Transportation Research Part C 81 (2017) 188–208

Contents lists available at ScienceDirect

Transportation Research Part C

journal homepage: www.elsevier.com/locate/trc

An ontology-based framework to support performance monitoring in public transport systems

Filippo Benvenuti, Claudia Diamantini, Domenico Potena, Emanuele Storti *

Dipartimento di Ingegneria dell'Informazione, Università Politecnica delle Marche, via Brecce Bianche, 60131 Ancona, Italy

ARTICLE INFO

Article history:
Received 17 January 2017
Received in revised form 27 May 2017
Accepted 2 June 2017

Keywords:
Public transport system
Transmodel
Monitoring system
Key Performance Indicators
Ontology
Logic reasoning

ABSTRACT

Managers of public transport systems have been facing for years the strategic challenge of maintaining high quality of transport services to improve the mobility of citizens, while reducing costs and ensuring safety and low environmental impact. A well-established way to evaluate the performance achieved by the system or by specific activities is to monitor Key Performance Indicators (KPI). However, existing management systems, which refer to flexible yet large and complex data models, provide a limited support to define and select relevant KPIs for the objectives at hand, and even the identification of whether and how the data model is capable to achieve a certain informative need is a critical and time-consuming task. This work is aimed to propose a framework to ease the development of a monitoring system in the public transport domain. The approach is based on the ontological representation of all the knowledge regarding indicators and their formulas, business objectives, dimension analysis and their relation with the Transmodel, the European reference data model for public transport information systems. On its top, a reasoning framework provides logic functionalities to interactively support designers in a set of common design tasks: the choice of the most suitable indicators for the performance monitoring needs at hand, the definition of new indicators and the identification of the minimal set of Transmodel modules needed to calculate them. A case study is included to discuss these applications, while an evaluation shows the feasibility of the approach.

1. Introduction

In recent years, the significance of providing a Public Transport System (PTS) that minimizes waste of economic resources and, on the contrary, maximizes user satisfaction and environmental sustainability, is taking a key role in the technological improvement of our society. As described in United Nations, Department of Economic and Social Affairs (2015), in 2014 the 54% of the world population was living in urban areas and it is expected that by 2050 this value will increase of about 12%, settling around 66%. By considering these percentages, it is evident that managers of PTSs are encountering growing difficulties in maintaining high quality of services in order to improve the mobility of citizens, while reducing costs and ensuring safety and low environmental impact of performed journeys. To this end, monitoring systems are built to evaluate specific performances related to processes, in order to determine if business objectives (e.g., minimization of delays) are met or not.

* Corresponding author.
E-mail addresses: f.benvenuti@pm.univpm.it (F. Benvenuti), c.diamantini@univpm.it (C. Diamantini), d.potena@univpm.it (D. Potena), e.storti@univpm.it (E. Storti).

http://dx.doi.org/10.1016/j.trc.2017.06.001
0968-090X/

In these contexts, the reference to Key Performance Indicators (KPI) is a well-established way to evaluate the performances achieved by specific activities and tasks, by giving an immediate and synthetic view.

Most of available management systems for PTSs are designed by referring to standard models, e.g. the National Transportation Communication for ITS Protocol (NTCIP)[1] which standardizes the communication between computer systems, or the Transmodel Data Model (TDM)[2] that defines a standard data model for a generic PTS. As for these last, typically it is not required for individual systems or specifications to implement the model as a whole. However, they are large and complex models. To give an example, the Transmodel defines 371 classes and arranges them in 14 core modules and 61 submodules, including a huge variety of measurements about various aspects associated with transport services. Hence, selecting the most relevant KPIs for a certain objective, or the procedures that must be followed to compute a certain indicator are all non-trivial tasks even with a small number of objectives, as well as understanding the modules of the management system for PTS that are to be used or where the information needed to calculate a KPI is stored.

Existing management solutions for PTSs are capable to provide only little support on how to setup and configure a monitoring system. Indeed, at the best of our knowledge, several studies focused only on a part of the development of a PTS, for instance analyzing in detail only a case studies of interest (e.g., sustainability (U.S. Environmental Protection Agency, 2011)), or a specific scenario (e.g., urban transport (Henning et al., 2011)).

From these motivations, the goal of this work is to present a framework aimed to ease the design of a monitoring system in the public transport domain.

The approach is built around the definition of a *knowledge base* including a conceptualization of the public transportation domain, on the top of which a set of *logic-based functionalities* are developed. More in detail, the main contributions of this work are the following:

- an integrated knowledge base, that includes a novel, minimal ontological representation of the Transmodel data model and KPIOnto, an ontology representing indicators, their properties and their mathematical formulas;
- a reasoning framework including Prolog-based functionalities aimed to support basic design tasks for a monitoring system;
- specific functionalities relying on the reasoning framework, enabling the following higher-level tasks:
  - support for suggesting the KPIs to monitor in order to achieve certain objectives;
  - identification of the procedure to calculate a given KPI;
  - support to determine which specific modules of the PTS management system are to be used in order to extract data needed to calculate the KPI.

As for the specific technologies used in this work, we refer to computational ontologies for knowledge representation, given that they allow a formal way to describe concepts and relations of a domain, and in particular to OWL (Web Ontology Language)[3] as the de facto standard for ontology authoring. The approach we discuss in this work is however neutral with respect to the specific technologies and software architectures adopted for the PTS management system, as it moves from a conceptual perspective. As such, the reference to the Transmodel data model is the only requirement for the exploitation of the framework.

This paper extends an earlier paper (Benvenuti et al., 2016) in manifold ways: (1) the model has been extensively revisited and it includes an integrated knowledge base and its validation. Together with indicators aimed to formally describe all the relevant knowledge related to a public transport service, this last includes also (2) a minimal ontological representation of the Transmodel data model, which is novel to the best of our knowledge. Then (3) we introduce a reasoning framework and a more detailed set of functionalities together with a validation and a case study and (4) we provide a more comprehensive analysis of related work.

The rest of the paper is organized as follows. Next section introduces a case study that will be used through the paper. Section 3 discusses the proposed knowledge model: in detail, Section 3.1 is devoted to introduce the Transmodel. In Section 3.2 we discuss KPIOnto, an ontology aimed to represent performance indicators together with their mathematical formulas, and its relations with the model. Section 4 discusses and evaluates reasoning functionalities built on the top of the ontological model, that are aimed to provide automatic support for design and analysis of a performance monitoring system for a PTS. A set of more advanced functionalities is discussed in Section 5 together with examples referring to the case study. In Section 6 we introduce some research work on support frameworks for transport systems and monitoring systems, and we underline similarities and differences with our approach. Finally, Section 7 draws some conclusions and discusses future work.

2. Case study

In this section we introduce a case study that will be used through the paper to examplify the proposed approach, and that has been developed within a collaboration with PluService srl, a private company operating in Italy on information

[1] https://www.ntcip.org.
[2] https://www.transmodel.org.
[3] http://www.w3c.org/OWL.