Developing an Operational Concept Framework to support government policy and regulation on Connected and Automated Vehicles

Richard Fullalove, MScEng, CPEng, NER
Manager, Systems Engineering Process
Asset Standards Authority
Transport for New South Wales

Summary

The connected & automated vehicle (CAV) has experienced rapid growth with a related high tempo of innovation. Road and mass public transport authorities have struggled to keep up with this rapid rate of innovation. Every day we see in the news that a vehicle or sub-system supplier has introduced a new innovative solution to a problem, and that transport authorities have introduced interim policy and regulation to govern the test and evaluation or full implementation of CAVs on the road network.

This paper proposes use of an established systems engineering method, the operational concept definition (OCD) as a means to facilitate systematic identification and analysis of "a day in the life" user story for a CAV from a transport authority perspective, and how this method can best be used to review and develop public and private transport policy and associated new or altered road regulations to enable the safe and efficient introduction of CAVs on roads**.**

Keywords

Connected, automated, vehicle, CAV, operational concept definition, framework, OCD, mobility

THE CHALLENGE

The driverless road vehicle, commonly referred to by many jurisdictions as the "connected autonomous vehicle" (CAV), has seen a rapid growth in operational capability as a viable transport mode to challenge existing transport modes.

This challenge is characterised by rapid development and introduction of novel vehicles (from established manufacturers, and new players), novel vehicle sub-systems and functionality, and novel mobility-as-a-service (MaaS) offerings.

These innovations have come with mixed success, and there have been a number of events that challenge road transport authorities to put an appropriate policy and level of regulation in place to enable positive outcomes while limiting risks.

THE SOLUTION

Operational Concept Framework

Traditionally, in systems engineering the operational concept (or concept of operations) was developed in the early stages of aerospace and defence projects, and recently this practice has permeated into the transport sector.

Typically the justification for developing an operational concept to plan and define a complex novel system, in particular in the public transport sector, can be summarized as follows:

- The OCD tells the "day-in-the-life" story of how the system is expected to operate in its environment
- It is thus necessary to define operations and support assets and resources in an OCD
- The OCD is a valid reference point throughout the system lifetime
- The OCD is a living document that should be regularly reviewed and updated

In this particular application, instead of using an OCD to define the operational behaviours for the purpose of acquiring a system (i.e. build or buy), this paper proposes the transport authority using an OCD to develop high-level policy and regulations in order to facilitate the controlled introduction of CAVs onto the road network.

Also, while the road transport authority is clearly not in the business of designing CAVs, it may need to configure the existing road network infrastructure to facilitate the safe introduction of CAVs, including changes to road markings, signs and intelligent transport systems (ITS). An OCD could be used to facilitate the initial planning for this work.

Novel, complex and risky concepts such as CAVs and their interaction with the existing road network, intelligent transport systems (ITS) and other users will require a well-defined OCD.

We propose an operational concept framework (OCF) that can assist transport authorities in systematic identification and analysis of the operational scenarios for CAVs operating on the existing and future road network.

This framework is intended to enable transport authorities to evaluate these scenarios against existing road transport policy and regulations, to determine whether or not they may need to be updated to facilitate introduction of CAVs.

The framework provides a structure that can be used to add relevant future operational information as to how CAV will be expected to operate on the roads network. For brevity, this paper is limited to elaborating the key topics listed below:

- Levels of automation
- Operational context
- Operational outcomes
- Operational use cases
- Operational migration timeline
- Operational modes
- Operational interfaces
- Operational users/actors
- Operational zoning
- Operational scenarios
- Operational risks

We will now consider each of these topics in more detail in the following sections.

Levels of Automation

Before visiting each of the framework elements, we should re-state the levels of automation for CAVs as defined by the Society of Automotive Engineers (SAE) as follows:

- L0 (No Automation): Automated system has no vehicle control, but may issue warnings.
- L1 (Driver Assistance): Driver must be ready to take control at any time.
- L2 (Partial Automation): The driver is obliged to detect objects and events and respond if the automated system fails to respond properly.
- L3 (Conditional Automation): Within known, limited environments (such as freeways), the driver can safely turn their attention away from driving tasks.
- L4 (High Automation): The automated system can control the vehicle in all but a few environments such as severe weather.
- L5 (Full Automation): Other than setting the destination and starting the system, no human intervention is required in all driving modes.

