systems in the future automotive landscape.

Category C1: C-ITS Connected Vehicles

Austroads (AP-R584-18) [4] defines C-ITS as a subset of the broader suite of ITS. It uses wireless communications to share information between vehicles, roadside infrastructure, mobile devices, and centres. It allows vehicle and transport applications to work together cooperatively to deliver outcomes beyond achievable with stand-alone ITS and vehicle applications. Austroads (AP-R431-13) [5] has described several C-ITS vehicle positioning research prototypes developed by various large international projects, including Europe's Cooperative Vehicle Infrastructure Systems (CVIS), Europe's Co-Operative Systems for Intelligent Road Safety (COOPERS), Europe's SAFESPOT, the US Enhanced Digital Maps (EDMAP), Japanese Driving Safety Support System (DSSS), the US connected vehicle program (formerly Intellidrive and before that Vehicle Infrastructure Integration (VII)), SeCUring the EU GNSS adoption in the dangerous Material transport (SCUTUM), and Cooperative Vehicle Localisation for Efficient Urban Mobility (CoVel). [1] have described the critical communication protocols commonly used in connected vehicle technology.

Category C2: Cloud Connected Vehicles

The second category, C2, is the car manufacturer's cloud. Connected Vehicle Cloud is a digital platform enabling manufacturers to develop and manage new services for connected vehicles rapidly. The platform is tailored to fit the vehicle manufacturers' growing demand for scalability and flexibility with the necessary capabilities to support any connected vehicle service. All vehicle manufacturers are on a digital journey, but some are farther down the road than others. For example, Toyota has the Toyota connected service cloud, Ford has the Ford-Pass cloud, and Volkswagen has the Car2X cloud. These clouds provide services to vehicles, such as live traffic information, over-the-air updates, automated crash notification, concierge and booking services, etc.

The specific services provided by car manufacturer clouds can vary. Still, they typically include Telematics Services, OTA (Over-the-Air) Updates, Predictive Maintenance, Remote Vehicle Control, Customer Relationship Management (CRM), and Cybersecurity Services.

Several cloud service providers offer services tailored for connected vehicles, helping manufacturers develop and deploy solutions for connected cars. Some of the prominent cloud service providers in this space include Amazon Web Services (AWS), Microsoft Azure, Google Cloud Platform (GCP), IBM Cloud, Alibaba Cloud, and Bosch IoT Suite. These cloud service providers offer a range of tools and services that can be customised for various aspects of connected vehicles, including telematics, infotainment, predictive maintenance, and more.

Category C3: Fleet Management Connected Vehicles

In addition to the two categories of connected cars that Austroads has defined, I have added one more category of connected cars, C3. These vehicles are the cars that are connected to a commercial Fleet Management System (FMS). An FMS offers comprehensive services and features to help organisations manage and optimise their fleet of vehicles. These services enhance efficiency, safety, and overall operational effectiveness. The fleet management system might belong to a running business such as delivery and logistics companies (FedEx, DHL), ride-hailing and transportation network companies (Uber, Hertz), public transit agencies, trucking and freight companies, government and municipalities, or emergency services (Police, Ambulance, post).

Global Positioning Systems (GPS) play a crucial role in fleet management systems, providing real-time location information, speed, and direction, which are essential data for traffic data analysing systems.

Kotsialos A. and Vassilakopoulou P. [7] demonstrate a synergy between fleet management enterprise systems and traffic control systems for information sharing and collaborative planning, which is technology-specific and relates to position tracking and navigation technologies.

ITS Infrastructure

The efficiency of the road network is a pivotal challenge for contemporary road agencies, striving to maximise effectiveness and minimise adverse impacts on the community. Rather than resorting to expansive road infrastructure development, it becomes increasingly imperative for these agencies to offer sustainable, cost-effective solutions for tackling traffic congestion and orchestrating network planning. A key player in this pursuit of intelligent solutions is the ITS infrastructure.

