Describing road intelligent transportation systems using building information modeling

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Intelligent transportation systems (ITS), facilitating efficient commutes and convenient mobility, are key elements of smart cities. In recent years, simulation platforms have been employed to study specific road ITS applications. Although several research efforts have been conducted to design road ITS simulation platforms, semantic descriptions serving as a basis for designing road ITS simulation platforms have not yet been fully addressed. In this paper, a semantic model for road intelligent transportation systems is proposed, providing a formal basis for road ITS simulation platforms. First, background information on road ITS is briefly explained, followed by the description of the proposed semantic model. Next, an extension of the Industry Foundation Classes (IFC) schema is discussed as basis for ITS simulation platforms using building information modeling. The paper concludes with a summary and an outlook on future formalization efforts.

**Keywords:** Intelligent transportation systems, semantic modeling, vehicular clouds, building information modeling, Industry Foundation Classes

1 Introduction

Coupling physical and computational subsystems in vehicles, vehicular cyber-physical systems (VCPS) comprise all physical, computing, and networking processes related to intelligent transportation systems. An intelligent transportation system (ITS) is a combined application of vehicular cyber-physical systems. Intelligent transportation systems represent vehicles as intelligent VCPS components with on-board sensing/actuating, computing, and communication capabilities. Constituting key elements of smart cities, intelligent transportation systems offer safer commutes and more efficient mobility in terms of time and cost, lessen adverse impacts on the environment, and increase convenience and quality of life. Intelligent transportation systems are applicable to all modes of transport, e.g. road, aviation, maritime, and railway transport.

Road intelligent transportation systems refer to land-based systems that use roads as travel routes. A road ITS comprises several elements with different types and capabilities, numerous data-sharing processes with intermittent and temporary connections, and various applications, all resulting in a complex and heterogeneous system. Therefore, to develop road intelligent transportation systems, it is vital to design simulation platforms that can monitor and evaluate road ITS performance. Simulation platforms integrate behavioral models of different use cases to investigate road ITS capabilities, design flaws and potential improvements, and future mobility demands.

In the last decade, researchers have employed simulation platforms to study different road ITS applications. Boschian et al. (2011) have proposed a reference framework of intermod-
al transportation systems with an information management layer between different modes of transport. The reference framework integrates a simulation module and forms a platform for operational processes. A model-driven engineering framework that can develop road ITS simulations has been proposed by Fernández-Isabel and Fuentes-Fernández (2015). The framework comprise ITS data models for traffic simulations and sensor network components and guidelines on how to use the data models for different simulations, such as traffic lights control. Datta et al. (2016) have presented a road ITS semantic-based framework containing building blocks and software elements that describe different ITS-related operational phases.

Several studies have also been conducted on road ITS simulation platforms with focus on simulating traffic-related applications (Ghariani et al., 2014). However, formal descriptions of road intelligent transportation systems that provide a basis for simulation platform design have received little attention (Mirboland & Smarsly, 2019). To define a formal basis for simulation platforms, every aspect pertinent to road intelligent transportation systems must be analyzed and translated into a standardized formulation. Open standardized data formats, such as the Industry Foundation Classes (IFC), may be employed to formally define infrastructure information. However, the current IFC schema has few entities that may be used for defining road ITS components not related to infrastructure, such as vehicles or communication networks.

In this paper, a semantic model to formally describe road intelligent transportation systems is presented. First, background information relevant to road ITS components and requirements is presented. Next, upon elucidating the proposed semantic model, an IFC extension based on mapping the semantic model in the current IFC schema is discussed. The paper concludes with a summary and potential further standardization and formalization efforts.

2 Background

In this section, focusing on road ITS-underlying physical and computational components, background information needed for semantic modeling of road ITS is briefly discussed. Road ITS architecture, applications, infrastructure, and communication networks are illuminated in the following subsections.

