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Applying a semi-automated workflow for digital dynamic maps to support the operation of automated vehicles

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Abstract

Automated vehicles (AVs) promise new opportunities for urban transport and potential benefits to road safety, transport efficiency, travel comfort and emission levels. However, substantial technical hurdles need to be overcome before AVs can operate regularly on urban streets and highways. Besides considerable infrastructure adaptations, one way to enable the operation of AVs are digital dynamic maps (DDM or DD-map), which combine a high-definition map of the physical road scape with dynamic road data obtained from digital sources. Here we present the results of the EU Project SHOW on digital dynamic maps and their relevance for city planning, in particular how cities can benefit from the interplay with map providers. We provide a workflow to set-up and operate a digital dynamic map and discuss how this might benefit transportation systems.

Keywords: Automated Vehicles; Connected Vehicles; Intelligent Transportation Systems; Digital Maps ; Real Time Information

1. Introduction

Digital Dynamic maps (DDM or DD-maps) provide digital representations of road infrastructure and dynamic real time information (in particular traffic) that allows to guide automated systems within road traffic. For instance, digital dynamic maps can be a central element to control (connected) automated vehicles (or (C)AVs), see Yoneda et al. (2020); Seif and Hu (2020)).

This study provides a workflow (i.e. set-up guidelines) to facilitate the conceptualization of a digital dynamic map, including dynamically changing information in real-time, with a particular focus on how the map components may support the use of (C)AVs. The aspect of data acquisition and a list of diverse data sources to fulfill various functions

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within a DDM is a central part of this endeavor. We discuss which data may be included in a DDM automatically (an obvious requirement for real-time data) and which may be included manually (e.g. rarely changing infrastructure elements and underlying road dimensions). Thus, the workflow may be considered to be "semi-automated".

Our workflow assumes a map structure consisting of four layers of map information: static information (the representation of rarely changing features, often physical road infrastructure dimensions and locations), traffic regulations/rules (any rule that might affect the operation parameters of a (C)AV), quality information (in particular driving comfort, road quality and perhaps validation of previously reported features) and dynamic (real-time) information (especially traffic information and availability of infrastructure, like parking or fueling, but also environmental conditions).

We discuss each of the 4 layers and the resulting workflow separately, before we present our conclusions on how the information obtained for and by (C)AVs can benefit intelligent transport systems (ITS) and thus traffic operations, for instance in cities. The workflow could also be a useful tool for city planners, to support their efforts in making (C)AV operation easier and reap the benefits of (C)AV availability (i.e. integrate a considerable stream of (C)AV sensor data).

2. Methods

2.1. Localization

We will typically assume that geolocalization (utilizing a Global Positioning System (GPS) or Simultaneous Localization and Mapping (SLAM)) for data acquisition vehicles will be possible with sufficient quality to provide data to a map that a (C)AV could use during its activities (see Shin et al. (2020); Neil et al. (2020); Joubert et al. (2020), for further research on the localization of (C)AVs).

2.2. Layer Information

The map layers of this DDM concept were designed around the recommended time frames for updating (see for instance Pannen et al. (2020); Jomrich (2020)) of the types of information grouped within. Those types of information defined the static layer (static information), traffic regulations/rules layer (mostly static information, but can be changed without affecting the infrastructure), quality information layer (medium term information) and dynamic (real-time) layer (fast changing information). We note that multiple layers can be affected by the same information over different time scales (for instance road quality becoming poorer can result in road works becoming necessary and changes to the static information) and thus there is some uncertainty on where to draw the boundaries between layers/put certain types of information. See Fig. 1. for a graphical representation of the types of information and their association to the layers.

We note that the most basic information a DDM needs is a representation of how the diverse roads connect to one another (referred to as the "road model" in this work) and what the physical properties of the road are (termed the "lane model" in our approach). Components of the lane model are the type of information that may be beneficial to represent on a lane (segment) scale: lane widths and connections between lanes/lane segments. Representing data in this model allows to combine different types of information for direct usage when driving or planning to drive along the given lane (speed limits, driving behaviour, diverse regulations (e.g. right of way, overtaking), physical lane quality). The road model instead provides a higher-level view of the road network properties, for instance, a road graph to be used in routing.

The map components are summarized in Table 1 for further discussion.