ITS infrastructure encompasses an integrated array of physical and virtual components, laying the groundwork for implementing ITS technologies. Its primary objective is to enhance transportation systems' safety, efficiency, and overall management. This framework's traffic data flow is critical in effectively managing and optimising the transportation network. Real-time Traffic Monitoring, Congestion Management, Incident Detection, and Predictive Analysis are integral components that leverage traffic data to achieve these objectives. Saunders G. [10] described how the Connected Infrastructure ITS (CI ITS) will implement advanced communication technologies to enable seamless connectivity and efficient data exchange.

Current ITS Infrastructure

In Figure 1, the illustration depicts the flow of traffic data within the existing ITS infrastructure. The primary source of traffic data emanates from sensors strategically deployed along roadways. Various sensor types, including inductive loop, radar, lidar, and cameras, collect comprehensive information about parameters such as vehicle speed, density, occupancy, and other pertinent factors.

Subsequently, the gathered data undergoes a series of processing stages at the traffic management centres. This processing involves filtering, aggregating, and analysing raw data to distil meaningful insights into traffic patterns, congestion, and other elements influencing the road network.

The processed data is then transmitted through communication networks, with fibre optic networks playing a significant role. These networks facilitate data exchange between the roadside infrastructure and the traffic management centres. Informed by the processed data and decisions made at the TMCs, relevant information is relayed to Variable and Dynamic Message Signs strategically positioned along roadways. These signs serve as conduits for disseminating information to drivers, including details about current traffic conditions, recommended speed limits, and directions.

The current roadside-based ITS architecture necessitates critical components, including the fibre communication network, field ITS sensors, various devices and equipment, driver message signs, and an electricity reticulation network to power the ITS equipment and signs. Apart from the initial costs associated with the procurement and installation of these ITS devices, the cost of maintenance and renewal of the equipment, deployment, damages by vehicles, safety issues, aging technologies, and the cost of upgrading the equipment pose substantial financial burdens for transport agencies and governments.

