Rethinking transport
27–30 April 2020

TRA 2020 HELSINKI

Proceedings of 8th Transport Research Arena TRA 2020, April 27-30, 2020, Helsinki, Finland

Data needs, requirements and providers to create a concept for a data-sharing platform to support Road Operators' efforts to realize digitalization and to support cooperative automated driving

Kerry Malone[a]*, Max Schreuder[a], Frank Berkers[a], Katharina Helfert[b], Martin Boehm[b], Lena Radics[b], Christian Lüpges[c], Christian Kleine[d], Matthias Mann[d], Mark Tucker[e], Emmanouil Kakouris[e]

[a] *TNO, Sustainable Urban Mobility & Safety, Anna van Buerenplein 1, 2595 DA Den Haag, The Netherlands*
[b] *AustriaTech, Raimundgasse 1/6, A-1020 Vienna, Austria*
[c] *AlbrechtConsult GmbH, Theaterstra. 24, 52062 Aachen, Germany*
[d] *HERE Kennedyplein 222, 5611 ZT Eindhoven, The Netherlands*
[e] *Roughan & O' Donovan Innovative Solutions, Arena HOUSe Arena Road, Sandyford, Dublin 18, Ireland*

Abstract

The digitalisation of road networks and the rapid developments in automated driving will affect the core activities that National Road Authorities (NRAs) carry out, offer new business opportunities and provide NRAs with new and more efficient ways to achieve goals for road safety, traffic efficiency, the environment and customer service. Ultimately NRAs will digitise their road networks, opening up new opportunities which will in turn change the way NRAs interact with existing but also new stakeholders. Based on three use cases, the paper develops a future view of the process flow in each use case, and identifies a first draft of the data requirements and data quality criteria in providing the use cases.. The use cases are provision of High-Definition maps for automated mobility, distribution of digital traffic regulations, and infrastructure support for cooperative automated driving. The results presented are in draft version, subject to change before finalization.

Keywords: digitalization; digitization; connected and cooperative automated driving; security; digital infrastructure; data requirements; data quality criteria

* Corresponding author. Tel.: +31 6 23 99 87 21;
E-mail address: Kerry.malone@tno.nl

1. Introduction

The digitalisation of road networks and the rapid developments in automated driving will affect the core activities that (national) road authorities carry out and provide them with new and more efficient ways to achieve their goals for road safety, traffic efficiency, the environment and customer service. In this context, digitalised data plays a key role and enables the connectivity needed to improve efficiencies in managing, maintaining and operating the road network. Equally, digitalisation, along with connectivity, are crucial prerequisites to enable connected and cooperative automated driving. Digitalisation of road assets can provide a number of benefits to road authorities including new (business) opportunities resulting from data sharing, the improvement of enhanced traffic management with Intelligent Transport System (ITS) equipment, improved asset management thus allowing for more reliable performance monitoring of assets and more efficient maintenance processes. Road Operator business practices will need to adapt to exploit these opportunities

To support road authorities in their digital transition and in their interaction with other actors in cooperative automated driving, the Conference of European Directors of Roads (CEDR) commissioned and funded the "advanced options for authorities in light of automation and DIgitalisation hoRIZON 2040", (DIRIZON) project in the Transnational Research Programme Call 2017 on "Automation". The DIRIZON project's goal is to assist the aforementioned road authorities in identifying how these developments will affect their operations and their interaction with others. In this respect, DIRIZON will determine the implications of digitalisation and automated driving on specific core topics and their consequences on data needs and requirements for data-exchange.

Work Package 3 (WP3), "Digitalisation and Automation: Implications for use cases, Relationships with Stakeholders and Data needs and requirements", extends the use cases selected in this project, as presented in DIRIZON Deliverable D2.1 [Tucker et. al, 2019] by developing a future view of the process flow in each use case, and identifying a first draft of the data requirements and data quality criteria in providing the use cases. This project takes a bird's-eye view of data, looking at the whole eco-system where other actors can provide data, thus, beyond the data that can be supplied by Road Operators. This involves exploring the use cases of the future in which different Society of Automotive Engineers (SAE) levels of vehicles use the road, and the activities of the process flow. This particular part of work in the project is on-going and will be completed in 2019, allowing the results to be presented at the TRA 2020. Here the paper provides the work as of October, 2019, to be considered a draft with a high likelihood that it will be refined. The DIRIZON project as a whole will be completed in August 2020.

