Semantic model for IoT-enabled electric vehicle services: Puzzling with ontologies

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***Abstract*— The purpose of this paper is to present our ideas of applying semantic modelling and ontologies to the issues of products and services. Two selected issues are discussed: i) the collection and reuse of product-service lifecycle data in an IoT-enabled framework. The role of product-service ontology is demonstrated as a backbone of vehicle lifecycle management; ii) ontologies and semantic interoperability as enabling technologies for the creation of services such as charging location finding or traffic information services. In both cases, a particular product – electric vehicle with electric battery – is taken into account as a case study.**

Keywords — Ontology; IoT; product-service lifecycle; electric vehicle; semantic modeling

I. Introduction

According to the recent report about 'Connected Vehicle' [1], "*the connected vehicle space is a fast-growing market and a strategic priority for the Automotive Industry*". The huge volume of data that connected vehicles can generate constitutes big product data which might be useful with the management of lifecycle information. Depending on the way the data are combined with the other sources of information, such data can provide valuable insights on product improvement as well as product-service creation. The area of services might be very large including customer services and quality, CRM and marketing, maintenance, and R&D in design and product improvement. Here are some syntheses from the survey [1], which emerged from 14,195 consumers across 12 countries:

- The importance of elements installed in connected navigation services: Traffic Information (45%), Speed Camera (31%), Weather Information (28%);
- The importance of having a kind of convenience services: Vehicle Lifecycle Management (44% will consider for future usage, 30% very likely to start using.); Remote service (33% will consider for future use, 24% already using, 18% very likely to start using)
- The interests in technologies which support driving and parking: Car parking space detection system (75% would like to use, 6% use)

Such trends encourage industries to make changes moving from product-oriented manufacturing business to a service-oriented strategy considering the whole lifecycle.

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Thanks to the remarkable development in technologies related with connected vehicle and smart products [1, 2, 3, 4] vehicle performance data can be gathered and analysed with the support of an embedded platform such as [4]. The collected product data on manufacturers' repository can then be shared with authorized third parties, such as insurance companies or service centres. New features for future models can also be derived from analysing collected product data.

In traditional product lifecycle management (PLM), product data are collected from sensors installed in products. Nowadays, the notion of 'product data' has been extended thanks to the technical achievement in Internet-connected objects. Considering the example of an electric battery installed on an electric car, the type of product data can range from the battery temperature, time, to the depth of discharge and state of charge, to users' driving behaviour or charging habits [5]. Connected vehicles' high-tech sensors and networking facilities are generating a high volume of data. There is no doubt that such data are now taking part of collectable information from all connected 'things'. The questions on data and information seems to be no more about "how to collect" or "where to store". Now the key question might be "how to combine them and make a transition to knowledge and inherent context as an added value?"

Our research focus lies on applying ontology-based semantic approaches to the PLM in the Internet of Things (IoT) environment with the aim of enhancing product knowledge sharing and product-service creation. The example of electric vehicles (EV) and connected cars is an attractive area of application due to several reasons: intelligent products; connectivity with heterogeneous network types; the electric battery, which is a part of a car, has a separate lifecycle independent of that of the car infrastructure; and different types of sensor technologies are installed and used.

The purpose of this paper is to present our on-going work of applying semantic modelling and ontologies to two selected areas. The first subject deals with product-service lifecycle information management in an IoT-enabled framework. The role of product-service ontology is demonstrated as a backbone of vehicle lifecycle management. The second subject concerns the role of ontologies in the creation of new services such as charging location finding combined with some traffic information. From now on, the paper is organized as follows. Section II discusses an ontology framework for product-service

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lifecycle which uses IoT message standards for data collection. Section III illustrates some examples of product-service lifecycle data and information extraction. We also discuss how rules of knowledge inference can be created and shared among different actors. Section IV presents our work in progress concerning a semantic approach to combine traffic information service. Concluding remarks are then given in Section V.

