Digital Railway: Trends and Innovative Approaches

Florin Codrut Nemtanu and Marin Marinov

Abstract The amazing development speed of innovative technologies especially in the field of ICT is the pavement for new applications in railway transport, and the benefits of these modern technologies are greater than the traditional technologies. These benefits are not measured at the application level but also at the integration of different systems and transport modes based on the exchange of data. The innovative approach is to link the railway vehicles to the infrastructure and to find the way to integrate infrastructures and vehicles from different transport modes. Digital railway is a new concept and new paradigm which is the way to change the architecture of the railway systems and to push a novel approach in designing and developing new railway systems.

Keywords Digital railway · Digitalisation · Digital architecture

1 Introduction

Intelligent transport systems are applications of electronics, IT, computer science and other innovative sciences in the field of transport systems in terms of increasing the efficiency of the transport system and to decrease the negative aspects of the transport processes (especially, pollution and accidents). The intelligent transport systems concept covers all transport modes, and sometimes the concept has a different name for a specific transport mode or for a specific application (in railway, European Railway Traffic Management System could be a good example of ITS applied in railway transport system and other innovative technologies (Nemtanu and Schlingensiepen 2018)).

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The increasing of the efficiency is not only for transport businesses but also for all actors involved in transport activities (passengers, logistics companies, etc.). This efficiency could be analysed from the perspective of different modes, integration or multimodality. For multimodal system, it is very important to collect real-time data, to process in real time all this data and to take decision at the level of multimodal system. For this reason, ITS is more than a simple technology applied somewhere in the economy, and it is the support system for multimodal transport businesses and new mobility focused approaches (mobility as a service—MaaS could be considered one of this innovative approach in terms of application of these technologies in transport systems and mobility) (Nemtanu et al. 2016; Schlingensiepen et al. 2015).

Digital railway is, in fact, the application of ITS in railway system having as main objectives the increasing of the efficiency and the decreasing of negative effects of railway transport. This innovative approach in railway transport will facilitate the integration of different subsystems of railway environment and the integration of the railway system with other transport modes in terms of preparing the base for mobility services. The European Commission started the development of ITS for rail domain, and they are defining two main categories of digital railway systems or ITS for rail: European Railway Traffic Management System (ERTMS—which is composed by ETCS—European Train Control System—and GSM-R—GSM for railway) and telematics application for passengers and freight (European Commission 2017; EC 2016; Frumin 2010).

The digital world as well as the digital technologies will affect the railway systems as any other system of human society. The main challenge is to develop a digital railway support system which can relate to any other digital system to contribute for the development of the digital world.

Why the digital railway is important? The transport service is a business and, in the same time, a valuable aspect of the human society's activity, and for both perspectives, the railway transport must be efficient, safe and environmental friendly. The digital technologies applied in railway transport system could contribute to all these three important issues (efficiency, safety and environmental impact). In the decision-making process of railway transport, as in any other decision process in the economy, the collection of real-time data about the subject of the decision as well as the quality and the speed of processing this data to ensure the fundaments for good decisions are done based on digital technologies or intelligent transport systems for railway transport.

The simplified model of digital support system (DSS) for any kind of decision-making process in a transport system is presented in the Fig. 1.

The digital support system is in contact with the transport processes in terms of acquired data (the quality of this data is also important, and the quality of data could be defined based on the following parameters: accuracy, coverage, significance, time-related issues, etc.), sending this data to process it and using the result of data processing in the decision-making process. The decision, taken based on this data, will be applied through different actions on the transport process. The primary data are collected to be processed as part of decision-making process. Based on