Operational Context

Operational Context describes the broader context within which CAVs may be expected to operate. This may include the context of the wider public mass transport system, "Smart Cities" initiatives, the "Internet of Things" related to all connected data-driven systems, and services, and other system initiatives and environmental conditions.

Planned and controlled introduction of CAVs onto the road network needs to be considered within the context of other new or existing network-level systems and the associated environment that CAVs will be expected to operate in, e.g.:

Public mass transport system. The CAV is only offering a variation on an existing point-to-point (P2) mode of road transport, as provided by existing private motor vehicles, taxi services, car rental services, ride-share services, and bus services (where a CAV bus variation may be considered). Introduction of CAVs onto the public road network has the potential to significantly impact mobility choices and associated public mass transport services and systems. In order to achieve the right balance of (public and private) road vehicle transport with other modes of mass public transport (including light rail, heavy commuter rail, metro rail and ferries), consideration needs to be given to potentially increased road congestion, the need to invest in other transport modes to avoid this congestion imbalance, and to ensure seamlessly integrated mobility options**.**

Smart City initiatives. CAVs need to be considered in terms of planning and design of future Smart Cities that monitor their overall performance using information and communication technology (ICT) and modifying services to optimize performance. This ICT-based service is used to enhance quality, performance and interactivity of urban services in order to reduce costs and resource consumption.

Internet of Things. An integral part of implementing Smart Cities is the Internet of Things (IoT), which massively broadens the scope of systems and devices that can be connected via the internet in order to operate collaboratively to achieve emergent properties. Since the expectation is that CAVs will be connected to each other and to fixed infrastructure systems, they are expected to form part of the IoT, and all that comes with it, including data bandwidth issues, network access issues, privacy and cyber security. These need to be considered as part of a wider policy and supporting regulation.

Big Data initiatives. The explosion of data in modern society and the recognition of information as an asset have led to initiatives to mine this data from the many connected devices and systems to provide useful analytics that drive continual improvement. Data from CAVs and their interaction with ITS and other connected systems will enable usage patterns to be interpreted to assist in decision-making and the targeted investment in improving mobility solutions. This will need to inform policy and be regulated.

Intelligent Transport Systems. The introduction of CAVs onto the road network will require that they communicate with each other as Vehicle to Vehicle (V2V) and with intelligent road traffic management systems as Vehicle to Infrastructure (V2I). Enabling higher automation levels (SAE Levels 3 to 5) will require CAVs to communicate with existing and planned Intelligent Transport Systems (ITS) provided by public (and private) road transport agencies.

Operational Outcomes

Operational outcomes represent the high-level enterprise goals and operational capabilities that are needed from a public and private road transport perspective. For CAVs these may include goals and capabilities such as "reduce road congestion", "reduce human-error-related accidents", or "increase road vehicle sharing/utilization".

In order for public road transport authorities to plan for testing, authorisation and eventual operational deployment of CAVs on the road network, they need to understand what the operational capability outcomes are.

These outcomes will be in the form of performance measures that can be used to determine expected benefit or improvement over the existing situation (i.e. human-only drivers).

For a typical capital investment project, these operational outcomes would be the highest level enterprise goals/outcomes that underpin the business case for investment. In the context of CAVs these outcomes will be used to shape government road transport policy and how this is implemented in state or federal policy. This paper discusses the key outcomes that could drive public road transport policy decisions and updates regarding CAVs, including but not limited to the following:

Reduced road congestion. The expectation is that CAVs by their nature are connected with each other and with road transport infrastructure (i.e. Intelligent Transport Systems) to collaborate in a more harmonious way than human drivers, to reduce traffic perturbations and "waves" that occur due to variability in human driver behaviour. By collaborating and communicating, CAVs are expected to be able to optimize their route from departure to arrival by selecting the least congested route, avoiding road blockages, and maintaining more consistent following distances and traffic flows.

Reduced road accidents. By removing the human from some or all road vehicle operational tasks that can be more consistently and precisely controlled by artificial intelligence in software, there is an expectation that the risk (likelihood and severity) of road accidents will decrease overall. Modelling and analysis of this risk reduction may result in a quantifiable metric that can be used as a justification and basis for implementing a pro-CAV policy, in particular from the road safety perspective as opposed to the economic perspective.