Together with the CEDR/Cooperative Automated Driving (CAD) working group in Oslo on November 6-7, 2018, the following use cases were selected for DIRIZON and presented in DIRIZON Deliverable D2.1 [Tucker et. al, 2019]:

1. Provision of High-Definition (HD) maps for automated mobility
2. Distribution of digital traffic regulations
3. Infrastructure support services for cooperative automated driving

In order to identify the data needed, identification of data quality criteria, and a proposal of the data quality criteria for the data categories for Infrastructure-to-Vehicle (I2V) communication, this work package started with understanding how the service is provided in each use case. The process flow diagrams are generic and not country-specific. They are target situations, that is, they do not sketch what the situation is today but how it could be in the future. Finally, the process flow diagrams indicate the roles or activities that need to be carried out.

The paper is structured as follows. Sections 2, 3 and 4 present use cases 1, 2 and 3, respectively. Section 5 creates data categories and Section 6 reviews existing knowledge form the literature, projects, and programmes on data quality criteria Section 7 summarizes data quality criteria for connected and cooperative automated driving.

2. Use Case 1: Provision of High-Definition Maps for Automated Mobility

2.1. Description

High-Definition (HD) maps are defined here to be the provision of detailed mapping in a machine-readable format to support a CAV's ability to understand its precise positioning, plan beyond sensor range, possess contextual awareness of the environment and local knowledge of the road rules. Hence, HD Maps can assist automated vehicles to optimize their precise positioning and control on the road surface and potentially extend their ODD.

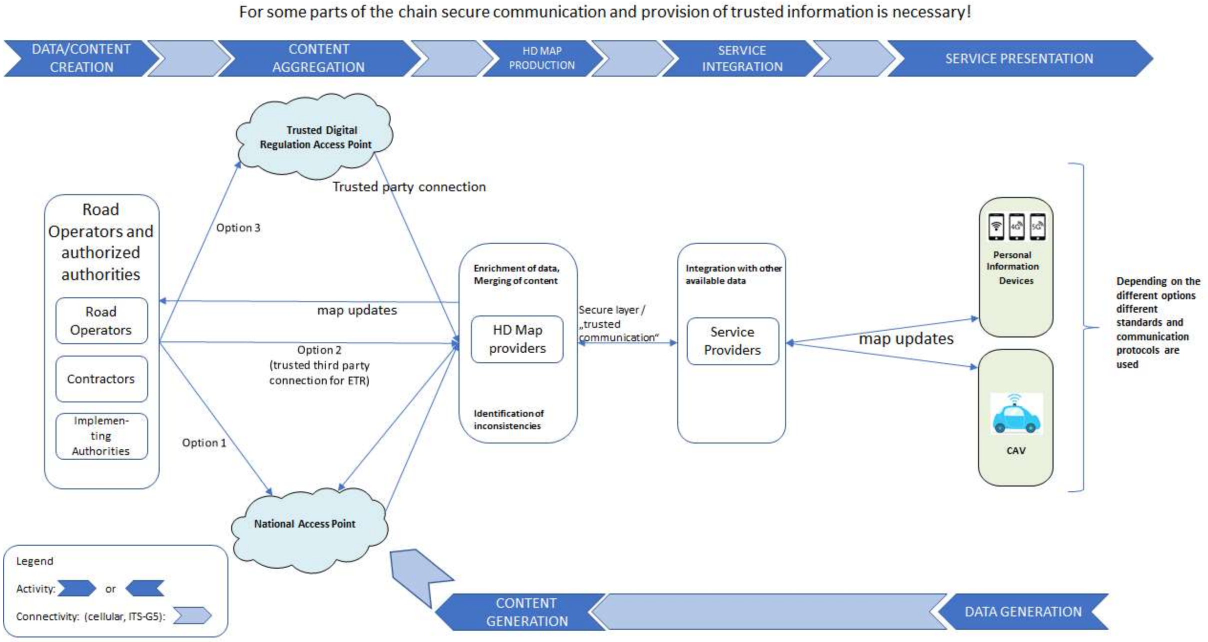

Fig. 1 Process Flow diagram for Use Case 1: Provision of High-Definition Maps for Automated Mobility

HD maps are required for automated driving. These digital maps will exploit and digest the appropriate data from relevant sources, and they will provide input to decision-making for the (automated) vehicle users. HD maps will be built up in layers, depending on the type of data (from static to dynamic). The base layer of HD maps will be populated with static data†. They will provide to (automated) vehicles information on pertinent road infrastructure (e.g. road design, road geometry, and lane information.)