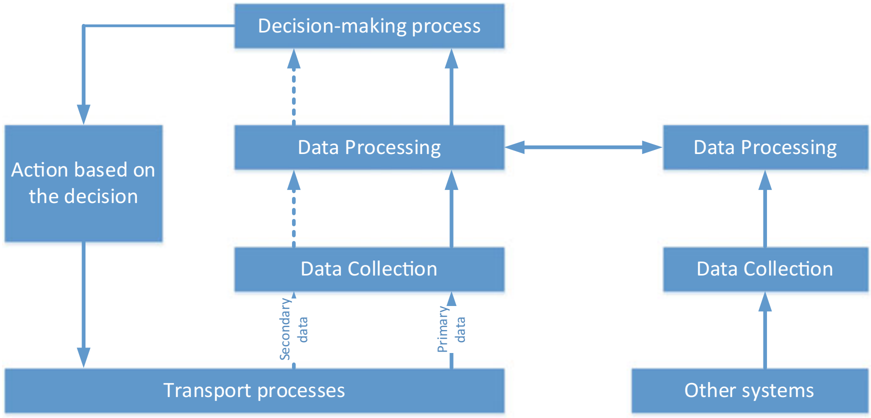


Fig. 1 Simplified model of digital support system

secondary data, the feedback of the application of the action is sent to decision-making process in terms of providing a control and to adjust the action.

At the layer of data processing, the digital support system could be interconnected with other systems to exchange data. This is the case of integration for multimodal services (one example could be the multimodal traveller information system).

This model could be used as a reference model for digital railway support systems. The digital railway is defined by using the digital support systems together with other main components (digital procedure, digital administration, digital skills, etc.).

The digital railway can be defined as a new concept in organising and governing the railway transport system based on digital support system using digital skills of the employees in a digital business environment in terms of increasing the efficiency (the competitiveness should be considered as well) and decreasing the negative aspects of railway transport system.

2 The ITS Architecture for Digital Railway

The architecture of an intelligent transport system is a high-level vision of the system in which the function of system is described and the components of the system are defined as well as the relationships among all components. The ITS architecture has the main role to define a model of the system based on different viewpoints of that intelligent transport system (functional, physical, communication, organisational and security viewpoints). The main reference of ITS architecture application in transport systems is the European project FRAME (Frame Forum 2017), and the authors used this framework architecture for other applications and research projects and papers (Nemtanu and Dumitrescu 2006; Nemtanu 2010; Nemtanu et al. 2004).

The ITS architecture for digital railway is focused on the digital support system for railway transport, and the main component is the functional viewpoint of it.

The railway transport system has three main entities in its structure: the railway infrastructure, the railway vehicles and drivers/operators. These three entities must cooperate with each other in terms of providing railway transport services and ensure the requested level of safety. The railway infrastructure is not only the tracks and switches but also constructions (bridges, tunnels, etc.) and installations (interlocking, ETCS, etc.).

Based on the model presented in Fig. 1 and considering the three main entities of the railway transport system, the following high-level functional viewpoint could be defined:

The digital support system (DSS) has three main components: data collection, data processing and action/execution (execution of the decision) Fig. 2. All these three components have an interaction with three main parts of the railway transport system: railway infrastructure, railway vehicles and drivers/operators (as human intervention in the system). The main trend now is to move digital system from human decision to machine decision. At the level of data processing, the interconnection with other systems is possible and the system could exchange data with external systems in terms of providing specific services.

