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Evolution into a new-generation Traffic Data Platform to support emerging interoperability and multi-modal traffic applications

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Abstract

Traffic is getting smart, participants and infrastructure are getting connected and more data is digitally available. Different kinds of platforms were set up to support new applications and use cases: to manage traffic, to operate fleets, to influence and optimize routing, to provide essential data such as highly precise and local dynamic maps as well as to collect data about the traffic infrastructure. If traffic stakeholders and their interacting use cases incorporate, then also the data platforms should be fused to improve interoperability. The German Aerospace Center's Institute of Transportation Systems (DLR-TS) also operates three specialized data platforms to improve emergent traffic applications and support mobility research.

The *Traffic Data Platform (TDP)* provides all basic tools for storage, map-matching, processing, fusion and management of traffic data from various sensors and third party sources such as floating object data, observed data and data from sensors like induction loops or traffic eyes as well as different road networks. Additionally, information about infrastructure and exceptional events such as natural disasters are integrated.
The *Bahnserver* (railway server) provides methods for centralized collection, automated processing, 3D visualization of rail network infrastructure elements as well as position-based real-time information of vehicles. It provides tools for merging and validation of different data sources in one database, plotting of units with automatic telemetry reporting and intuitive visualization of geo-referenced measurements.
The *Digital Atlas* collects heterogeneous geodata about road networks and urban infrastructure to provide 3D environments and detailed topographical and topological road descriptions on lane level with high accuracy for driving simulators and advanced driver assistance and automation systems.

These three platforms are operating in the same traffic environment and have similarities in used data and supported applications. Therefore it is obvious to fuse these platforms to make use of the best of the three worlds: DLR is migrating the *Digital Atlas* and the *Bahnserver* into *TDP* to extend it with their features. This supports inter-map-matching to use maps with different levels of detail from different sources, harmonized visualization services, enhance user management for fleet operators using only few maintenance units or thousands of private end-users. This paper will present the three platforms and their use cases, describe the approach of fusing the systems and give prospects about the potential of the new-generation traffic data platform.

Keywords: ITS and Traffic Management; Digital Maps; Sensors / Monitoring / Maintenance / Asset Management / Use of Robotics / Drones; Visualization; Real-time data; Historical data

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1. Introduction

Traffic has been growing for decades. While aerial traffic can grow more or less easily due to mostly point-shaped infrastructure requirements, road and rail traffic has to cope with challenges of historically grown networks and limited space to expand. The traffic demand is growing faster than the capacity. To tackle these tasks databases were developed to manage traffic, monitor traffic flow and vehicle fleets as well as to maintain infrastructure and store the underlying geodata such as road and rail networks. Also the Institute of Transportation Systems of the German Aerospace Center (DLR-TS) developed three special purpose databases that will be introduced as state of the art data platforms.

1.1. Traffic Data Platform (TDP)

ITS traffic information systems require robust and reliable tools for data management and provision. For this purpose DLR-TS has developed a *Traffic Data Platform (TDP)* as ITS infrastructure for standardized storage, management and provision of all collected raw as well as processed traffic data and traffic information, T. Tcheumadjeu et al. (2010, 2010). Using common TDP data interfaces, TDP users and partners can have access to all data (e.g. traffic data, infrastructure data and simulation data) available within the TDP in a secure way, Detzer et al. (2015).

1.1.1. Purpose and concept

Figure 1 shows an exemplary ITS system architecture with typically many different data to be imported, processed and refined, feeding services to serve various applications and clients via client interfaces. In such an architecture the TDP is the central data management solution where all data to be stored are handled.