3. Results

3.1. Workflow-Fundamental Structure

The (work)flow of setting up a map includes some initial one-time steps (i.e. creating the static layer and the traffic rules), which are succeeded by setting up several (automatic) updating routines, to ensure all layer information is current and relevant.

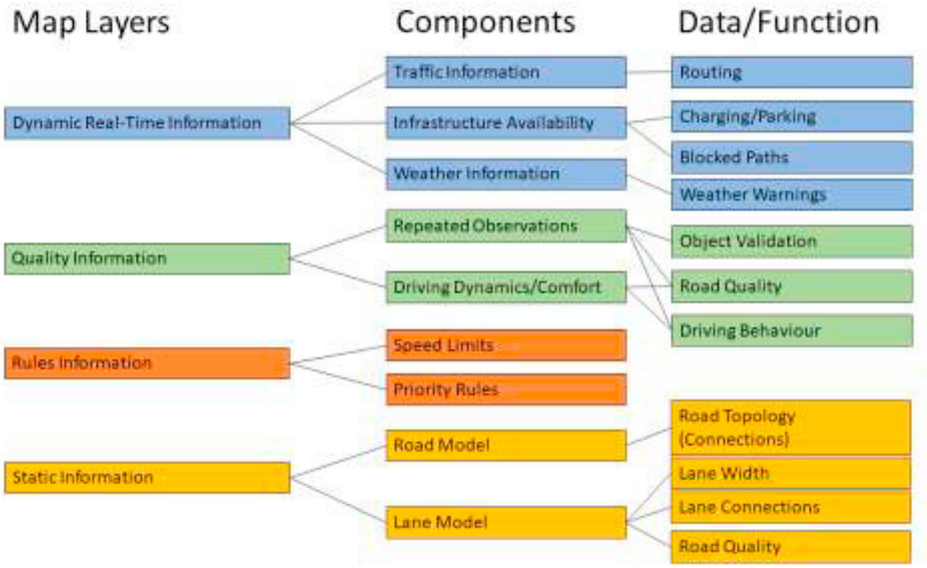

Fig. 1. Depiction of the 4 DDM-Layers with their most central information aspects.

Table 1. Components identified for the DDM.

Component	Layer	Acquisition
Lane Dimensions	Static Information	Initial Set-up (Lane Model), for instance LiDAR
Lane Connectivity	Static Information	Initial Set-up (Lane Model), manual or preexisting
Road Graph	Static Information	Initial Set-up (Road Model), manual or preexisting
Road Quality (for instance skid resistance)	Static Information	Initial Set-up (Lane Model), mechanical Measurement
Road Signs	Static Information	Initial Set-up (Local Position), video with manual annotation
Road Type (material)	Static Information	Initial Set-up (Lane model), mechanical Measurement
Speed Limits	Rule Information	Initial Set-up (Lane model), manual annotation or public source
Driving Rules	Rule Information	Initial Set-up (Lane model), manual annotation or public source
Object Validation (Location and Metrics)	Quality Information	Repeated sensory checks of object positions/lengths
Vehicle Dynamics	Quality Information	for instance CAN-BUS data, to identify unusual spots
Driving Behaviour/Conflicts	Quality Information	Video analysis and proximity warnings
Traffic Information	Dynamic Information	Current traffic information, forecasts from a traffic model
Infrastructure Availability	Dynamic Information	Parking/Charging etc availability provided from a remote source
Connectivity	Dynamic Information	Areas of lower connectivity reported in advance. Loss of connectivity reported
Road Closures	Dynamic Information	Reported by a central system and in turn found by video
Weather	Dynamic Information	Relevant weather data reported to the vehicle from a remote source

Map-information will sometimes need to be derived form a map-management-backend or a similar processing procedure in the (C)AV itself. The approach most likely to produce good results is a function of how much information and computing power is available within a (C)AV or in a map-backend respectively. When combining multiple data sources in a similar way for the usage of vehicles (traffic, weather or other events, detailed map information on lane quality), a powerful map management backend would be more suited to store the data and derive recommendations that depend on the wider system of road infrastructure (such as routing based on the overall traffic situation). Needed information could then be made available to the active vehicles periodically or upon request.

