An Ontology for Sustainable Intelligent Transportation Systems

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Abstract. Nowadays, the need of Intelligent Transportation Systems software tools and services for Sustainable Transportation is urgent. This paper proposes an ontology specially tailored for Intelligent Transportation System characterization. The main features of the proposed ontology is the ability to incorporate sustainable variables when characterizing a transportation system, and the coverage of open fleet concepts together with its dynamic features. Moreover, it is enhanced to facilitate its integration with other intelligent components that in a wider and complete application tool can provide intelligent computation over the data specified with the proposed ontology.

Keywords: Ontology · Intelligent Transportation Systems
Sustainability

1 Introduction

An issue that has triggered concerns over the recent decades relates to the capacity of the global economy to accommodate an enduring demographic, economic and resource consumption growth. Since a growing share of the global population is urbanized, sustainability has increasingly become focused on urban areas. Major cities are requiring a vast array of supporting infrastructures including energy, water, sewers and transport. A key to urban sustainability issues is linked with the provision and maintenance of a wide range of urban infrastructure. Every city has specific infrastructure and environmental problems. Transportation, as a core component supporting the interactions and the development of socioeconomic systems, has also been the object of much consideration about to what extent it is sustainable. Sustainable transportation can be defined as the capacity to support the mobility needs of people, freight and information in a manner that is the least damageable to the environment [12]. Components for evaluating sustainability include the particular vehicles used for road, water or air transport; the source of energy; and the infrastructure used to accommodate the transport (roads, railways, airways, waterways, canals and terminals).

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Transportation sustainability is largely being measured by transportation system effectiveness and efficiency as well as the environmental and climate impacts of the system [6].

In addition to Sustainable Transportation another concept that lately is more and more demanding solutions is "Intelligent Transport Systems" (ITS). ITS is a generic term for the integrated application of communications, control and information processing technologies to the transport system. The resulting benefits save lives, time, money, energy and the environment and stimulate economic performance. In this sense the two concepts are closely related, being the second a supporter for achieving the goals of the first.

ITS covers all modes of transport and considers all elements: the vehicles, the infrastructure, the drivers and users all interacting together dynamically. The main function of ITS is to provide services and information for the full spectrum of users in particular drivers, passengers, vehicle owners and operators, but also vulnerable road users like pedestrians and cyclists and support safe and efficient traffic management by the transport network operators. The intention is to improve the operation of the entire transport system. With ITS, road users such as motorists, freight and commercial fleet operators and public transport customers can make better judgements on their travel decisions. Factors such as traffic conditions, road maintenance or construction work may potentially impact on travel times; weather conditions will affect the road network and safety.

This work is motivated and inspired by the need of ITS software tools/services for Sustainable Transportation. Sustainable transportation is now often used to indicate a shift in the mentality of the community of transportation analysts to represent a vision of a transportation system that attempts to provide services that minimize harm to the environment. In order to facilitate the development of such tools there is an urgent need to provide ontologies that can express all the features of a transportation system together with the sustainable concepts and data that must be also included as first class goals in any optimization systems for improving mobility in urban areas. Moreover, the proposed approach follows an open transportation fleet paradigm[1].

Section 2 summarizes the most relevant state-of-the-art works on ITS ontology and reveals the lack of a proper treatment of sustainability issues by those works. Section 3 describes the proposed ontology. Section 4 provides an overview description of a framework in which the proposed ontology is integrated. Section 5 cites a few sample applications that were implemented using the ontology. Finally, Sect. 6 summarizes the conclusions and future works.

2 Related Work

In [5] an ontology-driven architecture to improve the driving environment through a traffic sensor network is proposed.

[1] Open fleets extend the traditional fleet concept towards a new dimension of openness: vehicles may interact with their environment in a Smart city [9], or join and leave the fleet at any time.

The work described in [7] presents the state of research in Intelligent Transportation System ontologies relying on results from the EU-funded research project T-TRANS. In particular, it first compares approaches of structuring Intelligent Transportation Systems. In a second step, the shortcomings of these approaches are discussed and the relationships of Intelligent Transportation System concepts are demonstrated by linking Intelligent Transportation System applications with technologies.