Fig. 1 shows the process flow of the provision of high-definition maps for automated vehicles, for a future, generic implementation. Road operators or authorized parties provide road model, lane model and localization data to a National Access Point. Road operators or authorized parties provide data needed for an HD map via a National Access Point (option 1) and / or to the map providers (option 2). These data include road model data (road geometry, width, gradients, and junctions), lane model data (number of lanes, widths, and attributes), localization model data (beacons, signs, and landmarks) or other relevant road-related information (e.g. public parking information, etc). Road operators provide certified / signed Digital Traffic Regulations (DTR) data relevant to the HD map either to the Trusted Digital Regulation Access Point (option 3), or directly to HD map providers via a trusted party / secure connection (option 2). Fig. 1 shows the National Access Point and the Trusted Digital Regulation Access Point are functionally different, with the Trusted Digital Access Point requiring an extra level of certification and security, as its data have binding power. However, they do not need to be completely separate entities. For example, the Trusted Digital Regulation Access Point could be a secure section within a National Access Point. The exact configuration is up to the responsible authority. WP5 of DIRIZON will investigate the blueprint for the data sharing platform, and will consider the repercussions of requirements on the Trusted Digital Regulation Access Point for the blueprint of the platform.

The CCAM and smartphones also provide feedback to HD Map providers and Service providers when inconsistencies are found between the information provided in the services and the environment sensed by the vehicle sensors or the smartphone mounted on the windshield or perceived by the human driver (map updates). Probe vehicle data is provided to the service providers.

HD Map providers provide automated feedback to road authorities that provide road, lane and localization data. The feedback concerns on how and whether the data provided are used and feedback on the quality of the data

† Currently discussions on HD maps do not focus on the differences between static and dynamic, but focus on the process side, e. g. what is part of the base layer and what will be provided in a service on top.

provided. This allows the Road Operators to better optimize their process.

If they have not received it directly, the HD map providers can pick up DTR from the Trusted Digital Regulation Access Point, and digitized road and lane models and localization data from the National Access Point. This information is integrated into its HD map, along with the certificate for the regulations.

The HD map provider provides its map to the service provider. The service provider uses the HD map in its service such as navigation, providing it to CAVs and to (portable) electronic devices to be used by human drivers. The information provided to the CAVs and to the (portable) electronic devices is then "visualized" for use.

The CAVs and (portable) electronic devices also provide feedback to Service providers when inconsistencies are found between the information provided in the services and the environment sensed by the vehicle sensors or the (portable) electronic devices mounted on the windshield or perceived by the human driver.

The Service Provider passes on relevant feedback to the HD Map providers. Although presented here in the process flow diagram, the actors involved in providing feedback need to agree on the sharing of these data.

HD Map providers provide automated feedback to road authorities via the National Access Point and Trusted Digital Regulation Access Point. The feedback concerns how and whether the data provided are used and feedback on the quality of the data provided. This allows the Road Operators to better optimize their process.

The topic of enforcement, e.g. to verify if the car follows the distributed regulations, is not covered in this core topic.

2.2. Data needs for the Provision of HD Maps

At this point in time, there are no publicly available explicit data quality requirements for data to be used by automated vehicles. Therefore, this work focuses on providing a framework for thinking about which data quality criteria are appropriate, the identification of classes of data, and making initial suggestions for the data criteria. The initial suggestions are based on the EU-EIP [EU-EIP, 2018] as a starting point. These criteria need to be checked with the actors involved. The actors would also need to establish the responsibilities for checking of the data.

The paragraphs below provide examples in the categories, again, not an exhaustive list.
Static data means the digitized information about the road and traffic regulations. These include the

- road model (geometry, road width, gradients, and junctions),
- road classification,
- lane model (number of lanes and link attributes)
- HD localization model (beacons, landmarks), locations of, for example, tolling stations.

3. Use Case 2: Distribution of digital traffic regulations

3.1. Description

Distribution of digital traffic regulation becomes more and more relevant for Connected and Automated Mobility (as well as for other areas e.g. smart cities) and is currently being standardized within CEN/TC 278 WG17. It has been found that current legal responsibilities and authorisation schemes vary a lot between countries, states and cities. Rules are time-and-place referenced similar to a digital map. This means that there will be a need to maintain and encode traffic regulations electronically to be machine readable, processed and correctly interpreted by a receiver, in the context of this paper, a CAV.

The process of creating legislation at different governmental levels (national, regional and local), creating a harmonized digital equivalent for traffic regulations (e.g. normally represented thought physical signs) across Europe, and the enactment of these regulations are prerequisites but not part of the operations of distribution of digital traffic regulations. This use case focuses on how the static and dynamic regulations are distributed to the users (map providers, etc.)

Fig. 2 shows the process flow diagram for the distribution of digital traffic regulations. Traffic regulations comprise static and temporary (dynamic) regulations. These can be triggered by different sources:

- European legislation
- New national and regional framework conditions
- Current (pre-defined) situations to react on (e.g. weather-related, traffic condition related, environmental conditions (e.g. within low emission zones))

A traffic regulation can be the effectuation of a traffic ban, traffic restriction or a traffic facilitation (either route/section-related, vehicles category-related or time-related or a combination of these). The traffic regulation authorities define the regulation within their area of competence, whether it be long-term static regulations or temporary traffic regulations. The enacted regulations are implemented by the implementing authorities (Road Operators, administrative bodies, police, etc.). The implementing authorities notify the traffic regulation authorities of the implementation.