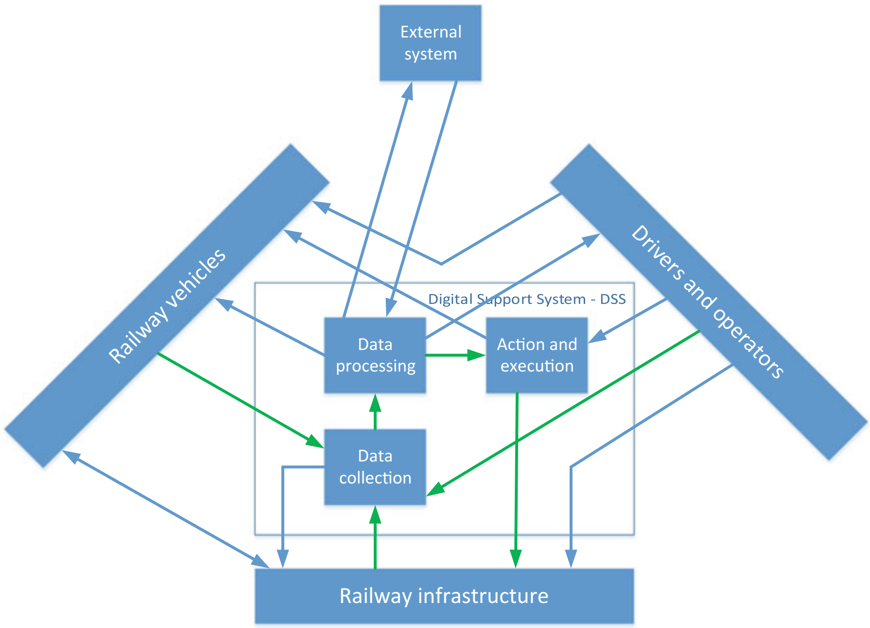
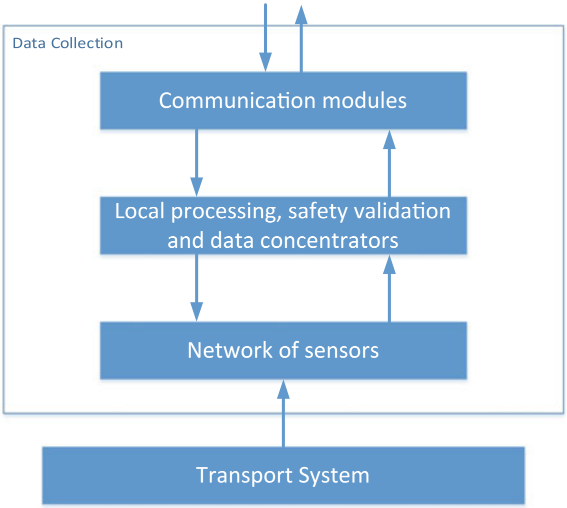


Fig. 2 High-level functional viewpoint

Fig. 3 Data collection component of digital support system



The first main component of DSS is the data collection subsystem (the structure is defined in Fig. 3) which has the role to collect data based on various sensors and data sources and to send raw or simple processed data to the next component or back to the infrastructure. The first layer (and very important) of this component is the network of sensors (in this case, the sensor could be defined as an entity which is able to convert a physical quantity or a state of a transport process or phenomenon into an electrical signal which is the carrier of the data), and this network has the direct contact with the transport processes or transport environment.

The data collected by sensors are sent to the local processing unit, and the data are validated by this component to fulfil the safety request. This component has also the role of a data concentrator (data which are coming from different sensors are packed together and sent to the next component). The safety validation is important, and this function is implemented in software or hardware, and the principal task is to establish if the data are valid or not for safety-related processes (the accuracy, the coverage, the significance, etc.).

The data which were locally processed, validated and concentrated are ready to be sent to the next component, and a communication function is in charge with this task sending the data from this component to another one. The communication could be wired or wireless, and a plenty of technologies are available to implement this function. In fact, this component will send the digital image of the process or phenomenon where the data were collected and the main challenge here is to find the optimum physical quantities which are able to describe the process and to find the best sensing solution to measure these quantities. Some examples of these physical quantities could be: the presence of the train on a specific part of the track, the speed of train, the state of the railway switches and so on.