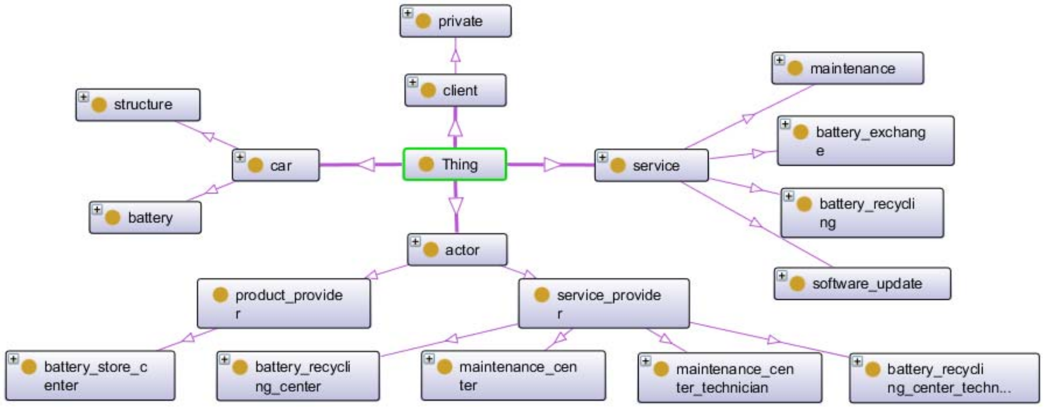


Fig. 1. Electric vehicle service ontology: borrowed from [6]

II. SEMANTIC APPROACH TO PRODUCT AND SERVICE LIFECYCLE INFORMATION SHARING IN IOT

Semantic modelling in the context of PLM is of importance in industry as well as in research [2]. Following the evolution of ICT and connected objects technologies, the type of collected information as well as the focus of information reuse in PLM has also been evolved accordingly. Rather than collecting only the product information during its usage phase, now manufacturers' interest goes to the customer's feedback and preference profiles in order to create new business opportunities in terms of product-services. Subsequently, a holistic approach to product-service-customer lifecycle turned out to be an important factor.

A. Product-Service Lifecycle Ontology

The framework for Product-Service Lifecycle Ontology (PSLO) tackles the integration of services and other actors into the boundary of PLM. PSLO is composed of physical product lifecycle ontology, service upper ontology, and a domain specific ontology of electric vehicle (EV) services. Fig.1 depicts a part of the domain specific service ontology for EVs. The EV service ontology represents electric car and related services including four main classes: 'actor' (as business actors), 'car' (as products), 'client' (as users of products and services) and 'service'. PSLO makes it possible to trace the data and their relations during the lifecycle of products and services in accordance with users and business actors. Here are some characteristics of the ontology:

- Modelling the relationship between car owners, cars, and electric batteries as well as manufacturer information.
- Service ontology being focused on the relations between key constituents including: which services are offered, by whom (technicians), at which place (maintenance centres), for whom (clients, owners of cars), and so on.
- Possibility of tracing the service operations including the maintenance of cars and electric batteries, battery swap or replacement, with relative information such as at which maintenance centre the operation was performed, by which person (i.e., technician) the work was achieved.
- Rich set of object properties, dedicated to electric car and battery lifecycle data, such as battery product information, swapping, wear level statistics and other historical data.

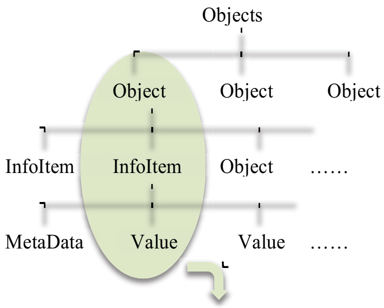
The ontology framework is modelled in OWL2 with RDF/XML serialisation, and then instantiated on OpenRDF Sesame [18]. Sesame is an open source Java framework for processing RDF data, i.e., parsing, storing, inferring and querying of/over such data. It offers easy-to-use API that can be connected to all leading RDF storage solutions. It is possible to connect with SPARQL endpoints and create applications that leverage the power of linked data and Semantic Web. The framework constitutes the backbone of the IoT data, which is presented in the following subsection.