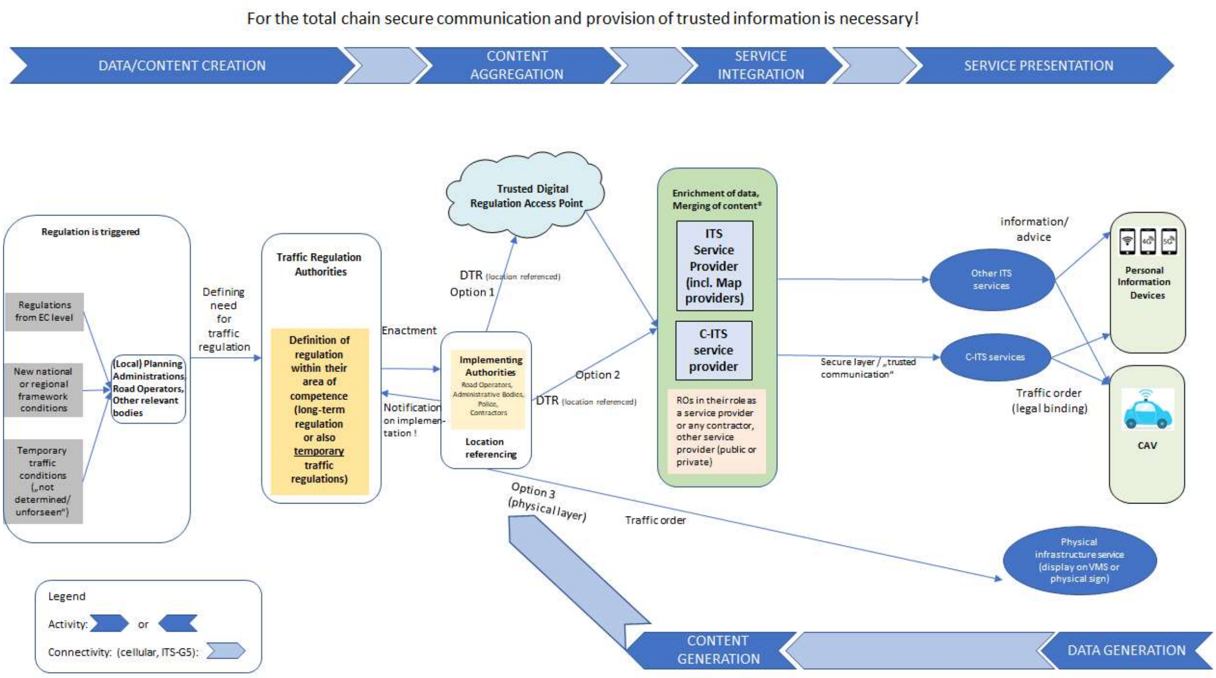

Fig. 2 Process flow diagram for distribution of digital traffic regulations (DTR)

There are three options for communication of the digital traffic regulations to road users as depicted in Fig. *1*. The first two options require a secure communication and the usage of a Public Key Infrastructure (PKI). The purpose of a PKI is to facilitate the secure electronic transfer of information for a range of network activities. It is required for activities where more rigorous proof is required to confirm the identity of the parties involved in the communication and to validate the information being transferred.

- Option 1 is for the implementing authority to provide the regulations to a Trusted Digital Regulation Access Point. These regulations must be picked up by Service providers, for use in their (C-)ITS services, integrating the binding information to vehicles and (portable) electronic devices s. The application of a PKI should lead the driver or automated vehicle to trust the information and observe the traffic regulation.
- Option 2 is for the implementing authority to provide the regulations via a bidirectional communication with service providers. The further communication is similar to option 1
- Option 3 shows what already takes place: the regulations are displayed via physical infrastructure via static signs or on VMSs.

This use case makes clear that communication takes place in a trusted environment and its delivery must be ensured. CEN/TC 278 WG17 states that "this service needs strong security support. Regulations need legal proof from the generating entity all the way to the end user, so that all main security features like confidentiality (privacy), integrity (trust) and availability (DoS) is present. This includes security services new to the ITS domain like non-repudiation. Luckily the PKI structure developed for C-ITS will work directly out of the box, so this work is mainly related to apply C-ITS security in the context of METR" [Eversen (2018)].