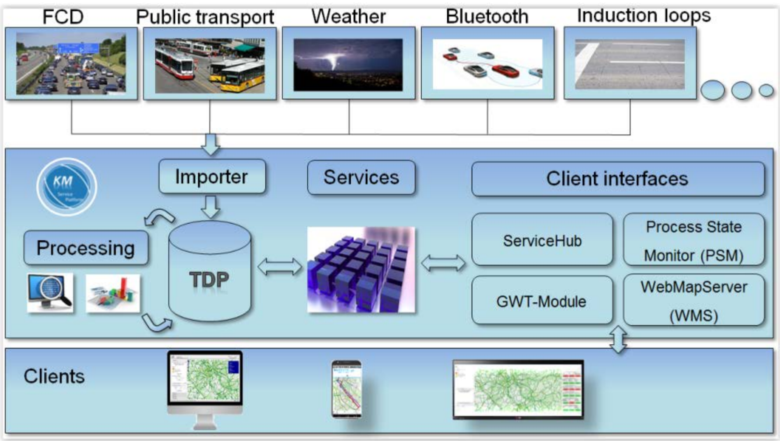

Figure 1: ITS System architecture with Traffic Data Platform (TDP) as central data management solution.

In many research projects, which are in detail different, but very often use very similar data, this typically has to be set up every time after a conceptual phase. At DLR-TS the TDP was developed and enhanced since 2008 to serve as a re-usable basis for the realization of telematics services and applications to save time and resources and thus to give time especially to focus on the really new research aspects of new projects. The main functionalities of the TDP are:

- traffic data storage and processing from different sources,
- data aggregation, processing, data fusion, data prediction, management storage and monitoring,
- overview on data base and storage load,
- dynamic and multi-/intermodal routing services.

The most important principles are:

- flexible and standardized data storage and services interfaces for client applications,
- modularity, scalability and reusability of components,
- building synergies between the components,
- quick and easy use of “best practice”.

The main focus of the TDP is traditionally on road data and road traffic management, but over the years also public transport data were integrated whereupon primarily journey planners of local public transport operators where tethered to the existing system. Especially to serve and optimize aspects of intermodal journey planning, infrastructure data (bus stops, train stations) already have been integrated into the TDP.

1.1.2. Used architecture and technology

An instance of the TDP is typically set up for a city/region or even administrative areas as there are e.g. federal states. It consists of various data base schemata and is created with standardized psql scripts. The contents of the schemata are:

- "**tdp_[region]_system**": Is always created because it holds the special definition of the area the TDP is created for and additionally some more "meta" information about TDP-contents.
- **"tdp_[region]_user**": Is typically created to handle user data for the use of connected applications and services.
- "**tdp_[region]_data**": Contains many raw traffic data from FCD (Floating Car Data), FOD (Floating Observer Data), stationary sensors as well as "third party" traffic information.
- "**tdp_[region]_infra**": Contains all infrastructure information – except for the basic map – like public transport stops and stations, POI, probably "third party" maps and data referenced to these.
- "**tdp_[region]_[map-version]**": Holds the most important data. At first the basic net itself in form of nodes, links etc. which acts as the central map where all information are referred to. At second probably assignment tables are stored which link the basic net to "third party" nets in schema "infrastructure". Finally all other data related to the basic map which may be very dynamical data as there are e.g. map matched traffic sensor data, relations from induction loop sensors to the basic net and especially fusion data tables which represent current as well as historic traffic states.

In total the TDP by now is able to handle FCD, smartphone device data, induction loops, TMC, TPEG, airborne video data, data from Bluetooth and Wi-Fi scanning (FOD, FOD Observed; see DYNAMIC approach, T. Tcheumadjeu et al. (2017)), third party traffic information (Inrix[2], HERE[3], TomTom[4]), time-aggregated data, fusion data, current traffic information and historic traffic information. Especially for integration of third party data, an InterMapMatching approach based on OpenLR[5] is used to reference all data to a defined basic map. In all schemata the names of the data base tables have thematic prefixes, thus everything is clearly arranged, even with 50 or more tables in a schema.