Reduced single-user vehicle traffic. CAV technology promises to enable a range of future personal vehicle ownership and "Mobility as a Service" (MaaS) options that rely could on ride-share schemes to increase the utilization of road vehicles by increasing the number of occupants per vehicle.

Reduced total vehicle pollution. By reducing road congestion, inefficient acceleration/deceleration patterns, and reducing the amount of single-user-vehicle traffic, it is expected that CAVs will reduce the overall national CO2 emissions per person per road vehicle.

Increased human productivity. By removing or reducing human involvement in the driving task, it is expected that this will free up time for the CAV operator/user to perform other functions that relate directly to their work, in particular during the daily commute to and from the place of work.

Improved equitable mobility access. The introduction of CAV technology to mobility-impaired users will enable more equitable access to mobility services, thus providing a social enablement outcome to society as a whole. This would clearly be a positive operational outcome at both state and federal level.

Operational Use Cases

Operational Use Cases represent the various usage scenarios that may exist or be planned for the future deployment of CAVs on the road network. Examples may include personal CAV ownership, "mobility-as-a-service" (MaaS) CAV usage, and heavy freight transport in the form of driverless or highly automated trucks.

In the context of this paper, we define the operational use (or "usage") case to describe the range of possible uses of CAVs on the road network. These use cases link the operational stakeholders and users with the CAV.

Some examples (there will undoubtedly be more) of potential CAV operational use cases that need to be analysed to drive public road transport policy and regulations include:

Privately-owned CAV. This use case involves private ownership of a CAV for typical use in commuting to a place of employment, travel to/from a public transport service, retail and personal business travel, leisure travel, and personal emergency travel. The CAV is parked at the owner-users place of residence in a private or communal parking and lockup facility. The owner-user has personal and direct access to the CAV at all times. Issues of private vehicle ownership and liability would need to be addressed in regulation.

Mobility-as-a-Service CAV. This use case involves the user does not own a CAV, but subscribes to a mobility-as-a-service (MaaS) service to request a CAV to perform typical mobility activities including commuting to a place of employment, travel to/from a public transport service , retail and personal business travel, leisure travel, and personal emergency travel. The MaaS CAV is not parked at the user's residence (it may be parked at a MaaS service facility or elsewhere). The owner-user only has access to the MaaS CAV upon submitting a request, and availability depends on demand from competing MaaS CAV users. CAV usage and liability needs to be addressed in regulation where the user has control of the vehicle, else regulation would need to cover the MaaS CAV provider.

Bus Mass Transit CAV. This use case involves introducing CAV functionality to bus mass transit systems. This service may be similar to existing human-operated bus services, except that it would be driverless or staff by an attendant who does not perform the driving function.

Human Mobility-impaired CAV. This use case may be a special variant of the privately-owned and MaaS CAV user case. It would reflect the special needs of mobility-impaired users, which may also include vision-impaired and hearing-impaired users, as well as other potential disabilities. Revisions to road regulation may need to consider enabling or restricting usage under certain scenarios, and dealing with degraded and emergency mode situations for the mobility-impaired user.

Commercial/Freight CAV. This use case involves the use of CAV-enabled commercial and freight delivery and transport road vehicles. Commercial/Freight CAVs would be owned by the freight operating company and would be used for the transport of goods and commodities. These CAVs would likely be subject to revised regulations regarding automation of light/medium/heavy goods vehicles and their access to the road network.

Operational Migration Timeline

The Operational Migration Timeline relates to sequence and timing of stages of authorisation and deployment of various levels of vehicle automation across limited geographic locations in the beginning, eventually expanding capability and use of CAVs to the road network. The migration timeline could reasonably be expected to look like this:

- Current situation: Levels 0, 1, 2 automation prevalent (2017)
- Interim future situation 1: Levels 1, 2, and 3 prevalent (say 2025)
- Interim future situation 1: Levels 2, 3 and 4 prevalent (say 2035)
- Final future situation (nirvana): Level 5 throughout (say beyond 2050)

It is expected that it will not be possible to simply implement all levels of automation for CAVs across the entire road network in one event. Specific levels of operational capability will need to be introduced in a controlled manner, with a related introduction of changes to policy and road regulations to control the associated risk.