3.2. Data needs for Distribution of Digital Traffic Regulations

Currently, first standardisation activities in the light for digital traffic regulations have started. Therefore, this use case is in a nascent stage. The data will be both static, as listed in use case 1 on HD maps, and dynamic. Dynamic regulations include dynamic speed limits; road, lane and bridge closures; and road works. The definition of the specific content of the digital traffic regulation also needs further to be defined, standardized, and profiles need to be developed. The profile will include many of the same data definitions already defined for C-ITS use cases, for example, Road Works Warning.

4. Use Case 3: infrastructure support for cooperative automated driving

4.1. Description

Infrastructure Support for Connected and Cooperative Automated Driving (ISAD) is digitized information, on top of the HD map and the digitized traffic regulations, to support CAV functioning. The use of a HD map is assumed. Thus, this core topic covers vehicles in a mixed environment, supporting connected and automated vehicles (CAVs) by extending their Operational Design Domain (ODD) and improving safety, traffic flow and environmental impacts. The focus within this use case is the infrastructure support services provided by the road operator. The type of data that CAVs need to extend their ODD are related to the local traffic situation, by definition beyond its sensor system scope, like data based on measurements of other vehicles' real-time speeds and travel times, traffic volumes, and detection of incidents and accidents, on the road segment level and, if possible, at the lane level.

Some of these data can already be supplied by other sources: real-time speeds and travel times on road segments or trajectories by ROs and third party service providers. In the future, the infrastructure-based detection and measurement systems can be complemented by other sources of data, such as probe vehicle data (locations, travel times, speeds, braking actions, weather conditions, road slipperiness, temperature, ..). Additionally, the standardization of road signs to enable the signs to be read by cameras in CAV is required, but is not further discussed within DIRIZON.

The work in DIRIZON makes use of ISAD concepts developed in the on-going INFRAMIX project [INFRAMIX, 2019]. INFRAMIX will extend the electronic horizon, based on a combination of data from vehicles and the infrastructure, to contain dynamic information about traffic flow (e.g. speed and density of vehicles, if possible in certain situation even separately for trucks and private cars) as a basis for individualized speed and lane recommendations.

The Data Task Force launched a proof of concept to collect data for road safety [Felici, 2019]. The available materials on the proof of concept of the Data Task Force do not indicate that the proof-of-concept includes data quality checking. Also, no information is provided on the level of automation of the vehicle, which is needed in the INFRAMIX concepts.

Fig. 3 shows the process flow diagram for the infrastructure support for cooperative automated driving. Data on traffic, incidents and accidents and environmental data generated by various sources (loops, cameras, etc) are collected and made available, either via the National Access Point and/or the Traffic Management Center.

The Traffic Management Center makes use of the data on traffic, incidents and accidents and environmental data to carry out its traffic management functions. The binding traffic management measures are provided to the Trusted Digital Regulations Access Point. Traffic management data, advice, information and warnings (non-binding) are provided to the NAP. The Traffic Management Center also provides advice to individual CAVs in order to extend their ODDs, using all available sources of data including vehicle sensor data [Lytrivis, P., et al., 2018]. The Traffic Management Center provides its traffic management services in the traditional manner on VMSs or signs.

Content aggregators, (C-)ITS service providers and HD map providers enrich their own services using data from the National Access Point, providing these services to vehicles and (portable) electronic devices. These information are "visualized" for the user. The user can be a driver or an automated vehicle. The final decision on how to use the advice or warning lies with the driver or vehicle. Regulations have to be followed.

(Portable) electronic devices and CAVs provide vehicle sensor data (e.g. speed, type of vehicle). These data are collected via roadside stations and via C-ITS Service Providers.