B. The Open Group IoT message standard: O-MI, O-DF

As far as the standards are concerned, IoT standards such as O-DF (Open Data Format) and O-MI (Open Messaging Interface), which are the Open Group [17] IoT standards, facilitate the collection of information on things to a semantically provided knowledge structure [7]. The key idea of O-DF and O-MI is to make it available product instance-enabled lifecycle information in IoT. The messages, created using O-MI/O-DF, help trace how the product has behaved or how the customer uses each individual product. The message content is generated with the help of sensors and actuators. O-MI can be used for transporting payloads also in other formats than O-DF. O-DF can be viewed as a generic content description model for things in the IoT.

O-MI allows read/write/cancel operations concerning the data that the message contains without imposing any message enclosing structure. As for the subscription mechanism, two types of subscription mechanisms are supported: i) with callback address: the data is sent to the subscriber node using an O-MI response at the requested interval; ii) without callback address: the data is memorized on the subscribed node as long as the subscription is valid.

O-DF is a generic envelope structure designed to represent any objects and information. As illustrated on Fig.2, the top-level ‘Objects’ element can contain any number of ‘Object’ as sub elements. Inside an ‘Object’ element, users can include the object id with description as well as the main message content with the help of the ‘InfoItem’ element. It is also possible to construct a hierarchical view of each object. The use of O-MI and O-DF are proposed in the context of the PSLO framework while customising the InfoItem field for RDF dataset instances.




```
<Object type="sina-rdf">
  <id>sina-ontology-ps</id>
  <InfoItem name="rdf-content">
    <description>the message content sent to SINA<description>
    <value>
      <rdf:RDF xmlns="https://ict4sm/pslo-ev.owl#"
      xmlns:xsd="http://www.w3.org/2001/XMLSchema#"
      xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
      xmlns:pslo-ev="https://ict4sm/pslo-ev.owl#”
      xmlns:rdf=http://www.w3.org/1999/02/22-rdf-syntax-ns#>

      <owl:Ontology rdf:about="https://ict4sm/pslo-ev.owl#"/>
      <owl:NamedIndividual rdf:about="&pslo-ev;battery_15">
        <rdf:type rdf:resource="&pslo-ev;battery"/>
        <plso-ev:battery_charge rdf:datatype="&xsd;integer">100
        </pslo-ev:battery_charge>
        <pslo-ev:battery_type rdf:datatype="&xsd;string">60
        </pslo-ev:battery_type>
        <pslo-ev:battery_wear rdf:datatype="&xsd;integer">93
        </pslo-ev:battery_wear>
        <pslo-ev:compose rdf:resource="&pslo-ev;car_15"/>
      </owl:NamedIndividual>
      </rdf:RDF>
    </value>
  </InfoItem>
</Object>
```

Fig. 2. O-DF envelope for the battery state data sent to PSLO

III. TOWARDS A LIFECYCLE MANAGEMENT BASED ON THE IOT

This section discusses how the framework can contribute to sharing information using O-DF and O-MI IoT messages. In PSLO, semantically reasoned information and knowledge can be recursively added to the RDF database pool, which can be delivered to other subscribers through O-MI requests. The adoption of the O-DF structure to the communication of ontology data resulted in using an ‘InfoItem’ block dedicated to a PSLO graph dataset. The ‘sina-rdf’ element on Fig.2 is such an Object description, within which an InfoItem element is defined, i.e., ‘rdf-content’ for indicating the RDF instance content. PSLO-specific O-DF/RDF parser are implemented, without completely re-implementing an O-MI node, for the purpose of extracting the data content into PSLO. Fig.3 illustrates an example of EV services, integrating different actors such as the manufacturer, the car owner, maintenance centre as well as the electric car. The electric battery is one of the vehicle subsystems, which has either automotive service life or a second life after being removed from the automotive service cycle. Different data, in the O-DF format (Fig.2), can be transferred to the PSLO RDF repository.