On the other hand the authors of [14] study a unified representation of urban transport information using urban transport ontology in order to solve the problems of ontology mergence and equivalence verification in semantic fusion of traffic information integration.

One of the most used ontology for Intelligent Transportation Systems is the one proposed in [3]. The authors propose an ontology that is enhanced for the personalization of user interfaces for developing transportation interactive systems by model-driven engineering.

In [13] the authors propose two ontologies for way-finding with multiple transportation modes. Whereas the work described in [8] proposes a system that is based on public transportation ontology.

From this literature review we can conclude that sustainability variables and features are not taken into account by any work and the new concept of open fleets is still no included in any ontology from the specialized state-of-the-art.

3 The Ontology for Sustainable Intelligent Transportation Systems

The public transport system plays an integral role in any Sustainable Intelligent Transportation System since urban areas rely on public transport services. Public transport infrastructure systems such as bus, tram, metro and rail are the key designs for mobility. As discussed in [1] an urban public transport network is a complex system which is a result of interaction between a set of distributed and evolving entities such as the means of public transport, people and the network infrastructure. The complexity of the public transport system is further amplified by other dynamic parameters such as traffic jams, unexpected events such as accidents and changes in routes, weather, sustainable features such as air quality, CO2 emissions from transportation means, etc. To this end we propose an Intelligent Transportation System Ontology as a way to coupe with the specification of the different elements in a transportation model.

The Intelligent Transportation System Ontology is based on the work of [3]. Nevertheless, other works such as [13] that proposes two ontologies for way-finding with multiple transportation modes, and [8] in which a system is proposed based on public transportation ontology, were also taken into account for the ontology definition.

The ontology proposed is complete in terms of the six dimensions defined in [3] and extended with the open fleets concept and the sustainable specific attributes and/or relationships that are key in order to realize the optimized movement of passengers, objects (products, parcels, etc.) in the city. Following the ontology is described with special focus on its original elements.

Figure 1 shows the different ontology concepts that built up the model and deal specifically with the transportation multi-modality or transportation mode. In the proposed ontology there are three modes. (i) Public to which pertain the modes that are provided by transportation operators, with transportation lines running in a transportation network following a schedule (see Fig. 2 for a detailed view). (ii) Private to which pertain Cars, Bicycles, Trucks, and Motorcycle that can again be Owned or Rented by citizens/users. For the case of rented Private Transports there are two possibilities: with driver or without driver. The former case applies to Taxis and or Uber like systems, in which the user pays for the itinerary to the owner of the transport. (iii) Priority to which pertain special type of transports such as: Ambulance, Police Car and Fire Truck. Vehicle Type is used to describe the features of the different modes, and are key for reasoning purposes in any application tool for intelligent transportation systems, i.e. when a given transport must be considered for recommendations issues to the users that are willing to move in an optimized way. The optimized recommendation might consider two main goals: maximize the economic compensation of the users (for example, choosing the cheaper routes and/or transportation means, the fastest or shortest route), and; to minimize the harm to the environment (in terms of CO2 emissions). The arguments and/or variables that are taken into account for these two goals in the Vehicle Type description are: the price features and the sustainable features related to CO2 emissions per passenger and per product/parcel volume. In addition these arguments are combined with the GPS Location, Number of Seats and Parcels Capacity in order to infer an