The second component of a DSS is the data processing functional unit (presented in Fig. 4) which is in charge with final and complex processing of data received

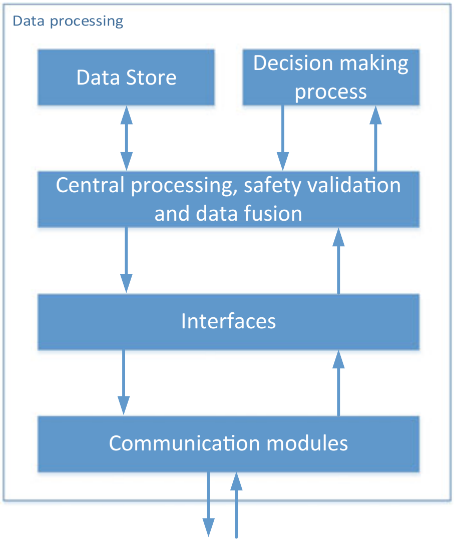


Fig. 4 Data processing component of digital support system

from the data collection functional unit. In order to receive the data from data collection functional unit, this component needs a communication functional module which is able to establish a communication link between these two components. An important issue is the reliability of this communication link in terms of providing a high level of safety. Without this communication link, the data will not be transmitted and the data processing functional unit is not able to process any data and the action/execution functional unit could not apply the result of the decision (a command for a railway object). The radio railway solutions are facing opportunities and challenges (Moreno et al. 2015), but based on the GSM-R or next generation Long-Term Evolution-Railway (LTE-R—a 4G mobile communication standard for railway) the radio communication solution will be robust and reliable.

Another important part of the data processing functional unit is the interface, and this part has the role of adapting and converting data into a special format which is used in processing and decision-making process.

The role of this component of DSS is to take the data from different sources and to fuse all this data to be ready for processing into the decision-making process. The decision-making process will prepare the command message to be executed and sent to a railway object (this railway object could be a signal or part of the infrastructure switch machine). The data store will keep the data for all these processes which are not real-time processes. The command will be sent using the same communication functional module and will pass also the safety validation module.

The last component of the DSS is the action/execution one (presented in Fig. 5) which is in charge with the application of the decision and to command a railway object to be in a state or in another one. Every component of DSS needs a communication module in order to transmit and receive data from other components.

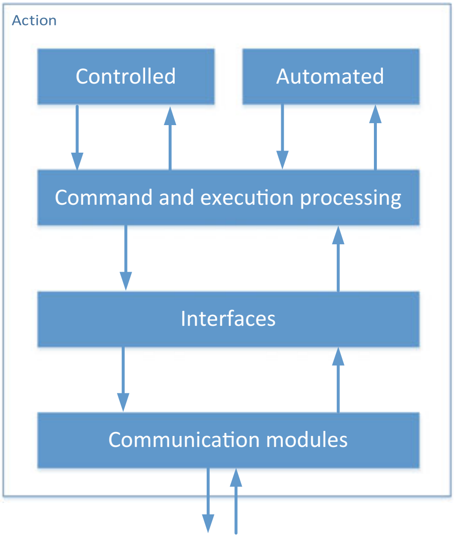


Fig. 5 Action component of digital support system

The decision is converted into commands, and these commands are sent to railway objects. This process could be with human intervention and control or automated (in the second case, the control is also requested but the machine will check the state of the railway object based on the control data received from this object).

3 Digital Trip

Based on the proposed DSS architecture, the concept of digital trip can be defined. A digital trip is a collection of digital data (structured and updated) which are describing all the characteristics and components of a real trip (train stations, bus stops, multimodal nodes, vehicles, routes, ETDs—estimated times of departure, ETAs—estimated times of arrival, travel times, rail conditions, etc.) and which is needed by the DSS to provide support for travelling using the railway transport system.

The digital trip as a collection of data or virtual representation of a trip is starting by the traveller, and the need of travel expressed by this is the main force to plan and generate a digital trip (the model of digital trip generation is presented in Fig. 6). The traveller has a correspondent in the digital world, and this correspondent is the digital profile of the user or virtual traveller (this digital profile is also a collection of data about the transport needs, behaviours and trip characteristics of a person, who is defined as traveller in this model). The trip plan is generated as a result of the negotiation between the trip requests expressed by the traveller and the resources provided by rail transport (or any other mode of transport) using the DSS.