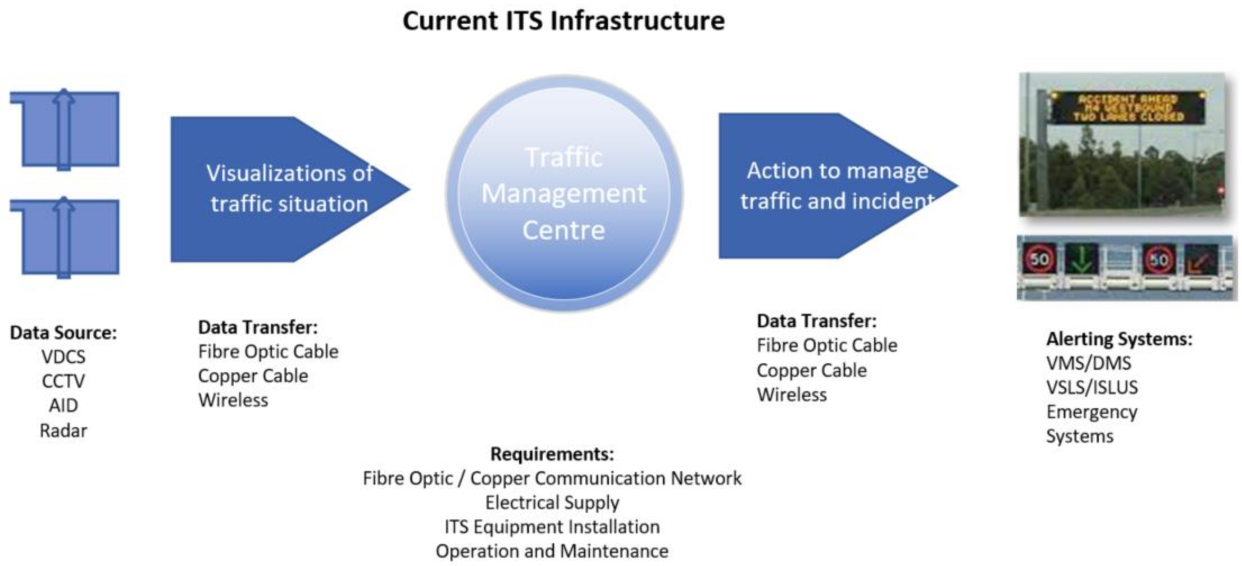

Figure 1 Current ITS Infrastructure

CV-Based ITS Infrastructure

In Figure 2, representing the concept of a Connected Vehicle (CV)-based ITS infrastructure, the data source is the information captured from Connected Vehicles. Vehicles equipped with communication capabilities can transmit data regarding their position, speed, and other pertinent details to the TMC through roadside infrastructure, interactions with other vehicles, car clouds, and fleet management systems. Advanced traffic data analysis systems leverage cutting-edge technologies and analytical techniques to process and extract meaningful insights from the extensive data generated by these connected vehicles.

A notable feature in this vision is the incorporation of virtual traffic signs, which are digitally displayed or projected on the monitor within the car rather than being physical entities. These virtual signs provide processed information and notifications directly to the driver inside the vehicle, enhancing communication and interaction.

Establishing an efficient connected vehicle network, including the C1, C2, and C3 connected vehicle categories described earlier, is the primary requirement for this infrastructure.

Unlike the current ITS infrastructure, this approach eliminates the need for traffic sensors, a fibre optic communication network, physical signs, and electrical power reticulation in the roadways. By utilising vehicles as sources of traffic probe data, this paradigm proves to be a potent tool for creating more intelligent and efficient transportation systems. It enables a real-time understanding of traffic conditions, leading to improved traffic management, enhanced safety, and better mobility for commuters.

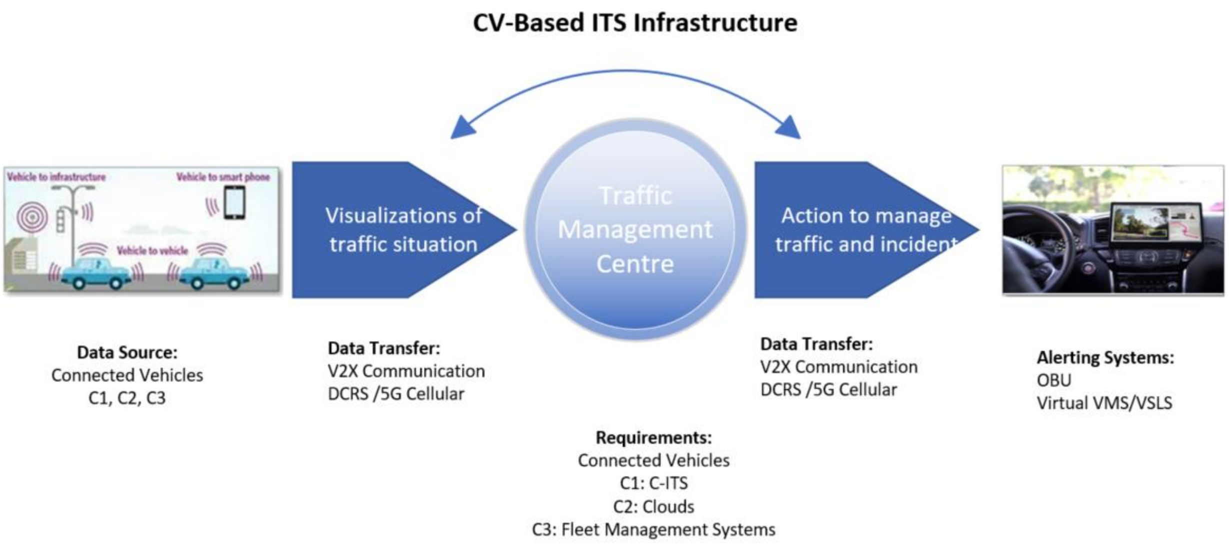

Figure 2 CV-Based ITS Infrastructure

CV-Based ITS Infrastructure clients

The CV-based ITS infrastructure offers innovative and sustainable mobility solutions by capturing real-time traffic data from connected vehicles (C1, C2, and C3 categories). The AI-driven analyses this data in real-time, providing tailored services for each client category:

- *Client category 1: Government and the city councils*

The primary clientele in the first category comprises governmental entities, encompassing transport agencies and local councils tasked with traffic management and network planning. This category relies on real-time C-ITS traffic data for various purposes, including law enforcement, traffic management, network planning, and improving road safety and efficiency.