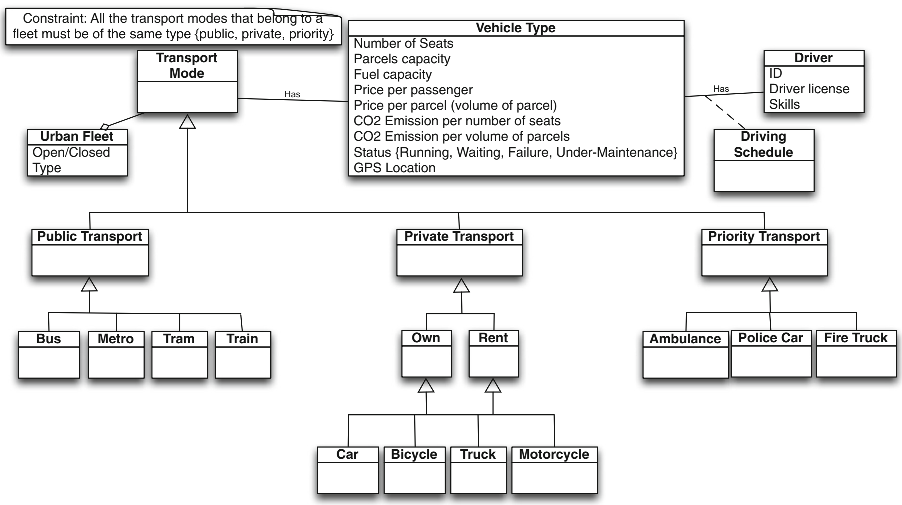

Fig. 1. Main ontology concepts of the Intelligent Transportation System Ontology

optimized recommendation to the user that at all time tries to achieve the two mentioned goals.

An Urban Fleet (see Fig. 1) is defined as a group of transports in which all the transports belong to the same Transportation Mode. It can be Open or Close. An Open Urban Fleet is one that can change dynamically, i.e. a transport owner can decide to enter or exit the fleet at any time. A Close Urban Fleet is one in which no new transport owners can decide to enter the fleet in a dynamic fashion.

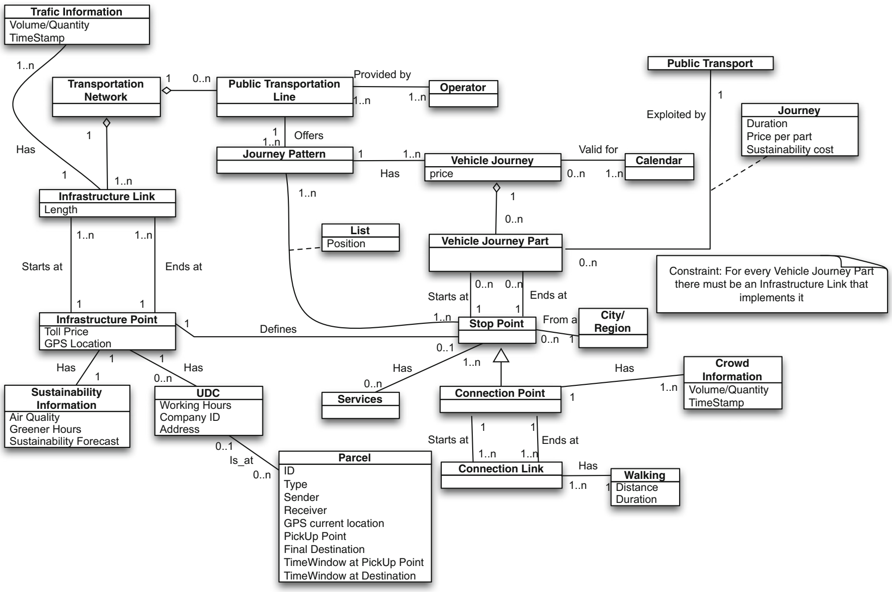

Fig. 2. Ontology definition of the transportation network

Figure 2 presents the Transportation Network ontology. It is defined by the set of Infrastructure Links that defines the transportation infrastructure itself and the set of Public Transportation Lines that runs in the network. An Infrastructure Links connects Infrastructure Points (see Fig. 3): railway junctions, wire junctions, road junctions (a road junction is valid for cars, trucks, and maybe bikes), and bike-lane junctions (an special type of road junction only valid for bikes). An Infrastructure Link can be a: road element, wire element, railway element, bike-lane element. Moreover a road element must be categorized as bike or no-bike allowed. Every Infrastructure Link has a Traffic Information associated that is used in order to infer recommendations to the users about timing issues when intending to move trough the given Infrastructure Link. Moreover, every Infrastructure Point is associated with Sustainability Information about Air Quality, "Greener" Hours to navigate the point, and Sustainability Forecast (mainly about CO2 data). The Sustainability Information is intended to be taken into account by for example a recommender model when analyzing the sustainability cost for the overall system for the given itinerary (a route made up of connected Infrastructure Links).

A Public Transportation Line (Fig. 2) is provided by an Operator and offers a set of Journey Patterns. The description of the Public Transportation Line is based on the work of [3] augmented with sustainability features and the Crowd Information associated with the Connection Points in a line.

Finally Fig. 4 shows the specification for User in the system and products/parcels that can be transported in an urban area.