The TDP was first developed for PostgreSQL, but is meanwhile also realized for Oracle systems as well as MySQL. Part of the TDP is the TDP-ServiceFramework, which supports module communication and logging in form of Java libraries. Each software module using the TDP database may embed these to interact most simply and efficiently with the database and use standardized logging. Furthermore, an integrated communication framework based on ActiveMQ technology may be used with service-client principles for synchronous inter-module communication as well as contacting a central MessageBroker to send and/or receive asynchronous small notification messages.

1.1.3. Success stories

Over the years the TDP was and is used in many research projects at DLR-TS and is continuously enhanced and optimized also with respect to backwards compatibility.

At first, many projects and applications focused on the generation, fusion and visualization of road traffic information as can be seen for example in Figure 3 which shows a Real Time Traffic State Map based on a fusion of floating car data and induction loops. Also routing based on current as well as historic traffic states was implemented. To conform to requirements of travel assistants as it is realized at DLR-TS with the intermodal travel assistant *KeepMoving*, the TDP was on one hand enhanced especially concerning user management and integration of public transport journey planners. On the other hand existing solutions concerning traffic

2 http://inrix.com
3 https://here.com/en
4 http://navigation.teleatlas.com/portal/home-de.html
5 http://www.openlr.org/

information have been optimized. For users the travel assistance is still available via web browser, but also via smartphone app with a full navigation and route guidance solution. A Public Screen Portal (PSP; see Figure 4 left) was developed to provide specific location-relevant traffic information at special places (e.g. main entrance of a company or hotel), which are e.g. current travel times and best routes from this place to popular destinations (train station, airport, city center, etc.).

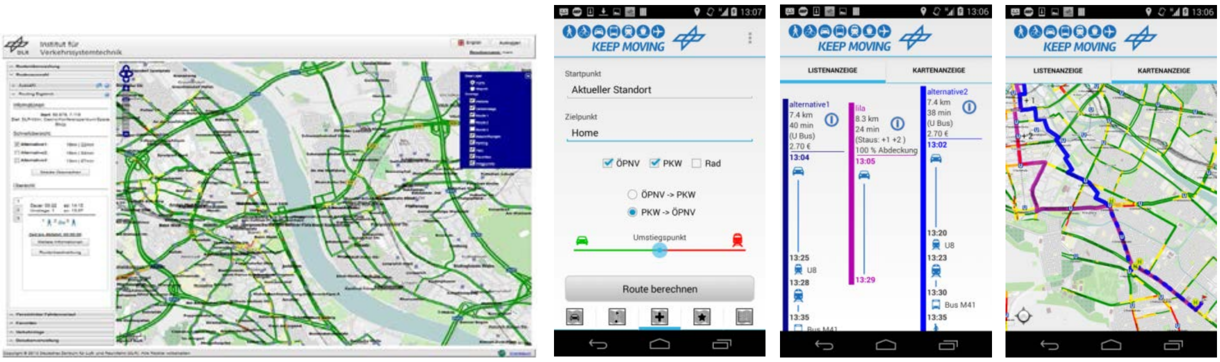

Figure 2: KeepMoving Web portal (left) and Smartphone-App (right).

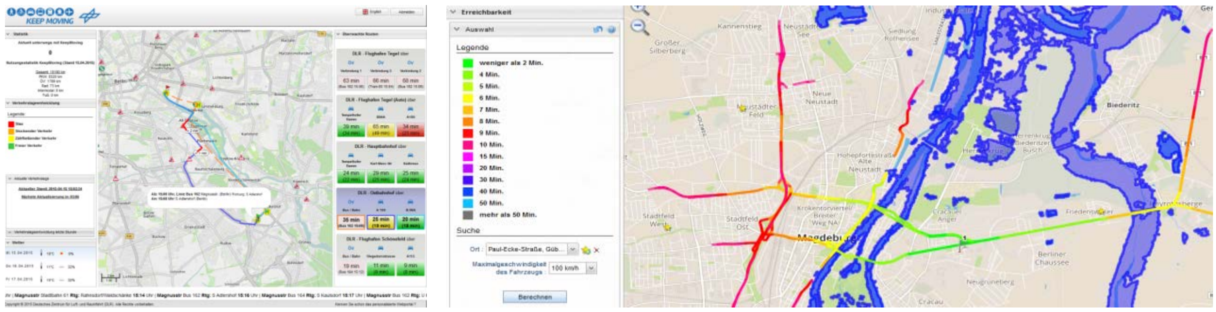

Figure 3: Web browser based Public Screen Portal (PSP) of KeepMoving (left) and flood mask together with destination availabilities in web browser based portal KeepOperational (right).