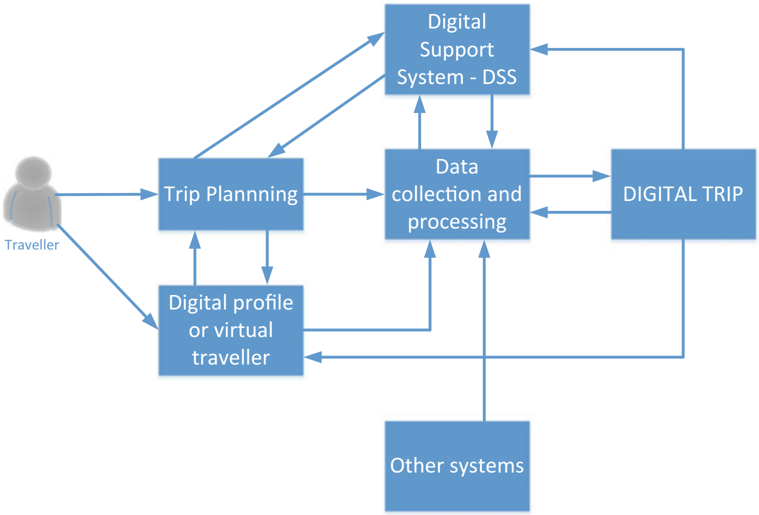


Fig. 6 Model for the generation of a digital trip

Data collection and processing functional unit will receive the trip plan and will update it (pre-trip and on-trip updating) and monitor the execution of the plan (on-trip monitoring). The digital trip is more than a trip plan; it is starting with a trip plan but will be fed with real-time information about the characteristics and components of the trip.

The DSS will provide all information about the components of the railway transport system which are parts of the planned trip and will add data to the digital trip. The model is also connected with other systems for a multimodal approach, and the multimodal digital trip is also available for implementation.

The main advantage of using the digital trip is to have a real-time virtual image of the trip in terms of transport resources and conditions. This digital trip is the main result of DSS as a collector and processor of data from railway transport system, and this digital trip could be used by MaaS platform to provide mobility services. The main challenge of MaaS is to be connected with DSSs from different transport modes and to integrate all digital trips into a multimodal digital trip.

4 Trends of Digital Railway and Innovative Approaches

The digital railway is more than a digital technical system; it is a new paradigm of using digital resources in railway transport processes. For this reason, a simple application of new digital technologies is not enough to fulfil the needs of digital railway. There are more digital things which are mandatory for this digital concept:

digital skills of people, digitalisation of organisational processes, digital technologies, digital environment (platforms, software, hardware, cloud space).

Internet of Things (IoT) is also a new approach and technology which will facilitate the development of digital railway (Buyya and Dastjerdi 2016; Nemtanu and Pinzaru 2016; Chaouchi 2013). The IoT will provide the technical solution for collection of data in real time, communication with different railway things or objects (in terms of using IoT, the railway objects will be defined as digital railway objects or digital railway things) and the control of these digital objects (the railway objects are digital objects because every object will have an electronic device which will be installed to collect data and to execute command in a digital format). The challenge will be to map the IoT network on railway transport systems and to implement this technology in a manner to support the railway safety.

The data collected by different sensors or devices of IoT have to be processed, and there is a huge need of software and hardware. One solution provided by actual technology is to use cloud computing for this part of the DSS. Data processing component of DSS could be implemented based on cloud computing technologies, and the result is the cloudification of DSS or, generic speaking, the cloudification of transport systems (Nemtanu et al. 2015).