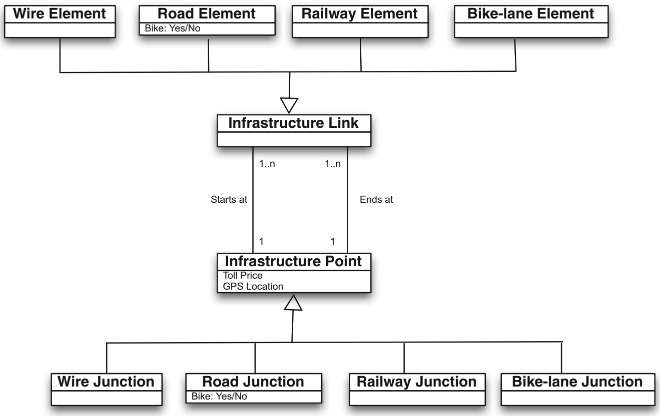

Fig. 3. Classification of infrastructure links and points

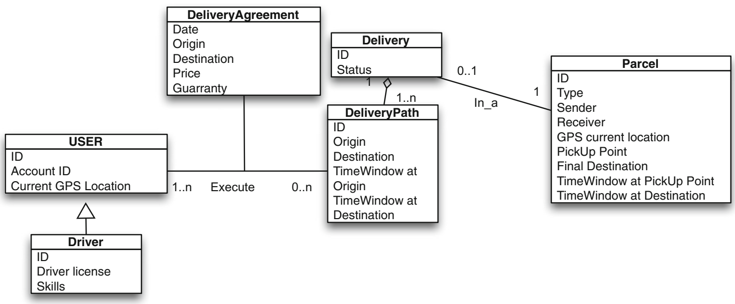

Fig. 4. Users, deliveries and parcels

4 A Framework that Incorporates the Ontology

The ontology presented in this paper can be used as it, in an isolated way, by any application. Nevertheless, it is important to direct the reader attention towards an intelligent framework specially tailored to the development and execution of intelligent applications for transportation systems. The Framework is called SURF and was originally presented in [2]. This framework is made up by a series of services and utilities that can support open fleet managements. Figure 5 shows the architecture devised for open fleet management divided into four layers, which are the following:

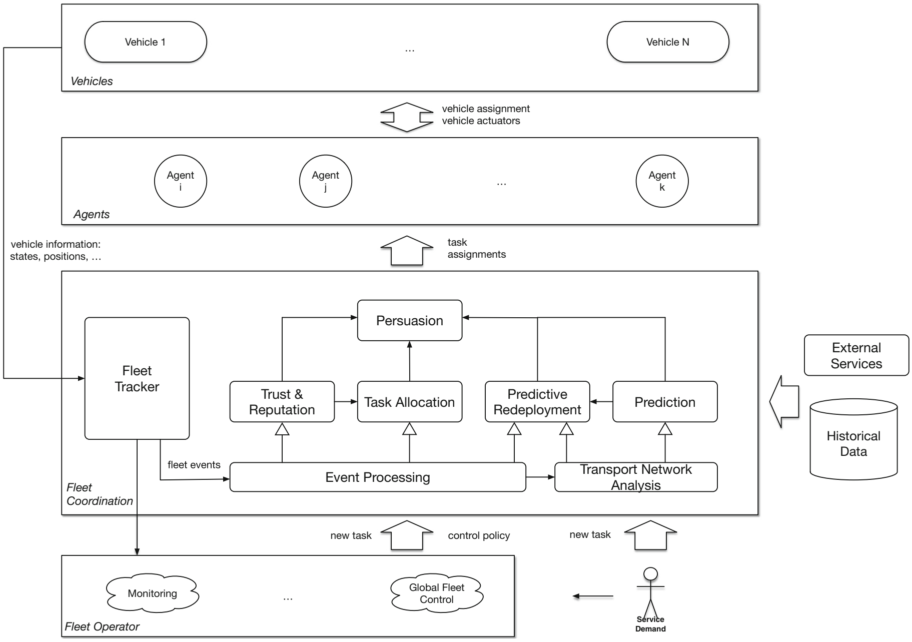

Fig. 5. General view of the SURF framework

- "Fleet Operator", which includes the basic components used for global fleet control and monitoring. This layer represents the control operator of the system which is in charge of supervising the global operation of the system.
- "Fleet Coordination", this is the heart of the framework, with all the different perception inputs, provide information about vehicle status, position, ... and they also receive information to be displayed to the vehicle driver. As its main goals, this layer follows the operational states and positions of the vehicles determining whether or not a re-calculation of task assignments and/or deployment of idle vehicles should be done. This layer is divided into