Operational Modes

Operational Modes describe situations and conditions for how CAVs will operate under normal, degraded and emergency modes, the initial conditions that trigger transitions to and from these modes, and how both human and software interact will need to act in a seamless way to ensure that no safety risk arises during these transitions.

Normal mode operation is when all designed CAV functionality and capability is available and fully operational, and there are no adverse environmental conditions.

Degraded mode operation is when a CAV loses some functionality and has degraded capability from the design baseline, and/or experiences degradation in performance due to external environmental conditions (e.g. slippery roads, low visibility, lightning, excessive heat/cold).

Emergency mode operation is when a CAV experiences a loss of critical functions (e.g. steering or braking) and a significant degradation or loss of operational capability, preventing it from performing its operational role safely.

Operational Interfaces

Operational Interfaces are those interfaces and interactions that occur between the CAV and its environment during operation, where the environment may include other vehicles (CAV or non-CAV), infrastructure, pedestrians, emergency services, and the physical environment itself (e.g. temperature, humidity, light, noise, vibration, pollution, EMI).

The emphasis on "connected" in defining CAVs indicates that there will be many possible operational interfaces for CAVs to consider from both a policy and regulatory perspective.

In order to leverage all expected CAV benefits, these interfaces need to be identified and analysed for implications to existing and future policy and regulations. Figure 1 illustrates some operational interfaces that need to be considered.

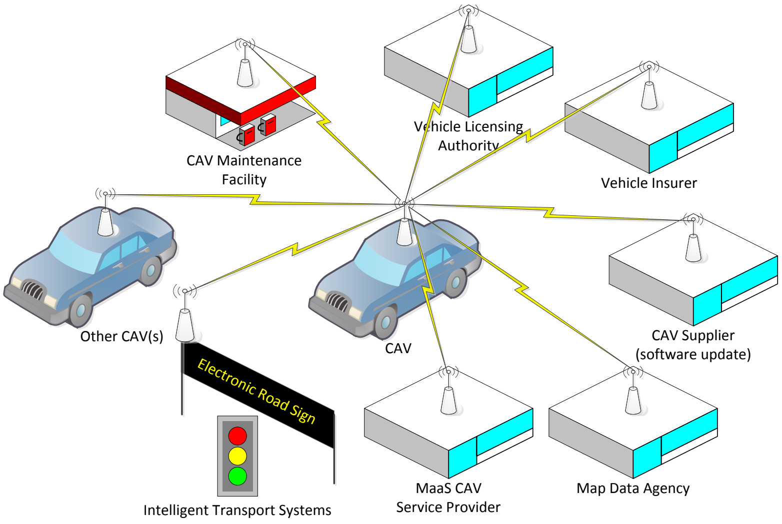

Figure 1: CAV Operational Interfaces (some possible examples)

Other CAVs will need to interact with the CAV (V2V) in order to ensure improvements in traffic congestion, safety and emissions, and includes collision avoidance and platooning.

Intelligent Transport Systems and related systems will need to interact with the CAV (V2I) to coordinate and safely regulate road traffic flows on roads and to control road intersections.

CAV Maintenance Facilities (which may include the CAV supplier) may be able to remotely diagnose faults on the CAV and provide support or be prepared to accept the CAV for services and repairs in a more efficient manner. This capability may not directly drive road policy.

CAV Suppliers will be able to remotely upload the latest software (e.g. Tesla) as well as map data updates, and provide all the remote diagnostics mentioned for Maintenance Facilities.

Vehicle licensing authorities may be able to interrogate the CAV to determine roadworthiness state in real-time from the onboard diagnostics, and potentially issue improvement notices to the CAV owner/operator before an incident arises. This level of intrusion would clearly need to inform policy and regulations.

Map Data Agencies may be interrogated by the CAV to upload the very latest road map data to ensure that the CAV's software-based perception of the world matches the physical world.

MaaS CAV Service Providers will need to operate, supervise and monitor their CAV fleet in terms of dispatching to customers, re-tasking and withdrawing from service.