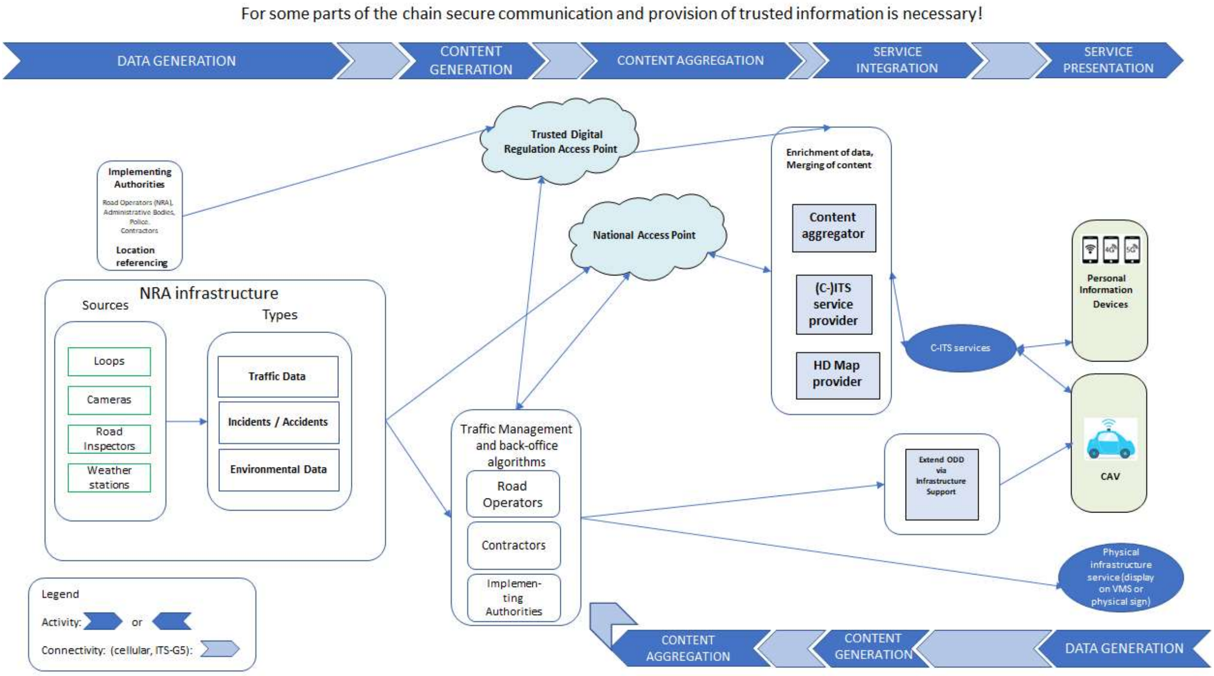

Fig. 3 Process flow diagram for Infrastructure Support for Automated Driving

The use case considers the dynamic development of both vehicles' ODD and infrastructure services over the short, medium and long term; during this transition period, automated, connected and conventional vehicles coexist at different levels of (automation) technology.

Infrastructure support services and vehicle equipment can be used to collect dynamic or real-time data to extend the ODD of cooperative automated vehicles.

4.2. Data Needs for Infrastructure Support for CAVs

All of the data needed for HD maps and Distribution of Digital Traffic Regulations are needed for Infrastructure Support for Connected Automated Driving. At this point in time, there is no definitive list of data required to provide ISAD. There are some indications of which type of data are necessary, on the basis of existing documents and direct contact with the INFRAMIX project, and from the Proof-of-Concept currently being carried out by the Data Task Force [Felici, E, 2019]. Traffic data include (as examples) traffic volume, speed, occupancy, and travel times per lane, percentage of automated vehicles in the traffic stream (in space and time), if possible, enriched with vehicle sensor data. The concepts in [INFRAMIX, 2018] require knowledge of SAE-levels. Events or conditions are primarily safety-related and are covered by the SRTI. These include temporary slippery road, animal etc. on the road, unprotected accident area, short-term road works, reduced visibility, wrong-way driver, unmanaged blockage of a road, and exceptional weather conditions. Additional data include location and length of traffic queues, accidents and incidents, availability of parking and parking costs, and weather conditions.

5. Data Categories

Sections 2, 3, and 4 provide detailed information on the data needed in the use cases. All of these data have been collected and are considered together. The paragraphs below provide by category all the data collected. This is not an exhaustive list.

- Static data means the digitized information about the road and traffic regulations. These include the road model, road classification, location of tolling stations, lane model including speed limits, access conditions, and other traffic regulations, the HD localization model (beacons, landmarks), the locations of, for example, parking spaces and service areas, charging points, public transport stop, and delivery areas. Note that HD map providers may provide the locations of parking spaces etc.in a basic map or in a premium version, depending on the specific client group.
- Traffic data include for examples traffic volume, speed, occupancy, and travel times per lane, plus vehicle types and the SAE level of vehicles. The concepts in INFRAMIX require knowledge of SAE-levels in the traffic stream [INFRAMIX, 2018]. It is not clear if these are of individual vehicles or at an aggregate level.
- Events or conditions are primarily safety-related and are covered by the SRTI. These include temporary slippery road, animal etc on the road, unprotected accident area, short-term road works, reduced visibility, wrong-way driver, unmanaged blockage of a road, and exceptional weather conditions. This list can be expanded to include additional services, like end-of-queue warning.
- Dynamic regulations include dynamic speed limits; road, lane and bridge closures; and road works.

These four categories place requirements on the data quality criteria for CAVs.

6. Data Quality Criteria

This section provides an overview of data quality criteria identified in the literature and through interviews.