In recent months more enhancement and functionality of the TDP was done by the optimization of data structures to serve applications like a Traffic Quality Analysis Tool, which is used to analyze big data amounts of detected and generated traffic states and information of the past. Furthermore, in the context of the support of action forces a *KeepOperational* system was developed to support headquarters of police, fire departments and technical emergency services at big events and in case of disasters with a web-browser operation portal (see Figure 4 right), Detzer et al 2015.

1.2. Bahnserver

In the domain of railway technologies it is important to operate fleets and maintain railway networks in a cost-efficient way. Therefore solutions for monitoring rails and infrastructure as well as predicting malfunctions in advance are developed. For this purpose DLR-TS has developed a *Bahnserver* (so-called railway server, Schubert et al. (2016)), to collect, automatically process, merge, visualize and also to export heterogeneous data. This data can be individually accessed by Bahnserver users and partners.

1.2.1. Purpose and concept

The Bahnserver has been developed since 2014 to serve as a re-usable platform to store huge amounts of data that is provided by different sources such as sensor measuring data from units in the field, real time telemetry data and operational data such as time tables. The Bahnserver provides methods for centralized collection, processing, visualization and serving of spatial data as well as position-based real-time information for railway systems applications. It currently supports:

- detailed infrastructure visualization of railway tracks,
- geo-referenced analysis and visualization of track defects,

- visualization of project-specific map tiles built from different sources such as railML[6] or OpenStreetMap (OSM)[7], and
- real-time visualization of geo-referenced field units.

Integration of previously unavailable data sources like Deutsche Bahn's OpenData portal[8] and communal land register data[9] offers the possibility of generating extended maps and datasets, which can be used in further projects and applications.

There are two types of data managed by the server: On the one hand real-time data such as telemetry and Global Navigation Satellite System (GNSS) data sent by units in the field every few seconds and on the other hand static data such as railway networks or georeferenced infrastructure elements in the field. Both data can be visualized simultaneously in a 3D web map interface (GUI).

1.2.2. Used architecture and technology

The Bahnserver database schema (BDBS) was developed to be used in an Oracle relational database. The underling schema is based on the Mapdata 3.1 and Railway Infrastructure Map (RIM) data structures, Schubert et al. (2016). The main changes in the database schema are the use of Oracle-specific data types as modifications to enhance the database performance.

The BDBS was also extended to support storing data from other sources such as the import of rolling stock information from a railML file. The database is divided into eight different namespaces. The relevant namespaces for saving geo-referenced data are the following:

- Topology elements are saved in the namespace **TO**. Data such as nodes and edges which model a railway topology is saved within this namespace.
- Geometry information of a track is saved in the **GE** namespace. Examples are the curve radius or the curve gradient of a track.
- Railway infrastructure elements are saved in tables from **IT** namespace. Examples from infrastructure elements are balises, bridges and sleepers.

Visualization of domain-specific geodata – like measurements of field units – often requires base maps as spatial context. For (web) visualization purposes, such base maps are commonly served as raster tiles depicting either aerial photography or topographic or thematic features. To cope with high request loads and to offer low response latencies at the same time, DLR-TS hosts an internal map server providing different tile datasets to be accessed by visualizing client applications running on the Bahnserver, refer to chapter 1.3.