different modules, the most important ones are the following: a Fleet Tracker, which receives information about the operational states and positions of the available vehicles; the Event Processing, which analyses the incoming events and determines which are the modules that must receive these events; the Task Allocation module calculates the global assignment of all pending tasks to agents/vehicles; the Predictive Redeployment module, obtains adequate positions for all idle agents/vehicles at a specific moment; the Persuasion module provides actions to agents that tend to improve the overall performance of the system; and, the Trust and Reputation module is in charge of modeling the expected behavior of agents/vehicles in the system using previous situations.
– Agent Organization, it is formed by the agents which manage the different urban transport entities. In this case, one agent can be in charge of a vehicle or a fleet. Their main goals are task assignments and vehicle deployments allowing the coordination. Agent receives possible tasks to do from the Fleet Coordination layer, but they may not follow a certain global strategy rejecting task assignments and also leaving the fleet.
– Vehicle layer, it is formed by the vehicles and public transport stations forming the fleet including the drivers (this could be optional in case of autonomous vehicles). This layer can be seen as a set of sensors and actuators which are included in each vehicle.

5 Applications that Rely on the Proposed Ontology

This section briefly presents three sample applications that were implemented using the ontology proposed. Nevertheless, the list of possible new and different applications is large and can get longer as new ideas and user requirements appear.

One of the issues to be addressed in Smart Cities concerns the **smart transport of parcels inside a city** [9], commonly known as last mile delivery. Our approach for parcels' last mile delivery is named *CALMeD SURF* [11] and is based on crowdsourcing, taking advantage of the movements of the citizens in the urban area, that move for their own needs. This application is addressed as a mobile phone app for: customers that want to deliver a parcel, and users that want to serve as occasional deliverers in an urban area. The main idea is that the users register in the application (as customer or deliverer), and *CALMeD SURF* will locate them in the city on real-time. In this way, when there is a parcel delivery request, the system uses a graph, that is dynamically generated from the active users and the instantiated transportation ontology, where each node is either a user (a potential deliverer, and/or customer) or a delivery center/office. The system proposes optimized parcels delivery paths to the crowd of potential deliverers (those who are closest to the calculated delivery path) to participate. If some of the potential deliverers rejects the proposal, it calculates an alternative path (i.e. a new path and a new set of potential deliverers) in order to achieve the parcel delivery goal. The calculated path may include several deliverers that may pass the parcel from one to another (connecting sub-paths). One of the optimization criteria used by the system, closely related with the goal of minimizing the harm to the environment, is to minimize the deviation of the deliverers from the path to their own destinations. Trying in this way to minimize new emissions originated by movements that are solely used for parcel deliveries.

Nowadays, one of the most popular urban transport systems in order to aid in reducing emissions is the **shared vehicles system**. One such system is the shared bicycle system which have an special interest due to its characteristics. The distribution/balancing of bicycles over time and space through the different pick up/drop off stations in the city network is one of the key problems to solve in order to maintain an efficient bike sharing system. Traditional approaches rely on the service provider for balancing the system, but this approach, in general, adds extra costs. Our proposal [4] consists on an multi-agent system that includes user actions as a balancing mechanism, taking advantage of their trips to optimize the overall balance of the system. The proposed approach, when necessary, tries to persuade the user to deviate slightly from its origin/destination by providing appropriate arguments and incentives. With this information the multi-agent system analyses the transportation network (specified using the ontology presented in this paper), scoring alternative stations and routes and making offers to balance the bikes across the stations.

One of the most used online web-services and/or mobile apps every day are applications for **route planning**, getting not only the route according to the means of transport that the user selects, but also recommendations of places of interest that can be found along the way. Unfortunately, these applications do not consider the profile of the end users, and generate the same routes for a person who has a disability as for those who do not. In [10] we propose a model for a recommendation system based on the user profile to generate automatic and personalized routes on foot or on public transportation for people with disabilities. The proposed solution extends the ontology described in previous section in order to add and extend the user profile definition for disabilities characterization and the network structure elements description.