The EU-EIP project aims to "provide a recommendation on quality requirements for the European SRTI and RTTI as well as the data content of them. Criteria are developed to make more concrete the levels of service and quality for RTTI and SRTI provided by the C-ITS" [EU-EIP, 2018, p.3]. The guidance provided focus on the initial steps in the information service value chain (content detection and content processing). The EU-EIP project states that the later parts of the value chain (service provision and service presentation) are planned to be developed by the project in 2016-2020 [EU-EIP, 2018]. Thus, these aspects are not available to the DIRIZON project at the time of working on this deliverable.

The EU-EIP project provides a basis for DIRIZON by defining quality criteria for provision of RTTI and SRTI [EU-EIP, 2018]. These criteria are:

Table 1: EIP definitions of (minimum; in parentheses) service and quality criteria for actual event based and status oriented information

	Definition of Criteria for RTTI and SRTI from EU-EIP, 2018, pp 9-10	
Level of Service	Geographical Coverage	Percentage of the road network covered by the (content provision) service. (event and status-oriented information)
	Availability	Percentage of the time that the (content provision) service is available. (event and status-oriented information)
Level of Quality	Timeliness (Start)	The time between the occurrence of an event and the acceptance of the event. (event information)
	Reporting period	The time interval for refreshing / updating the status reports. (status-oriented information)
	Timeliness (update)	The time between the end or (safety) relevant change of condition and the acceptance of this change. (event information)
	Timeliness (update)	The average age of the sensor data used in the most recent reporting period. (status-oriented information)
	Latency (content side)	The time between the acceptance of the event or its end or (safety) relevant change of condition and the moment the information is provided by the content access point. (event information)
	Latency (content side)	The time between the calculation for the reporting data and the moment information is provided to the content access point. (status-oriented information)
	Location accuracy	The relative precision of the referenced location for the published event with respect to the actual location of the actual event (area or road). (event information)

	Reporting accuracy	The relative accuracy of the reported quantity (speed or travel time) versus the actual value (average experience of road users in a given reporting period). (event information)
	Classification correctness	100% - percentage of the published events known not to be correct (concerning actual occurrence of this event type / class). (event information)
	Classification correctness	The percentage "A" of the reported locations for which the relative inaccuracy of the status report is larger than percentage "B" in a given reporting period. Expressed as A/B. (status-oriented information)
	Event coverage	Percentage of the actually occurring events which are known to be correctly detected and published by type / class, time and location (i.e., detection rate). (event information)
	Report coverage	The percentage of reporting locations for which a status report is received in any given reporting period. (status-oriented information)

The process flow focusses on operations, thus the criteria in Table 1 related to *event information* are relevant for determining the levels for quality criteria. Although the focus is on the initial steps in the information service value chain, the concepts can be used for the whole service, from detection to provision to the driver or vehicle.

Several projects and studies identified data quality criteria. These include C-Roads [C-Roads, 2018], a Dutch report [Calvert, 2016], and a German study [Van Driel, 2016]. These identified criteria similar to those identified by EU-EIP.

A running TKI[‡] project in the Netherlands is investigating CAD applications in mixed traffic. An interview with project participant about criteria led to the addition of two criteria for CAD. They are:

- Variance: for many or all of the criteria, a variance should be provided. This provides the CAV extra information to judge the reliability of the provided information, for the vehicle to decide how to use the information.
- Predictability: this criterion results from the experience of Service Providers with data provided for Green Light Optimal Speed Advisory (GLOSA). In countries with traffic lights with dynamic cycles, the predictability (or reliability) of the advice is adversely affected by the possibility by a jump in the cycle length (shorter or longer), and thus the (implicit or explicit) prediction of the Time-to-Green or Time-to-Red. This requirement is specific to GLOSA, but may be extended.

7. Summary

Using the data categories, the findings on data quality criteria and the quantification of these criteria presented in Section 6, this chapter proposes the following data quality criteria for CAVs. These criteria are developed from the point of view of the vehicle or driver. The criteria cover the whole chain of delivery, thus at a high abstraction level. Note that not every criterion will be used in every category:

- Geographical coverage: Road types in the road network covered by the service.
- Refreshment rate: The rate at which the data are updated in the vehicle, regardless if there has been a change in the data provided or not. This criterion is expressed in refreshments per unit of time. It can be seen as the sum of latency and timeliness.
- Availability: Percentage of the time that the service is available with fresh data. Expressed as a percentage of the time. It can be interpreted as “up time” of the system.
- Timeliness/ Latency: the total time between the detection of an event or a change, and the delivery to the user.
- Location accuracy: Accuracy to within a specific distance
- Classification correctness: Correct identification of, e.g., a static road element, a vehicle type, event or condition, or a dynamic regulation.
- Event coverage: Percentage of the actually occurring events which are known to be correctly detected and published by type / class, time and location

[‡] A TKI project is a Dutch Public-Private Partnership programme for research and innovation.