A. *“Things” data example*

Here are some examples of semantically enriched ‘Things’ data contained in O-DF messages:

- Object class and instance: data about the definition of a *kind* or a subclass of an existing *kind* (e.g. EV-X2 is an *Electric Car*).
- Object instance with object property: this is the traditional scheme in PLM data collection (e.g., *battery charging level* of a specific battery, *Smart-Battery-2000*, is equal to *75% of the capacity*).
- Relation between objects: in an ontology model, a type of object relationship can be a unit of information (e.g., Ana *is the owner of* a EV-X2 which *is composed of* Smart-Battery-2000).
- Rule in the ontology model: one of the benefits from semantic modelling is its capability of inferring new facts thanks to an inference engine provided with a logic-based language. The inference rule itself can be transferred as the value of a specific ‘InfoItem’ (so-called rdf-content) in O-DF.

Fig.3 demonstrates some examples of message transfers:

- Between the battery and the EV, data regarding the battery temperature, charging level history data can be collected on the EV on-board device. Afterward, the data are transferred to the PSLO data repository (1) with the other data such as user driver habits or historical data on external temperature. Those data will contribute to the battery wear level assumption, which can be inferred from the battery degradation calculation [5].
- When a client buys an EV, the owner information is sent to the database (2).
- From the maintenance centre, when an operation is performed, the record is sent to the repository (3).
- A rule for information extraction can be created and sent to the repository for the purpose of gathering information which satisfies the rule constraints (4). The category of rule can vary ranging from customer information to knowledge required for product performance evaluation. In the following subsection, a simple rule example is discussed.
- In case a manufacturer or any actors are interested in knowing the above-mention inferred information, they can send an O-MI “subscribe” on the information targeted by the rule (4 & 5).

B. *Information extraction and knowledge sharing on Things*

This subsection discusses the way an actor sends a rule to the framework with the aim of extracting new information and sharing. The following scenario illustrates a fictive situation in which a rule of information extraction is required:

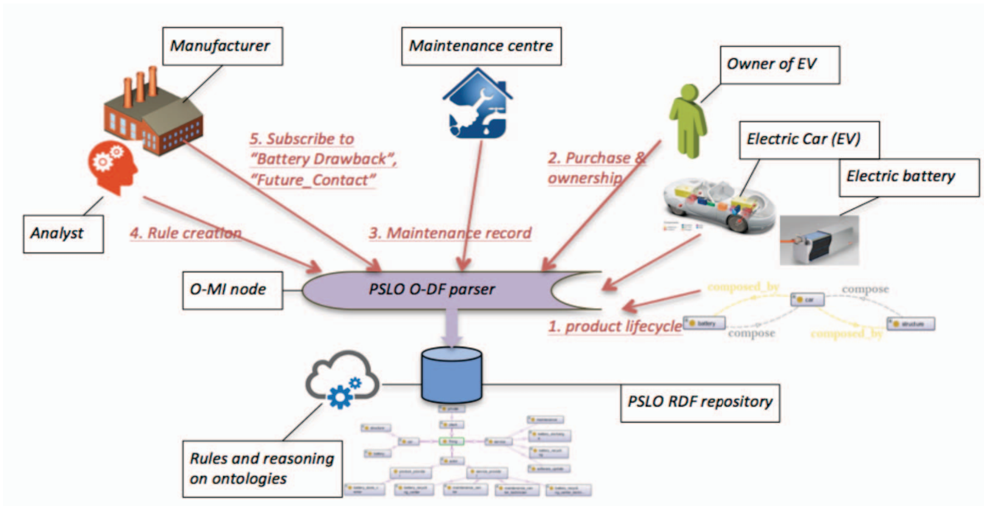


Fig. 3. PSLO and IoT message transfer from different *"things"* in Product-Service lifecycle ecosystem

An EV manufacturer wants to find information on electric batteries which need some functional improvement. Consequently, once a new battery model is developed, the manufacturer wants to offer a new service which will be promoted with the car on which the new battery will be installed. In order to promote the service, the manufacturer wants to identify the potential group of customers by: i) finding all cars on which the old batteries are in use; ii) and then identifying the current customers of the cars. Based on the list of customers, the manufacturer will directly inform the customers about the service.