3.2. Static Information

The fundamental map layer is the static information layer, containing mobility relevant information that is unlikely to change suddenly and unexpectedly. Therefore, the road topology (in particular the connections between roads) is a natural element of the static information. This layer is assumed to include the lane model i.e. the road details (width, lane connections). Included in the static information is the presence and location of road signs, specific objects/buildings (to be used in validation) and instances of other infrastructure (like charging spots or parking spaces).

If a DDM is not already available from a map storage, it can be easiest to start with a map (graph) from an open source like Open Street Maps (OSM) or an orthophoto (see Barsi et al. (2020)), to set up a first road model. Sufficiently good orthophotos can be sources for more detailed lane models, if the transformation to a lane model can be done with high enough quality for a (C)AV to identify the lanes during operation. If a very high quality is desired (measurement errors below 10 cm in the lane representation), a separate acquisition of the physical lane with LiDAR (light detection and ranging, see Guan et al. (2016)) or similar technology may be necessary.

If the area of interest can be obtained (at the road model level) from an open source like OSM, then it has been shown that acquired highly precise physical road data (in the “Lanelet2” format for instance, see Poggenhans et al. (2018)) can be combined, using the tool Graphium and detailed manual adjustments, to obtain a lane model. A detailed procedure can be found in Rehrl et al., (2022). While this is far from trivial, the advantage of such an approach is to use preexisting information included in OSM or similar maps i.e. make that information available to the DDM.

Alternatively, if well localized trajectories of several vehicles driving in the area of interest can be obtained, it would be feasible to find a representation of the track statistically, by overlaying the driving trajectories of a suitably large number of vehicles and smoothing (calculating expectations) to determine the average driving trajectories and thus the “lane” to drive on by statistical means (see Shi et al. (2009); Uduwaragoda et al. (2013); Guo et al. (2014)). The prerequisite of this approach is that the number of trajectories is large enough and that this data is confirmed repeatedly, since for instance the structure of lanes that cars are allowed to use might change over time (though such an adjustment might be addressed in the rule information alternatively).

3.3. Traffic Regulations/Rule Information

Making local traffic regulations available is a considerable challenge that needs to be overcome for (C)AVs to use any road available to common cars. Ideally, a digital representation of what road rules are in place should be devised by a joint effort of map operators, public or private (ideally in the form of an ITS available, at least to map makers or even openly, for public review). If such a public source is not available, manual addition of rules to the road segments (and sometimes even lane segments) is necessary. This could be augmented by automated behavioural acquisition of data on driven speeds and typical driving behaviours. Adding such information to the lane model is supported by common formats (such as Lanelet2, see Poggenhans et al. (2018)), although potentially many rules might be specified at the road model level and then preferably “passed down” to a matched lane model, with only some details to be added on the lane level. Ensuring that CAVs can easily read available signals/road signs could help with (semi-) automatic acquisition by test drives.

3.4. Quality Information

The defining idea of the quality information layer is to place therein information that could vary more flexibly than the two preceding layers, but still not on a real time (seconds or minutes) scale. A particular example of this is road quality such as skid resistance or road grip (see for instance Hofko et al. (2019) on measurement and prediction). This information could help vehicles adjust their driving and braking policies and increase ride comfort, as well as improve road safety. For the actual physical road properties, measurements by specially equipped vehicles would be necessary. However, a lot of information can be gleaned from CAN-Bus data (ISO (2015)), in particular vehicle accelerations, rotational dynamics e.g. yaw-rate, roll-rate, pitch-rate. Pitch-rate data of a sample of several vehicles, can be used to define measures of driving comfort (see an example in Genser et al. (2019)). Driving comfort can be affected by potholes and could be objectified through user feedback within the (C)AV. It would be possible to confer user reports on this, to a map backend and thus identify problematic road spots, as well as help other vehicles passing over these segments to ease the discomfort by adjusting system properties.

Within the quality information layer, we envision procedures of "validation" of the positions of known objects (in particular buildings or signs) with video or LiDAR (i.e. localizing their positions based on vehicle position and video or LiDAR analysis). Herein included are aspects such as repeated validations of lane width, based on video, GPS (driving trajectories within the lane) or high-end measurement systems (like LiDAR data). This information would be aggregated in the map backend, to improve the base line quality of DDMs in an area, provide better road graphs, but also, make map makers aware of changes, so that maps can be updated (we envision an automatic update proposal based on evidence collected with a manual plausibility and quality check). In particular the "validation" aspect would lend itself to include behavioural information, i.e., video information of where traffic participants are typically moving/crossing (see also Zaech et al. (2020); Kim and Mahmassani (2015)).