Transportation agencies utilise this real-time traffic data to make well-informed decisions regarding infrastructure investments, policy development, and system enhancements. The insights derived from data-driven analysis play a crucial role in optimising the long-term performance of the transportation network. In the context of connected vehicle platforms and services tailored for government and traffic management agencies, the central focus remains on augmenting traffic efficiency, enhancing safety measures, and improving urban mobility. The aim is to leverage technological advancements to create more intelligent and responsive transportation systems that meet the evolving needs of urban environments.

- *Client category 2: The businesses*

The second major client category within the CV-based ITS infrastructure comprises businesses, specifically those managing vehicles tracked by fleet management systems or vehicles connected to a car manufacturer's cloud. Connected vehicle platforms provide diverse services to enhance operational efficiency, cost-effectiveness, and overall fleet management for businesses. These services are tailored to meet the specific needs of companies overseeing fleets of vehicles, allowing them to streamline operations, reduce costs, and enhance overall efficiency.

Austroads (AP-R664-22) [2] introduces an agency business capability model to support connected vehicles. This model defines the requisite agency business capabilities and associated capability maturity target states from business and technology perspectives. The report emphasises previously identified high-priority data sets, including roadworks, incidents, static and variable speed limits, lane control signals, traffic control signals, and heavy vehicle access restrictions data sets. This underscores the importance of leveraging connected vehicle technology to provide businesses with crucial data for informed decision-making and optimised fleet management.

- *Client category 3: Individual vehicles and drivers*

The third client category in the CV-based ITS infrastructure comprises individual vehicles and drivers that are not connected to a fleet management system or a car manufacturer's cloud. Consequently, these vehicles do not receive additional data regarding real-time traffic information. The CV-based ITS infrastructure aims to offer upgraded and sophisticated services for these individual vehicles, focusing on improving safety and efficiency. Connected vehicle platforms tailored for individual vehicles often prioritise services that enhance the driving experience, bolster safety measures, and provide added convenience for individual users. These services are crafted to address individual vehicle owners' unique needs and preferences, offering diverse features that contribute to overall convenience, safety, and an enriched driving experience.

Connected vehicle platforms for individual users frequently leverage mobile apps and intuitive interfaces to ensure easy access to these services. This approach enhances user accessibility and interaction, allowing individual drivers to benefit from a suite of features that improve their safety on the road and contribute to a more enjoyable and convenient driving experience.

CV-Based ITS Infrastructure Services

The services provided to the three client categories within the CV-based ITS infrastructure encompass a comprehensive array of features:

- *Traffic Flow Monitoring:* Utilise data from CV to monitor and analyse the real-time traffic conditions.
- *Intelligent Traffic Management:* Implement innovative traffic management systems that use data from connected vehicles to adjust traffic signal timings and manage traffic flow dynamically.
- *Dynamic Route Guidance:* Provide real-time route guidance to drivers based on current traffic conditions and events.
- *Public Transportation Integration:* Integrate connected vehicle data with public transportation systems for improved coordination and efficiency.
- *Emergency Vehicle Priority:* Implement systems that prioritise traffic signals for emergency vehicles based on real-time data.