(1) Battery_wear (?b, ?y), lessThan (?y, 65), battery_date (?b, ?c) , lessThan (?d, "2011-09-24T06:00:00Z"^^xsd(dateTime) -> Battery_Drawback (?b).
(2) Battery_Drawback(?b), composed_by (?c, ?b), own(?client, ?c) -> Future_Contact (?clinet).

Fig. 4. Example SWRL rules (borrowed from [6]).

Fig.4 illustrates the rules initially defined in SWRL [21]. Fig.5 shows the rule concept described using SPARQL "CONSTRUCT" queries. Accordingly, Battery_Drawback is created as a new RDF graph and an inference engine searches corresponding RDF data. Another graph node, Future_Contact is also created. Message (5) in Fig.3 illustrates the message sending of this CONSTRUCT query into the PSLO RDF data repository being enveloped by an O-MI subscribe message.

```
(1) PREFIX pslo:    <http://example.org/pslo.owl#>
PREFIX pslo-ev:   <http://example.org(pslo/pslo-ev.owl#>
PREFIX rdf : <http://www.w3.org/2001/SMLSchema#>
CONSTRUCT   { ?b rdf :type pslo :Battery_Drawback.}
WHERE       { ?b pslo :battery_wear ?y. ?b pslo :battery_date ?d.
     FILTER ( ?y<70 && ?d < xsd:dateTime ("2011-09-24T06:00:00Z")
(2)
CONSTRUCT { ?client rdf :type pslo :Future_Contact.}
WHERE  { ?b a pslo :Battery_Drawback. ?c pslo :composed_by ?b.
```

Fig. 5. SPARQL CONSTRUCT queries which represent the rules

The reason of maintaining an RDF database is to take advantage of powerful functional supports offered by the system. For example, the SPARQL 'CONSTRUCT' phrase, as a rule description, can be sent under a string format being embedded in O-DF/O-MI. Sesame's 'GraphQuery' object takes the query string as it is, and then easily adds them to the repository (bottom of Fig.3) for further inference.

IV. TOWARDS THE FUSION OF OPEN DATA AND ONTOLOGIES

In this section, we present our second issue: creating a traffic service, which requires ontology fusion. The example traffic service concerns an EV charging station finder, which considers the real-time traffic condition and integrates it as constraints during the route finding algorithm. For that purpose, reusing some open access data stores as well as existing APIs and vocabularies are mandatory. The following subsection introduces, as one of such enabling technologies, an open source data service on charging stations.

A. Enabling open data service – OpenChargeMap (OCM)

The Open Charge Map [19] is an open data service, which offers data concerning charging stations. Independent operators and data providers such as supplier of Electric Vehicle Supply Equipment, (EVSE) network operators, national registries, and local charging info apps and sites collect the necessary data. At the time of writing, the website is providing information about more than 36500 charging stations around the world. Users can browse the charging stations by manually entering the address or the geographical locations. Charging information can also be communicated in JSON format, through the OCM API, in order to provide data to third-party developers.

So far, various third-party applications and services have been developed mainly based on OCM APIs. Here are some examples: inside a route and journey planner such as EV trip planner (www.evtripplanner.com); for data feeding from OCM to customer Apps and widgets, including the web site for the UK Zero:Net public charging network supplied by the UK Charity Zero Carbon World. This site uses the OCM API as a feed into their content management system. Therefore, it is recommended to use relevantly the existing open data service. In the following subsections, we discuss more about ontologies for traffic information sharing.

B. DATa EXchange II

Digitization and advances in technology along with socio-economic factors and policies are transforming the transportation industry like never before. One common problem of the traffic organizations is how to exchange information and to assure the quality of information among the whole system. Intelligent Transportation Systems (ITS) focus on integrating traffic information and all technologies related to transport, vehicles and users. ITS aim to provide road safety and to avoid congestions. System integration is another essential component of ITS and it is used to deal with these problems. A type of information system needs to exchange data with other systems to expand its scope and these data are typically exchanged using a common model known by the stakeholders. Within traffic domains DATa EXchange II (DATEX II) was developed by a large number of European Experts in order to be a common vocabulary for exchanging data. DATEX II has been set as standard by different organizations. This offers the possibility to build new services based on the data made available by DATEX II [9].