3.5. Dynamic Real-Time Information

Dynamic Real-Time information is intended to include data changing on the hours, minutes and seconds scales (and information derived thereof). As such, the first thing that comes to mind is traffic information. Since the vehicle will typically not have sensor information of all surrounding elements of the road system, it would be beneficial to have up to date traffic information provided by an intelligent transport system (ITS, see European ITS Platform (2021); EU-Directive (2010)), to be accessed by the vehicle or provided to the map backend and then passed to the vehicle. Having the vehicle routing react to this information (including planning information like forecasts of traffic models, see Chavhan et al. (2022); Thonhofer et al. (2018)) would be a big step forward to prevent traffic jams and use road infrastructure efficiently. Conversely, the (C)AV might provide information to the ITS or map-backend through video or other data and become itself a sensor to detect traffic problems early on. Here we have an example of how different layers interact since for instance traffic jams in similar spots on the road network could be included in the quality information (as "behaviour") in association with a particular road segment and time in a DDM.

Another important information in the real time layers is the availability of road lanes for travel i.e. is a path blocked due to construction works or crashes. This information should be distributed from a central system and/or between vehicles which might be the first to become aware of such blockages through their sensors. Some of this functionality (travel planning) needs to be available within each vehicle, as no connection can be guaranteed to be available. In case of loss of connection, the vehicle should be able to devise a route to its target and also have some information on where to drive for good conditions to connect again. Such information on areas with good connectivity should be included in the quality information as well.

A natural candidate for real time information is the availability of parking and charging infrastructure. Again, a central provision of this information to a (C)AV could much improve the efficiency of use of road infrastructure. Communication of this information requires a contact between the map backend and an ITS or the respective service providers. Alternatively, a (C)AV could query this information by itself if the map-backend is not providing this for some reason. It would not be necessary for the vehicle to include all this information in its own map but rather the respective queries to an ITS or the map backend should be established to profit from centralized real time planning.

In case weather conditions might impact a (C)AVs operation, a system of weather warnings should be in place. This system would notify the (C)AV of the expected affected areas/road segments and thus travel planning could be adjusted in real time if necessary. We envision the weather information to only be passed on a need-to-know basis and not see weather data included in the maps per se.

3.6. Data Sources and Map Set-Up

Following the earlier sections, the process of setting up a map includes the following steps:

- The static layer requires well localized (SLAM/GNSS) measurement drives to map the relevant lanes and the road topology.
- Some (C)AVs might require LiDAR measurements to reach sufficient precision.
- Ideally a matching lane and road model are used (allowing to pass down properties not changing on the road model scale to the lane model). As described, one way to do this is using Graphium and an OSM map to match with Lanelet2 data (Rehrl et al., (2022)).
- Traffic rules may be added manually at the road model level (passed down to the lane model) and/or acquired from behavioural/observational (video) data and (human) interpretation.
- Quality information needs to be aligned with vehicle sensors i.e. CAN-Bus data for driving dynamics (and thus driving comfort/road quality), video for localizing objects in combination with geopositioning, geopositioning for driving behaviour data and if available high-quality measurements (LiDAR).
- Traffic information would typically be inferred from traffic counts and a model of traffic flows in between traffic count locations. Weather data can be obtained from specialized providers. (C)AV sensors themselves provide much input (localized video, trajectories). Obstructions should be reported and connectivity should be constantly reevaluated.
- Given loss of connection, (C)AVs need to have sufficient information encoded in the map to fulfil a defined minimal function (e.g. reach the target destination or reach a safe place).

3.7. Benefits to Planners

Setting up DDM structures like those described in this work has several advantages for planners. In particular the integration of (C)AV sensors in the provision of quality information (road quality via CAN-Bus parameters) allows planners to localize necessary road works and potential infrastructure risks. The inclusion of (C)AV sensors in the dynamic real time information and the connection to ITS at the city level would improve routing efficiency and the information from video data and driving trajectories communicated by (C)AVs to the ITS would allow to identify road blockages and potential safety issues (if conflicts were to be extracted from video data or other safety warnings).