One of the key tasks of the server is to automatically process the received data without human interaction. This is done by different server daemons. One example is the processing of incoming GNSS data from units in the field. These units send all raw GNSS Data at the end of a measuring cycle to the server over a Virtual Private Network (VPN) connection. This data is automatically map-matched to the current railway network as also an automated Real Time Kinematic (RTK) processing is done. Figure 5 on the left shows the geo-referenced axle-bearing acceleration data from a unit in the field. In this example the axle-bearing acceleration data was georeferenced, map-matched and its absolute acceleration peaks plotted in the web interface from the Bahnserver. The cause of these red peak abnormalities was detected through a visual inspection in the railway by the Hafenbahnbetriebsgesellschaft in Braunschweig, one of the project partners.

Having a detailed railway network and infrastructure elements available in the database such as the entire Swiss railway network[10] (Figure 5 on the right) combined with real time and georeferenced sensor data from units in the field as also remote access to these units provides us the possibility of research topics such as infrastructure maintenance, simulation of specific situations and scenarios as also the processing from different georeferenced data.

6 https://railml.org/en/
7 http://www.openstreetmap.org
8 http://data.deutschebahn.com/datasets/
9 e.g. Berlin Open Data: http://daten.berlin.de/
10 Dataset received from the project partner Swiss Federal Railways (SBB) based on Voser (1992).

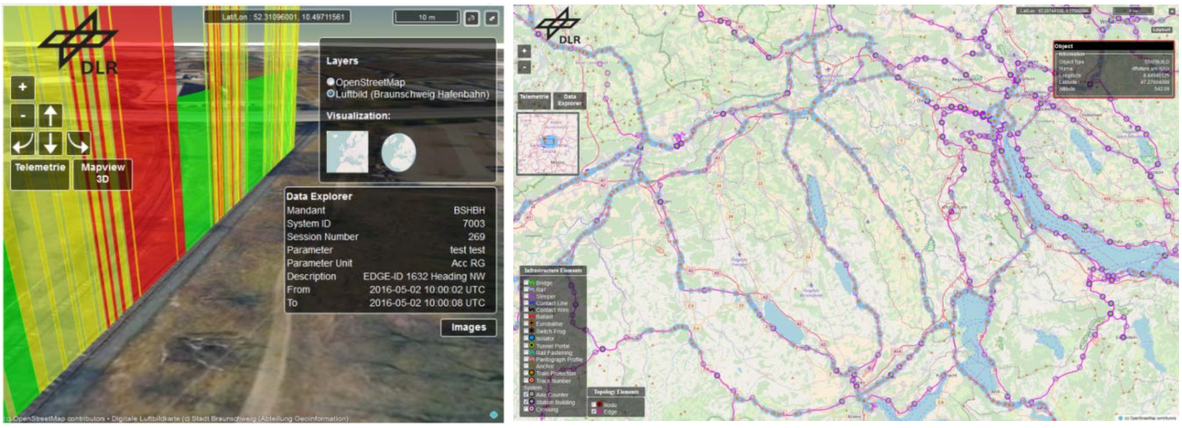

Figure 4: Geo-referenced axle-bearing acceleration data from a unit in the field (left) and visualization of a part of the railway network and infrastructure elements from Switzerland (right).

1.2.3. Success stories

The Bahnserver features a web GUI that can be accessed from outside the DLR, so that partners can visualize real-time data, such as specific vehicle locations, as also research results as shown in Figure 5. Another important feature is that the entire data is saved by project, physically separated without any risk that data from one project can be accessed from another project. The server is an important tool used in different projects in DLR-TS. Currently the Bahnserver is used by the Hafenbahnbetriebsgesellschaft in Braunschweig for shunting management and in cooperation with DLR-TS for monitoring of rail network conditions. The Swiss Federal Railways are using the Bahnserver to align different measurements of test drives on their railway network.