2.1 VANET and vehicular clouds

A vehicular ad-hoc network (VANET) is a network paradigm based on vehicle-to-anything (V2X) and infrastructure-to-infrastructure (I2I) communications. Self-forming VANETs with intermittent and autonomous connections result in diverse ITS topologies that change frequently (Dixit et al., 2016). Therefore, different data routing protocols and security standards are employed to guarantee data transmissions and communications integrity between network nodes. Merging the VANET paradigm with the Internet of Vehicles initiated the idea of vehicular clouds, where underutilized resources of vehicles are shared through V2X communications to run decentralize computing processes and to provide location-based services (Eltoweissy et al., 2010). Edge computing (EC), vehicular cloud computing (VCC), and information-centric networking (ICN) are main characteristics of vehicular clouds that grant robust data sharing and cloud formation. Figure 1 depicts an example of vehicular cloud formations.
With recent advances in the automotive industry, vehicles are enabled to absorb information from the environment and to perform decentralized computational processing, i.e. edge computing, handling time-sensitive operations in an efficient manner (Atchison, 2018; Gerla et al., 2014). VCC is the mechanism that combines and accesses underutilized onboard units in the vicinity to run location-based applications. In other words, VCC decreases road ITS deployment costs by distributing the computing load between network nodes and avoiding the use of expensive centralized computing infrastructure (Whaiduzzaman et al., 2014). ICN is a data-networking paradigm that puts emphasis on the content of data packets by decoupling the packets from publisher node IP addresses. Several ICN architectures and messaging protocols exist that specify standardized, machine-readable naming and beacon exchange between network nodes (Ahlgren et al., 2012; Wan et al., 2014).

2.2 Road ITS applications

Road ITS applications are designed to grant safety for ITS users and goods, to lessen adverse environmental impacts, and to advance convenient mobility scenarios (Mirboland & Smarsly, 2018). The European Telecommunications Standards Institute standard (ETSI EN 302 665) classifies road ITS applications into “traffic efficiency”, “road safety”, and “other applications”. However, with respect to topics and use cases, road ITS applications can be grouped into “traffic and fleet logistics management”, “telematics”, “maintenance management”, and “infotainment”. Some examples of different ITS applications with respect to topics and categories are listed in Table 1.

Table 1: Road ITS applications

<table>
<thead>
<tr>
<th>Topics</th>
<th>Categories (ETSI EN 302 665)</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic and fleet logistics management</td>
<td>Traffic efficiency</td>
<td>Optimized traffic signals, road traffic information, hazard warnings, packet tracking systems, navigation</td>
</tr>
<tr>
<td>Telematics</td>
<td>Traffic efficiency, road safety</td>
<td>Driver-assistant systems, intra-vehicle monitoring, autonomous driving, navigation</td>
</tr>
<tr>
<td>Maintenance management</td>
<td>Road safety, other applications</td>
<td>Damage detection or infrastructure, winter road services, disaster management</td>
</tr>
<tr>
<td>Infotainment</td>
<td>Other applications</td>
<td>Internet-based applications, gaming and news platforms, multimedia libraries</td>
</tr>
</tbody>
</table>
2.3 Intelligent road infrastructure

Functional elements with on-board sensing/actuating, computing, and communication resources that together build the ITS architecture are termed hereinafter “ITS stations”. In general, ITS stations are categorized into fixed or mobile stations according to ETSI EN 302 665. Fixed ITS stations are further grouped in central ITS stations, i.e. control centers or base stations for authorities or institutional decision-making operations, and roadside ITS stations, e.g. traffic shields, cameras, and poles. Mobile ITS stations constitute personal ITS stations, e.g. tablets and smart phones, and vehicles ITS stations, including all vehicle types, e.g. trucks, cars, and bikes.

It is assumed that all ITS stations are composed of four main on-board units: Sensing unit, computing unit, communication unit, and power unit. The sensing unit may contain sensing technologies pertinent to traffic detection systems or sensors to detect environmental changes. The computing unit represents main processing and storage devices, while radio transceivers, beacons, and Wi-Fi routers form the communication unit. The power unit includes different power supply means that may co-exist to deliver energy to ITS stations. Moreover, ITS stations may comprise control devices and actuators to manage traffic signals and flow on specific routes and structures.

2.4 Communication networks

Vehicles with on-board wireless communication capabilities can cooperatively connect to other network nodes via V2X communications, i.e. cooperative-ITS (C-ITS) communications (Gerla, 2012). According to the ETSI EN 302 636-3 standard, ITS communication (ITSC) networks comprise external networks (i.e. connections between ITS stations) and internal networks (i.e. connections within each ITS station). The architectures of both ITS external and internal networks are depicted in Figure 2.

![Figure 2: Road ITSC internal (orange) and external (blue and grey) networks](image)

The ITS external network architecture comprises an ITS domain and a generic domain. The ITS ad-hoc network presents wireless C-ITS communications between mobile and roadside ITS stations, while the ITS access network represents connections between fixed ITS stations. In generic domain, private and public access networks grant secure data services to authorized groups of users and public users, respectively.
The ITS internal network architecture represents functional networking components of ITS stations and the proprietary network. The latter presents the connection between all physical equipment, such as sensors, transceivers, mechanical and/or electrical actuators, and all on-board devices. The ETSI EN 302 665 standard has established a six-layer reference architecture for ITS station internal networks. Applications, facilities, networking and transport, access, management, and security layers compose the reference architecture and characterize different functionalities in ITS communications. Each layer includes a number of standards and protocols that are listed in the ETSI TR 101 607 standard. For example, ITS-G5 is one of the access layer standards that specifies V2X communications in the 5.9 GHz frequency band.