In the actual system, or in the future, in the digital railway system, the volume of data collected will be increased and the databases with data from various processes of railway transport will be interconnected. Another important trend is to use data mining in transport-related databases or data stores (D'Agostino 2016; Han et al. 2012) in terms of finding the correlations among this data. The data mining is an elegant solution to solve some problems based on the existing data, without any investment in data collection and communication. This solution is an intensive solution based on data analysis, and it is not an extensive solution (the second option is focused on new hardware and software implementation in terms of collecting new data), and the main role is to produce new data and information based on existing data.

The continuous implementation of digital technologies in railway transport and transport systems, in general, is producing new data and a huge volume of data. This huge volume of data has to be collected and manipulated as well as processed in a new manner, and the new technologies called big data (D'Agostino 2016; Oort and Cats 2015) have to be applied. The big data is characterised by the 5Vs characteristics: volume (huge amount of data), velocity (the data has to be collected in real time or near real time in terms of collecting usable data), variety (there are different structures and types of data), veracity (this is about uncertainty of data) and value (the worth of using the data) (Attoh-Okine 2014). All these characteristics have to be taken into consideration by DSS in terms of providing support of manipulating the big data.

Railway transport services are part of multimodal transport services. Door-to-door services are not possible based on a single transport mode and there is an involvement of at least two transport modes and the conclusion is that the door-to-door transport services are based on multimodal services. Starting with this statement, the new concept and solution to provide multimodal transport services is mobility as a service (MaaS) and MaaS could be the platform which will lead the development of digital support systems for all transport modes. In the MaaS environment, the railway transport system could play the main role for medium- and long-distance transport and the DSS for railway transport or digital railway will create the kernel of MaaS platform or digital support system.

Digital resources could be shared among different transport modes and different DSSs, and the digital railway has to be part of digital transport in terms of maximising the effects of digitalisation of transport systems.

5 Conclusions and Next Steps

Digital railway is more than a digital support system, it is a paradigm and a concept and the organisational processes, personnel and the components of the railway system have to be re-shaped under this new concept (everything has to be digital and interconnected with the digital environment).

The technical progress and the innovative technologies will accelerate the development of digital railway, and the mimesis from other technical domain will pave the way for digital integration of all transport systems. The technology is ready for this digital revolution in the railway domain, and the human intervention has to be reconsidered in the case of this new paradigm because this intervention has two main dimensions: the implementation of the innovative technologies (in the framework of digital railway) and the role of human beings in the digital support systems (as main part of the digital railway).

The digital world and digital life request the extension of digitalisation in the field of transport system, and the digital railway and digital support systems for railway transport are the main tools to extend the digitalisation in the railway transport field. The digital trip is based on the digital profile of the traveller (in fact, this is a digital traveller), and it will cover the mobility part of the digital citizen (this is a generalisation of the digital traveller to all roles of a citizen).

The digital railway is under the risks of cyber-attacks (the main components of this are computers and electronic devices with embedded software), and the new concept has to be focused on the cyber-security, and this will be also a challenge as any other domain where the digital technology was applied.

The railway systems are characterised by two macro indicators: efficiency and safety. The digital railway must be focused on both indicators in terms of increasing the efficiency (allocation of railway resources, the cost of railway services, the multimodal integration, etc.) and the increasing of safety level (reducing the number of incidents and fatalities, reducing the hazard in railway operation and maintenance).

Innovative technologies (cloud computing, IoT, big data, data mining, etc.) generate new paradigms and approaches in all domains of the human society, and the application of these in railway transport systems will accelerate the integration of these systems in the society as well as the integration among all components and subsystems of railway transport system.

The digital architecture of the society could be mandatory in terms of unique vision for the society development under the influence of digital technologies. The architecture of digital railway is, in fact, a part of the digital architecture of the society. This approach is needed in terms of avoiding future problems of interoperability and lack of interconnections between different digital components of different digital support systems.

Multimodal transport systems will be easily deployed using digital railway and digital support systems, and the mobility as a service will be supported by them. Railway transport system is able to become the backbone system of MaaS based on digital railway and digital support systems.

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