1.3. Digital Atlas

The automotive domain shows increasing demand of simulation for development and test of driver assistance and automation systems. Therefore precise real-world data is needed in various complex data formats, Richter et al. (2015). DLR-TS developed the *Digital Atlas* as a geodata server to host temporal and spatially varying data and provide it in standardized formats and standardized (web) services to different stakeholders. The data itself is pre-processed by complex and automated toolchains, Richter et al. (2016).

1.3.1. Purpose and concept

The Digital Atlas has been developed since 2012 as part of the project *Virtual World*. It started as a database to represent road networks and road infrastructure on lane level detail in the OpenDRIVE[11] data format. During project runtime the hosted data increased by, e.g. terrain data and road topography information form public authorities (cadastral data) as well as precisely survey data. These datasets are subsequently fused into an overall 3D environment for driving simulators, which consists of a detailed road network combined with a city model, vegetation, road furniture and land use in the end, Richter et al. (2016).
The same road networks are further used to derive maps for automated driving, Belz et al. (2017). On the one hand as highly precise map that is featuring lanes and their logical linkage including road marks and signals such as traffic signs and traffic lights. On the other hand topographic information can be derived to generate TOPO or MAP messages for car-2-car communication applications.

1.3.2. Used architecture and technology

Geodata aggregated in the Digital Atlas is served through different web-technologies to be consumed by client applications. To ensure uniform and standardized interfaces the focus lies on OpenGIS Web Services (OWS) as standardized by OGC. OWS are in circulation for a long time, are well-proven, well-tested and thus offer easy and robust access to heterogeneous data stores. The used software is mainly open source to benefit from an active and large community, easy extensibility as well as from mature documentation. This allows fast reaction

11 http://opendrive.org

to upcoming demands in research projects. Figure 6 depicts the used technologies, which are outlined in this section.

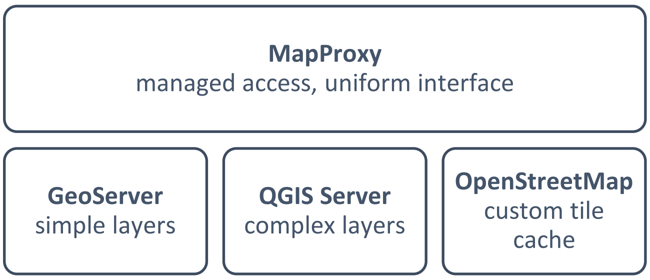

Figure 5: Map service hierarchy for publishing of heterogeneous geodata stores.

On the one hand single and simple map layers are published through an instance of the well-established GeoServer[12] that offers the possibility to access a variety of data sources and database back-ends coupled with easy management, performance and scalability.

More complex map layers incorporating different data sources and layers with complex styling are published using QGIS Server on the other hand. QGIS Server offers comfortable prototyping of map documents via the powerful styling capability of QGIS[13]. Practically, this capability enables WYSIWYG[14]-like designing of web map service layers which keeps flexibility high and efforts low in dynamic project environments. Management and deployment of such layers is more complicated tough.

Many projects demand background context maps of OpenStreetMap (OSM) in custom styling, which cannot be accomplished straight away with GeoServer and QGIS. For this reason a toolchain is maintained to serve up-to-date OSM map tiles in the local backend at DLR-TS using well-established technologies of Mapnik and renderd/Tirex. Such tiles persist on a flat file system level but can also be accessed as OWS through MapProxy[15]. Custom styling using the same OSM raw data source for different designs allows adaption to various project requirements while serving freshest tile versions of all designs at any time.

To simplify access to the three web map providers described above, MapProxy as unifying instance is used. Not only does this reduce three possible service locations to just one general map service URL but it also features distinction between internal (DLR intranet) and external (WWW) map service accessibility. The latter is necessary because most of the served data still covers sources with underlying special licensing restrictions or yet unpublished research results.