3 Road ITS semantic model

Upon analyzing and classifying background information on road intelligent transportation systems, Figure 3 shows an extract of the proposed semantic model devised as a formal description of road ITS simulation platforms. For the sake of clarity, the class diagram shown in Figure 3 is minimized to the representation of classes and relationships between classes.

![Semantic Model Diagram](image-url)
The semantic model is composed of three main parts: **DigitalRoad**, **ITSSStation**, and **ITSCommunication** classes. The **DigitalRoad** class comprises **RoadStructure** and **ITSSStation** classes. The **RoadStructure** class represents the physical road structure, such as pavement and resting areas. The abstract class **ITSSStation** presents the core elements of intelligent road infrastructure and is categorized into the abstract subclasses **Fixed** and **Mobile**. Fixed ITS stations are of two types, **Central** and **Roadside**, whereas mobile ITS stations are categorized into **Vehicle** and **Personal** classes. ITS station on-board units are shown by **SensingUnit**, **ComputingUnit**, **CommunicationUnit**, and **PowerUnit** classes are shown in Figure 3 exemplarily only for the **Roadside** class. ITS stations may be equipped with one or more **Actuator** devices.

Communication networks in the ITS domain are represented by the abstract class **ITSCommunication**, which is connected to **ITSSStation** with a composition relationship, as ITS communications are dependent on ITS station infrastructure and resources. The **InternalNetwork** subclass implements the **ReferenceArchitecture** interface. Moreover, physical equipment attached to ITS stations are recognized by the **ProprietaryNetwork** class. The **ExternalNetwork** class, representing ITS ad-hoc and access networks, is a superclass to **V2X** and **I2I** classes. **I2I** communication can be either wired or wireless, whereas **V2X** communications are solely wireless. The abstract subclasses **LongRange** and **ShortRange** represent different wireless communication means and respective standards. Examples for each subclass are depicted by the **Cellular** and the **ITS-G5** classes.

### 4 Road ITS-related extension of the IFC schema

The IFC schema serves as an open, non-proprietary standard for defining and exchanging building information models in a comprehensive and standardized manner (ISO 16739, 2013). The entities defined in the IFC schema describe building-related information and components (Tauscher & Smarsly, 2016). The physical subsystem in a road ITS comprises the underlying physical infrastructure and intelligent road infrastructure. The former may be described using existing IFC entities, such as **IfcSectionProperties** and **IfcAlignment** that define geometry details of cross sections and positioning (BuildingSMART, 2017). In addition, further specifications relevant to road infrastructure, e.g. **IfcRoad**, **IfcBridge**, and **IfcTunnel** (Vilgertshofer et al., 2016), have been proposed to be included in future IFC schema versions.

A few entities exist in the current IFC schema that may be employed to formally describe intelligent road infrastructure. For example, **IfcSensor** can be used to partially define the sensing unit on ITS stations, and **IfcCommunicationsApplicate** can be obtained to represent on-board communication devices (Fitz et al., 2019; Theiler & Smarsly, 2019). However, due to a lack of entities to describe ITS-related infrastructure and components, the current IFC schema cannot be employed for fully mapping the proposed semantic model. Researchers have used object-oriented modeling tools to introduce non-standard IFC objects, which represent components of cyber-physical systems and relationships between the components (Smarsly et al., 2017). In future work, an IFC extension is to be developed to consider all aspects covered by the semantic model of road intelligent transportation systems.
5 Summary and conclusion

A semantic model of road intelligent transportation systems has been developed as a formal basis for road ITS simulation platforms. Background information relevant to road intelligent transportation systems has been analyzed and extracted for semantic modeling. Relationships and associations between elements of intelligent road infrastructure and vehicular cloud infrastructure have been depicted on a meta level. The semantic model, being technology-independent, is applicable for describing various road ITS applications. Current IFC schema capabilities for formally describing road ITS have been showcased and a potential IFC extension has been discussed. In future work, extending the IFC schema is envisaged to facilitate standardized descriptions of road intelligent transportation systems in terms of building information models.

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ISO 16739 (2013). Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries.