Operational Users/Actors

Closely related to the Operational Use Cases and Operational Interfaces, the Operational Users/Actors are those entities (human or machine) that perform an action across an interface that interacts with the operation of the CAV. These actors will perform actions across operational interfaces that differ under normal, degraded and emergency mode scenarios. In this case, it is more appropriate to use the term "Actor" than "User", as actors include the user as well as other parties that will need to *interact* with the CAV. Potential actors may include, but are not limited to:

- CAV owner/operator
- Vulnerable road users (e.g. pedestrians, cyclists)
- Emergency services

- Road operators
- Vehicle service centres
- Vehicle suppliers

The intention of this paper is not to discuss every possible actor and the permutations of interactions that each actor may have with CAVs, but rather to highlight the principle that certain actors may require new or altered regulations.

For example, in the scenario where a CAV is used in the perpetration of a crime or a terrorist act, police may need to be able to remotely disable the CAV to limit casualties. Clearly this will need to be supported by new policy and regulations.

Operational Zoning

Operational Zoning is the designation of physical zones or lanes where a CAV may be permitted to operate in a certain level of automation. For example, it may be necessary to provide an exclusive lane on a motorway or an area within a city CBD where only fully automated (SAE Level 4-5) CAVs are permitted to operate.

Due to the different levels of automation defined for CAVs, and the migration times associated with introducing CAVs of varying capability onto the road network, it will likely be necessary to assign operational zones where road vehicles of a certain capability will be permitted to operate. Until CAVs are ubiquitous on all road types, zoning may be based on:

- Segregated geographic areas (e.g. campus area only)
- Separate lanes (e.g. dual-use of existing bus/taxi lanes, or another separated lane)
- Road types (e.g. Level XX automation only permitted on motorways)

Operational Scenarios

Operational Scenarios are the essence of an operational concept and they describe conceptually how the CAV will behave, operate and interact with its environment, as a "day-in-the-life" story. They form the bulk of an operational concept framework, and each scenario is described in a narrative that tells the story about that scenario, how the CAV is expected to behave and respond, and possible variations of that central theme.

For brevity, this paper is limited to three representative examples of CAV operational scenarios.

Traffic Light Intersection is an operational scenario that describes how CAVs need to respond to the traffic light system (part of a wider ITS), other CAVs and non-CAVs approaching the intersection, pedestrians and other vulnerable users.

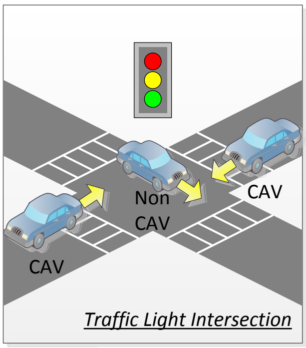

Figure 2: Traffic Light Intersection scenario

CAVs must have the capability to interact safely at intersections and roundabouts. The road authority may need to review existing road rules for defining CAV actions at intersections and roundabouts. There may be a need to invest in ITS to facilitate V2I communications.

In the future, it is conceivable that where only CAVs operate on a particular road network, all CAVs could collaborate and coordinate their movements through the intersection without the need for traffic lights using a "slot-based" system. The system may still rely on fixed roadside ITS to coordinate the slot movements under a "centralised" architecture, or it may be a "peer-to-peer" control architecture.

Road policy and regulations would need to be reviewed and amended to prohibit non-CAVs (i.e. human-driven vehicles) from operating in these exclusive "CAV-only" zones. Regulations would also need to be introduced to permit this kind of operation in these exclusive zones, until level 5 automation is ubiquitous across the road network.

Roadworks is an operational scenario that describes how CAVs need to respond to temporary roadworks performed by the road authority, where traffic is diverted along a temporary route past dangerous roadworks that are not in the global road map database.

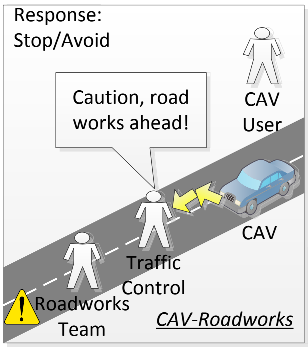

Figure 3: Roadworks scenario

The CAV will need to respond to the obstacle and diversion instructions without disruption or affecting safety of CAV occupants, other road users, and the road maintenance crew. This may include when and where to stop, and when to pass the roadworks along a diversionary route.

Regulations may need to be amended or introduced to deal with temporary roadworks, such as duties on the road maintainer to plan and notify, the CAV operator, and map data provider.

Roadside infrastructure solutions may involve use of temporary ITS "beacons" that coordinate the safe, efficient flow of traffic (CAV and non-CAV) around the roadworks.