1.3.3. Success stories

Currently, the Digital Atlas is used by DLR-TS to operate its Application Platform Intelligent Mobility (AIM, Knake-Langhorst et al. (2016)) where especially the reference track provides car-2-car communication technology for testing purpose in urban areas to project partners. Figure 7 shows a visualization of a management view using data hosted by the Digital Atlas on the left. On the right a 3D environment is shown that is foreseen to be used in driving simulator studies. It is the digital representation of the whole city of Braunschweig, including e.g. the reference track.

12 http://geoserver.org
13 http://qgis.org
14 what you see is what you get
15 https://mapproxy.org

Figure 6: Visualization of different geodata (e.g. TOPO messages of intersection parts and road topography) contained by the Digital Atlas (left) and a generated 3D environment from the same intersection using various geodata hosted by the Digital Atlas (right).

2. Emerging interoperability and multi-modal traffic applications

To manage the growing amount of traffic complex transportation systems are developed to handle the individual use cases. The previous chapter depicted three representative data platforms. It is obvious that some of the requirements of these data platforms are very similar: Collecting of vehicle data (may differ in complexity and frequency) and map-matching to traffic networks consisting of nodes and edges. Sometimes these traffic networks are more detailed and contain specific tracks and lanes. This information is derived from different data sources or different versions of the same data source. Collected data has to be automatically processed (e.g. for map-matching issues, mode detection, location accuracy improvement, etc.) and the results of the processing as well as the underlying data has to be visualized and provided to different devices and users using standardized (web) services and an user management system. Thus, it is a first good cause to think about synergies.

To manage rising traffic demand also new technology is introduced to gather additional data about traffic and make traffic cooperative. Cooperation is necessary because traffic meets in very limited space. Not every traffic participant is able to get all necessary information to operate efficiently and safely (e.g. reduction of speed due to limited visibility). Additionally, cooperation with communication can provide more insight into traffic for traffic operators, too. It seems obvious that such features should be represented in the used platforms as well. But there will be more stakeholders influencing traffic in the future: Besides of “classic” general traffic management also focused “location-dependent” traffic management, e.g. of intersections, will become important. Fleet operators do their logistics and influence other traffic participants, especially if they use an increasing amount of assisted and automated driving, which shows a growing demand of information. There are road and rail network operators with the need of monitoring and maintaining of infrastructure. Further, there is the need of an integrated traffic area and city planning to facilitate the next mega trend of Smart Cities, which is currently not really considered by local authorities. Another need is to address the rising complexity of requirements and boundaries of automated and cooperative (therefore connected) traffic of the future. Additionally, there is a change in behavior of traffic users in terms of using traffic as a service. Travelling is getting multi-modal and is managed by the users with the help of nomadic devices. Therefore the demand of data is changing but also new information (e.g. as observed data) is available, too. All these topics should be addressed in the data platforms as well, to work on the same data and check their impacts.

Also DLR-TS is facing these challenges as it is working on solutions for different kinds of research questions to support growing traffic and to straighten the way for future applications. It was therefore decided to make the first step and develop a roadmap to fuse the previously introduced platforms, use synergies in operating them and pave the road for upcoming research questions as well as to support the conduct of test sites and field operational tests in future.

3. Next Generation Traffic Data Platform

Essential part of the DLR-TS roadmap is to fuse functionality of *Bahnserver* and *Digital Atlas* into the *TDP* and adapt TDP components. Additionally, this opens the possibility of refactoring of some historically evolved modules and the introduction of technologies especially with regarding big data capabilities. Nevertheless, the migration has to be conducted during regular operation with 24/7 characteristics.

The TDP will serve as the central core due to its complexity and long-term use. Different components will be adapted and some enhanced. The visualization will be decoupled and supported by standardized interfaces and web services providing data as individual features or as aggregation (e.g. as rendered map tiles).

3.1. Adapting TDP Components

First step of evolving the TDP is to migrate Bahnserver's infrastructure and topology layer to TDP's infra and basic map table. Therefore some adaption had to be made especially to align data types according to TDP concepts and the possibility to represent 3D data in the TDP. An interesting part is additional information about the possible usage of connections because railroad switches are less flexible to be used than road intersections (nevertheless, the latter can have restrictions, too).