- Variance: for many or all of the criteria, a variance should be provided. This provides the CAV extra information to judge the reliability of the provided information, for the vehicle to decide how to use the information.
- Predictability: this criterion results from the experience of Service Providers with data provided for Green Light Optimal Speed Advisory (GLOSA). In countries with traffic lights with dynamic cycles, the predictability (or reliability) of the advice is adversely affected by the possibility by a jump in the cycle length (shorter or longer), and thus the (implicit or explicit) prediction of the Time-to-Green or Time-to-Red. This requirement is specific to GLOSA, but may be extended.

Using the level concept from EU-EIP and Calvert et. al, [EU-EIP, 2018; Calvert, 2016], a proposal is made below for each data category. The concept of levels needs to be seen as a proposal, to be discussed among Road Operators and with other actors for usefulness and desirability. Furthermore, the quantification of the criteria suggested need to be addressed as well. These are not presented in this paper, as the results need to be approved by the CEDR Programme Executive Board.

Acknowledgements

The authors are grateful to CEDR -- Transnational Road Research Programme 2017 Automation funded by Austria, Finland, Germany, Ireland, the Netherlands, Norway, Slovenia, Sweden and the United Kingdom -- for project support. Consortium partners included TNO, ROD-IS, AlbrechtConsult, AustriaTech, and associated partner HERE. However, the views expressed here are those of the authors and do not necessarily reflect the views of any organisation.

References

Calvert, S., Soekroella, A., Duijnisveld, M., 2016 Uitwerking eisen aan verkeerskundige toepassingen C-ITS' ['Requirements of traffic-related applications of C-ITS'], Eisenrapport TNO-2016-R10351.

C-ROADS, 2018, Evaluation and Assessment Plan, Final Version, Working Group 3 – Evaluation and Assessment, May 2018, website: https://www.c-roads.eu/fileadmin/user_upload/media/Dokumente/C-Roads_WG3_Evaluation_and_Assessment_Plan_Final.pdf, accessed on June 24, 2019.

Eversen, K., 2018, Presentation "Management for Electronic Traffic Regulations, METR",
website
https://docbox.etsi.org/workshop/2018/20180306_ITS_WORKSHOP/S04_ACCIDENT_FREE_AUTOM_DRIV/METR_QFREE_EVENSEN.pdf., visited May 28, 2019.

EU EIP, 2018, Determining the quality of European ITS Services, Deliverable SA 4.1, Version 1.1, 26 February 2018

Felici, E., 2019, "Exchanging vehicle-generated data for the purpose of safety related traffic information", booklet produced of the Data Task Force by Edoardo Felici of the Netherlands Ministry of Infrastructure and Water Works.

INFRAMIX, 2018, Lyrtrivis, P. et al., "Requirements Catalogue from the Status Quo Analysis", Deliverable 2.1 of INFRAMIX, Grant Agreement Number 723016, February 2, 2018.

INFRAMIX, 2019, website https://www.inframix.eu/infrastructure-categorization/, visited October 1, 2019.

ITS Directive, 2010, Directive 2010/40/EU of the European Parliament and of the Council of 7 July 2010 on the framework for the deployment of Intelligent Transport Systems in the field of road transport and for interfaces with other modes of transport Text with EEA relevance, website https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32010L0040, referenced on 19 June 2019.

Lytrivis, P., P. Lytrivis, E Papanikolaou, A. Amditis, M. Dirnwober, A. Froetscher, R. Protzmann, W. Rom and A. Kerschbaumer, 2018, "Advances in Road Infrastructure, both Physical and Digital, for Mixed Vehicle Traffic Flows", Proceedings of the 7th Transport Research Area 2018, April 2018.

SRTI, 2013, Commission Delegated Regulation (EU) No 886/2013 of 15 May 2013 supplementing Directive 2010/40/EU of the European Parliament and of the Council with regard to data and procedures for the provision, where possible, of road safety-related minimum universal traffic information free of charge to users Text with EEA relevance, website https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32013R0886, referenced on 19 June 2019.

Tucker, M., Kakouris, W., Schreuder, M., Malone, K., Helfert, K., Lüpges, C., Kleine, C., 2019, NRAs and Digitalisation, Draft Deliverable 2.1, DIRIZON project, July, 2019.

Van Driel, C., Yen, R., Freyer, K-G., Kalyoncu, M., Ohst, D., Egeler, C., 2016, "Mindestandorderungen Fur aktuell verfugbare Stauende-Daten und Konzept zu deren praktischen Erprobung in einem Testfeld, Kurzbericht/Summary und Kurzfassung / Abstract", FE 82.0637/2015 Stauende-Projekt, Rapp Trans (DE) AG, 2 August 2016.