Hacker is an operational scenario that describes how CAVs need to respond to cyber-attack that could disable functions, reduce performance, confuse sensors or actively take control of the safety-critical functions such as steering, throttle and braking controls. The CAV must have capability to sense and repel cyber-attack leading to loss of control.

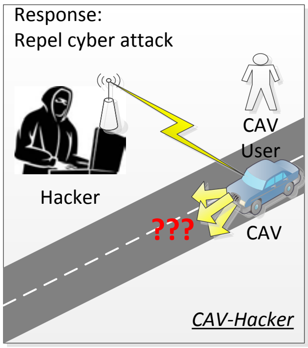

Figure 4: Hacker (cyber-attack) scenario

This may require regulatory requirements on CAV suppliers as part of national or state road vehicle design rules to assure that compliant vehicles are demonstrably cyber-secure. This may also place requirements on the map data provider to assure the integrity of the map data.

Roadside infrastructure may require investment in upgrading cyber-security of ITS systems, in particular where V2I communications are required (e.g. critical intersections). Some V2V and V2I technological solutions use Wi-Fi protocol variants (e.g. IEEE 802.11p) that sacrifice full authentication for performance, and this may introduce cyber-security risk.

Operational Risks

Operational Risks relate to the uncertainty and likelihood of external effects on the CAV, as well as deviation by the CAV (or the ITS with which it interacts) from designed intent, and possible consequences of these events.

Operational risks relate to operational context, interfaces, scenarios and modes. An example of a CAV operational risk might be "loss of lane-keeping function leading to undesired and uncontrolled change of lane by the CAV", which may lead to the following possible outcomes:

- CAV crosses into and remains in adjacent same-direction lane with no collision (no loss)
- CAV crosses multiple lanes and runs off the road (V2I collision)
- CAV crosses one or more lanes and collides with one or more other vehicles (V2V collision)

Operational risks (both safety and non-safety related) should be identified, assessed and treated in accordance with established international standards such as ISO 31000.

CONCLUSIONS

The operational concept as an artefact used by systems engineers in planning and specifying a novel system or product can also be used by transport agencies identify scenarios that require new or updated policy and regulations, in particular for introduction of CAVs onto roads.

This CAV operational concept framework suggests a structured set of topics to systematically analyse the rapid rate of CAV-related innovations to assist transport policy-makers to respond in a rapid yet structured and systematic manner to develop appropriate policy and regulation.

This framework of key topics provides a platform that can be expanded and adapted to accommodate future new CAV innovations as they are delivered from the industry, but does not prescribe the structure of any output documents as a result of using this framework.

REFERENCES

- ISO/IEC/IEEE 29148: 2011 *Systems and software engineering – Life cycle processes – Requirements Engineering*
- IEEE STD 1362:1998 *IEEE Guide for Information Technology – System Definition – Concept of Operations (ConOps) Document*
- Asset Standards Authority, T MU AM 06008 ST, v2.0, 26/03/2015, *Operations Concept Definition* (standard)
- Asset Standards Authority, T MU AM 06008 GU, v1.0, 28/05/2015, *Operational Concept Definition* (guide)
- MIT Technology Review, "*Audi's New Technology Is the Beginning of the End of Traffic Lights*", Michael Reilly, August 17, 2016
- National Transport Commission Discussion Paper "*Regulatory options for automated vehicles*", May 2016
- SAE International brochure, "*Automated driving - Levels of driving automation are defined in new SAE International Standard J3016*"

BIOGRAPHY

Richard Fullalove is a chartered professional engineer with a Master's Degree in Electrical Engineering and 30+ years' engineering experience across the system lifecycle, including planning, design, construction, integration, testing, commissioning and maintenance.

Richard has held various senior engineering management positions, focusing on innovation, design, engineering process improvement, system interface and integration management, systematic engineering solutions and high complexity transport capital projects.

Richard has worked on transport infrastructure capital projects for 20 years, of which the last 15 years focused on rail systems engineering, integration, system safety and assurance in heavy commuter rail, rapid transit metro, light rail, and heavy haul rail systems. Richard has recently moved into other transport modes, bringing his rail systems engineering experience with him to address challenges to transport authorities in areas such as the emergence of CAVs.