The next step is to represent lane- and track-level details of traffic networks as well. Especially the Digital Atlas makes use of this kind of network representation and the TDP will get the possibility to conduct a lane-detailed data map-matching. Specialized data (in terms of specific data formats) location referencing will be applied as well. Additionally logically links will be established to associate information (e.g. quality description) of different domains not only by their locations.

The visualization is currently done by different frameworks using different technologies. This functionality will be decoupled while composing a new abstraction layer. Specialized visualizations will be still developed but will use the standardized interfaces of the TDP and adopted from the Digital Atlas.

3.2. Enhancing TDP Components

Currently the TDP has a straightforward user and user data management. The Bahnserver's requirements are more specific. Different railway companies should access data discretely without cross-reference to data of other companies and field units sending sensor data have to be identified individually. Actual data processed by the TDP is floating object data and observed data that is in general anonymized. Current use cases regarding multi-modal transport and tracking of nomadic devices from individual users are addressing similar requirements of the Bahnserver. Therefore the more complex user management of the Bahnserver will be adopted and integrated in the TDP in a way that it can be used as an overall identity and user management.

A second important topic is the utilization of big data capabilities. Until now TDP, Bahnserver and Digital Atlas are each handling "just" terabytes of floating object and observed data, sensor data and underlying geodata such as aerial images. This is done with "standard technologies" such as relational (spatial) databases and management and processing components without specialized storage and computing capabilities. But it is foreseen to deal with way more incoming data than processed until now. Especially the already mentioned pre-processing is important to be set up online. Users should be able to get results as fast as possible for validation and further processing. As first step a test system was set up using Apache Hadoop[16] and Apache Flink[17] to gain first experience. The processing of real-time messages from units in the field will be the first prototype to make use of these technologies.

4. Outlook

The work of evolving the Traffic Data Platform is done in parallel to the research conducted by DLR-TS. Therefore the implementation, migration of data and testing of the modules will take time. Nevertheless, this opens possibilities to adapt requirements form new use cases and research questions very quickly and incorporate new technologies. In the current roadmap it is envisaged to finish the migration of Bahnserver's railway representation in the middle of 2018 whereas the migration (or referencing) of Digital Atlas content will

16 http://hadoop.apache.org
17 https://flink.apache.org/

be addressed afterwards. Also the implementation of the new user and identity management system will start at the same time. The new Traffic Data Platform according to the roadmap will be fully finished at the end of 2019.

DLR-TS is already providing all three platforms in different research and development projects in order that project partners can make use of this existing infrastructure and functionality. Additionally, parts of platform implementations and concepts are used to set up project specific instances e.g. for test site activities and traffic management projects. This ensures that third party stakeholders can benefit from the evolution of the Traffic Data Platform, too.

5. Conclusion

Nobody is questioning the growing amount of traffic. Therefore new solutions for tackling with issue of decreasing space and raising complexity of traffic management and infrastructure maintenance have to be found. One important part is the utilization of collected and available data describing the current status of infrastructure and traffic participants. Special-purpose databases have been developed to support different use cases. But traffic is becoming connected and has to be understood as an integrated undertaking of different stakeholders with different needs in the very same environment. Therefore it is necessary to bring these stakeholders together and thus an integrated data platform about traffic is necessary. The Institute of Transportation Systems of the German Aerospace Center is operating different platforms for different use cases but with similar requirements. To enable future applications and use cases a concept of fusing these platform into one overall Traffic Data Platform was developed. First implementation steps are already made including making use of cutting-edge technology with respect to big data processing. First analysis and implementation results are promising, thus the chosen way can be considered as feasible. It will enable DLR-TS and its research partners to approach future traffic issues in an integrated way. In a long-term perspective there will be no way around bringing different special and spatial data platforms together. The new-generation Traffic Data Platform can serve as a prototype.

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