Fig. 2. illustrates how the diverse systems augment each other and benefit traffic management. Also, a central platform to provide traffic rules and road information to (C)AV operators or map makers would itself be a valuable impetus towards digitalization of infrastructure and thus easier and more detailed planning in general, as soon as the road infrastructure becomes relevant (i.e., for construction or adaptation of roads for other/vulnerable road users).

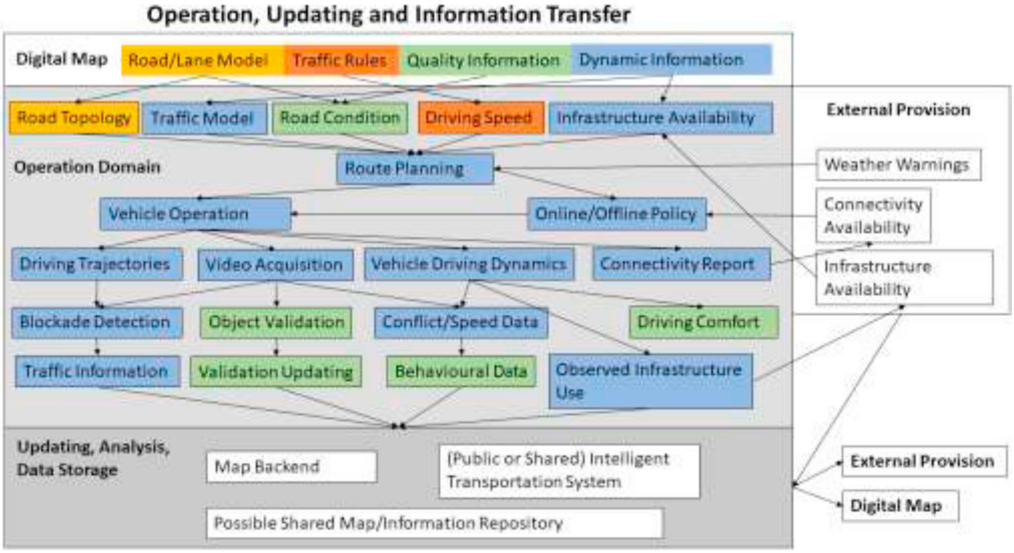

Fig. 2. The structure of operating a Digital Dynamic Map to enrich traffic data.

4. Conclusions

Many costly and complex steps need to be taken to set up a digital dynamic map (DDM). Our workflow provides data types, possible tools and possible use-cases to consider, that might help to conceptualize a DDM framework for a given area and vehicle. The elements of the workflow were organized in four different layers (static information, traffic regulations, quality information, dynamic real time information), based on their updating schedules. We discussed the properties of each of them and how they might benefit vehicle operators and planners in their work.

Based on our observations we strongly support a joint effort between map-makers/vehicle operators and government agencies to set up a joint data base or even ITS, containing traffic regulations, road data/dimensions and real time data (traffic, weather) on at least a large segment scale (see Buchholz et al. (2020)). Used as the base for an ITS or to route (C)AVs there is much potential for efficient road use to be gained through route planning, use of operation infrastructure. We note that there have been efforts in this direction (see ITS Actions plans, European Commission (2011); European ITS Platform (2021)) and we propose an extensive system of data types to be integrated within such approaches (such as vehicle behavioural data or localized CAN-Bus data). An example of an earlier effort is the graph integration platform (GIP) in Austria or the real time traffic information system (EVIS) which could be a candidate ITS to provide real-time information to map makers.

While the exact needs of a (C)AV depend a lot on its specific systems used, we believe the above mentioned map components would be of benefit to the vast majority of vehicles and the development of ITS and thus efficient use of infrastructure. These efforts would benefit substantially from contributions by the OEMs of sensors, to provide real time data. The willingness of OEMs (Original Equipment Manufacturers) to support this might depend on the legal framework of such cooperation (who holds the responsibility for data protection) and the benefits (validation against other data sources, finding new needs arising from the interplay of multiple components) of making use of a map combining multiple data sources. Working out a good framework for cooperative use of sensor data in a DDM could be a focus of further work on this topic.

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