6 Conclusions

This paper has proposed an ontology for Sustainable Intelligent Transportation Systems. Bearing in mind that sustainable transportation can be defined as the capacity to support the mobility needs of people, freight and information in a manner that is the least damageable to the environment, and the urgent need to have a way by which sustainability features are specified and taken into account by the tools that support this system, the proposed ontology can be considered an important contribution to the research and development field. The ontology is complete in terms of the six dimensions defined in [3] and extended with the open fleets concept and the sustainable specific attributes and/or relationships that are key in order to realize the optimized movement of passengers, objects (products, parcels, etc.) in the city.

Three sample applications that uses the ontology were also summarized, illustrating in this way the advantage that any application tool can get from using a more complete ontology that integrates open fleets and sustainability concepts.

As future work, we are working on more applications that uses the ontology and the SURF framework in order to provide different type of intelligent services for optimizing the movement of people and products in urban areas.

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References

1. Beamon, B.M.: Supply chain design and analysis: models and methods. Int. J. Prod. Econ. **55**(3), 281–294 (1998)
2. Billhardt, H., Fernández, A., Lujak, M., Ossowski, S., Julián, V., De Paz, J.F., Hernández, J.Z.: Towards smart open dynamic fleets. In: Rovatsos, M., Vouros, G., Julian, V. (eds.) EUMAS/AT -2015. LNCS (LNAI), vol. 9571, pp. 410–424. Springer, Cham (2016). https://doi.org/10.1007/978-3-319-33509-4_32
3. de Oliveira, K.M., Bacha, F., Mnasser, H., Abed, M.: Transportation ontology definition and application for the content personalization of user interfaces. Expert Syst. Appl. **40**(8), 3145–3159 (2013)
4. Diez, C., Sanchez-Anguix V., Palanca, J., Julian, V., Giret, A.: Station status forecasting module for a multi-agent proposal to improve efficiency on bike-sharing usage. In: Proceedings of the 5th International Conference on Agreement Technologies 2017 (2017)
5. Fernandez, S., Hadfi, R., Marsa-Maestre, I., Velasco, J.R.: Ontology-based architecture for intelligent transportation systems using a traffic sensor network. Sensors (Basel) **16**, 1287 (2016)
6. Mihyeon Jeon, C., Amekudzi, A.: Addressing sustainability in transportation systems: definitions, indicators, and metrics. J. Infrastruct. Syst. **11**, 31–50 (2015)
7. Kellberger, S., Castelli, L., Piera, M.A.: Development of an intelligent transport system ontology - linking applications and technologies across different transport modes. In: European Transport Conference 2013 (2013)
8. Mnasser, H., Oliveira, K., Khemaja, M., Abed, M.: Towards an ontology-based transportation system for user travel planning. IFAC Proc. Volumes **43**(8), 604–611 (2010). 12th IFAC Symposium on Large Scale Systems: Theory and Applications
9. Neirotti, P., De Marco, A., Cagliano, A.C., Mangano, G., Scorrano, F.: Current trends in smart city initiatives: some stylised facts. Cities **38**, 25–36 (2014)
10. Peralta, A., Giret, A.: Recommender system of walking or public transportation routes for disabled users. In: Submitted to The Workshop on Smart Cities and Intelligent Agents 2018 (2018)
11. Rebollo, M., Giret, A., Carrascosa, C., Julian, V.: The multi-agent layer of calmed surf. In: Proceedings of the 5th International Conference on Agreement Technologies 2017 (2017)
12. Rodrigue, J.-P.: The Geography of Transport Systems. Routledge, Abingdon (2017)

13. Timpf, S.: Ontologies of wayfinding: a traveler's perspective. Netw. Spat. Econ. **2**(1), 9–33 (2002)
14. Yang, W.-D., Wang, T.: The fusion model of intelligent transportation systems based on the urban traffic ontology. Phys. Procedia **25**, 917–923 (2012). International Conference on Solid State Devices and Materials Science, 1–2 April 2012, Macao