- *Traffic Incident Management:* Use connected vehicle data to quickly identify and respond to traffic incidents such as accidents, road closures, or hazards.
- *Parking Management:* Utilise connected vehicle data to manage parking spaces efficiently and provide real-time information to drivers.
- *Enforcement and Compliance Monitoring:* Leverage connected vehicle data to monitor and enforce traffic regulations, such as speed limits and lane usage.
- *Air Quality Monitoring:* Utilise data from connected vehicles to monitor air quality and assess the environmental impact of traffic.
- *Pedestrian and Cyclist Safety:* Use CV data to enhance safety measures for pedestrians and cyclists.
- *Data Sharing for Planning and Policy:* Share aggregated and anonymised data with city planners and policymakers to inform urban planning and transportation policies.
- *Fleet Tracking and Management:* Provide real-time tracking and monitoring of the entire fleet.
- *Driver Behaviour Monitoring:* Monitor and analyse driver behaviour, including speed, braking, and fuel efficiency.
- *Fuel Management:* Monitor fuel consumption, track fuel expenses, and identify opportunities for fuel efficiency.
- *Predictive Maintenance:* Analyse vehicle data to predict maintenance needs and schedule proactive servicing.
- *Route Optimisation:* Optimise routes for efficiency, considering factors like traffic, distance, and time.
- *Asset Tracking and Management:* Track not only vehicles but also other assets and equipment within the fleet
- *Cargo and Temperature Monitoring*: Monitor cargo conditions, including temperature for refrigerated vehicles.
- *Integration with Business Systems:* Integrate CV data with systems like ERP and CRM.
- *Geofencing and Geo-Tagging:* Set geographic boundaries and receive alerts when vehicles enter or exit designated areas.
- *Delivery Confirmation and Proof of Service:* Provide digital proof of delivery or service completion through connected vehicle data.
- *Integration with Mobile Devices:* Enable integration with smartphones and tablets for seamless communication.
- *Compliance Management:* Monitor and manage compliance with industry regulations and safety standards.
- *Data Analytics and Reporting:* Generate detailed reports and analytics on various fleet performance metrics.
- *In-Car Infotainment:* This system delivers entertainment services within the vehicle, including music streaming, podcasts, and other multimedia content.

- *Navigation and Real-Time Traffic Updates:* Offer GPS navigation services with real-time traffic updates and route Optimisation.
- *Remote Vehicle Control:* Allow users to remotely control certain vehicle functions using a mobile app, such as locking/unlocking doors, starting the engine, and adjusting climate settings.
- *Vehicle Health Monitoring:* Monitor and provide notifications for the health and status of the vehicle, including engine diagnostics and maintenance alerts.
- *Safety and Emergency Services:* Provide safety features such as automatic crash notification, emergency assistance, and roadside assistance.
- *Parking Assistance:* Assist drivers in finding available parking spaces and provide information about parking availability.
- *Stolen Vehicle Tracking and Recovery:* Enable tracking and recovery services in case of vehicle theft.
- *Personalised Driving Insights:* Provide insights into individual driving behaviour, fuel efficiency, and overall vehicle usage.
- *Smart Home Integration:* Integrate with smart home devices to enable garage door control, home climate adjustments, and security system integration.
- *Maintenance Reminders:* Send reminders for scheduled maintenance tasks based on vehicle usage and mileage.
- *Fuel Efficiency Tips:* Provide tips and recommendations for improving fuel efficiency based on driving behaviour.
- *Integration with Wearables:* Enable integration with wearable devices to provide health and fitness information and enhance the overall user experience.

Conclusion

This paper introduced the Connected Vehicle-Based Intelligent Transportation System (CV-Based ITS) infrastructure as a cornerstone of smart transportation and smart cities. We outlined the pivotal role of traffic data flow within the ITS infrastructure and elucidated how data from connected vehicles can significantly contribute to future transportation solutions and intelligent infrastructure. Three categories of connected cars were detailed, emphasising their role in providing essential traffic data for CV-based ITS infrastructure. Furthermore, we introduced the client and services framework for CV-based ITS infrastructure.

In pursuing future developments, we propose an exploration of CV-based ITS Infrastructure development encompassing software, hardware, and high bandwidth communication approaches. Software and applications are paramount in facilitating communication, processing data, data transfer, client data utilisation, and implementing intelligent applications. Simultaneously, the OBU, as a hardware component, holds a foundational position in C-ITS for V2X communication. Our ongoing technical research aims to enhance the concept of CV-based ITS infrastructure, solidifying its crucial role in shaping the future landscape of intelligent infrastructure.

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