DATEX II-based service developers should accommodate technical requirements, such as filtering or format conversions, which are mainly due to the lack of interoperability. In order to improve the performance in development, new approaches need to be investigated and tested. The Semantic Web is one of these approaches and it is the basis of the research work described in the following. The application of the Semantic Web in ITS focuses on establishing common traffic models based on semantics. These models use Semantic Web features to describe and work with information from knowledge-based perspective and they are the basis for a framework of semantic traffic services. In [12], a DATEX II semantic model is implemented and a set of data was translated. After that the validity of the model was proved, the performance and software costs are evaluated in order to compare both models. The results were very encouraging for the use of Semantic technologies: their experimentation result demonstrated an improvement in the execution time. The overhead for fetching accidents with hazards involved is decreased compared to the previous approach. Another important finding is that semantic APIs demonstrated a high performance level in terms of execution time for fetching situations. The authors of [12] introduced how to use DATEX II semantic model for publishing traffic information based on user profiles. In that work, the traffic profiles are defined by user preferences associated to the format or filtering criteria. The latter data are then applied to traffic information.

DATEX II is now mandatory to be used in accordance to the European Commission's ITS Action Plan for the trans-European transport network (TEN-T). The efficient integration of information described in DATEX is the key to success in creating intelligent traffic services. In order to increase the interoperability among different service contexts and user profiles, a semantically annotated model is to be investigated.

C. The Semantic Sensor Network Ontology and reasoning on sensor data

The Semantic Sensor Net (SSN) ontology is based on concepts of systems, processes, and observations [10]. It supports the description of the physical and processing structure of the sensors. By providing a general framework, sensors are no more limited to physical sensing devices but a device, a computational process or a combination of both that could act as a ‘sensor’ in its semantic meaning. The representation of a sensor in the ontology links together what it measures (the domain), the physical sensor (the device), and its functions and processing (the models). Central to the ontology is the Stimulus-Sensor-Observation (SSO) ontology design pattern, describing the relationships between sensors, stimulus, and observations. The SSO has been developed as mutual basis for heavy-weight ontologies for the Semantic Sensor Web, as well as to explicitly address the need for light-weight semantics for Linked Data. It should be noted that that the main classes of the SSN ontology have been aligned with the classes in the DOLCE Ultra Lite (DUL) foundational ontology [15] to facilitate reuse and interoperability.

Logical reasoning is a powerful mechanism to derive new and implicit knowledge from semantically annotated sensor data, and to answer complex user queries. [10] illustrates how semantic annotation and linked data contribute to answering sensor data queries. Through the semantic annotation, the real world resources and sensor data can be connected to the existing semantic Web. This associates abundant data and knowledge to the original and inferred sensor data, improving the ways that sensor data is utilized. Data can now be exploited to design enhanced context-aware services. Quality and trustworthiness of the sensor data will also have direct impact on future real world services that make use of them; leading to a situation where one can “gather” knowledge to perform “adaptable” decision making in dynamic environments.

D. Multisensor Data Fusion and semantic reasoning

As we discussed in earlier sections, ITS would produce substantial amounts of data that are useful in case we are able to derive knowledge from them [16]. Building a complete picture of the environment could be achieved either using a single sensing element or by the fusion of the data gathered from multiple sensing elements. The operation of the human brain is probably the best analogy to a multisensory data fusion system, where the brain acts as the fusion node and makes sense of input provided by the five human senses.

Data Fusion is one of the most important challenges that needs to be addressed to develop context-aware ITS services. Multisensory data fusion aims to overcome the limitations of individual sensors and produce accurate, robust, and reliable status information. The benefits of Multisensory Data Fusion include, but are not limited to, enhanced confidence and reliability of measurements, extended spatial and/or temporal coverage, and reduced data imperfection aspects [11].

Uncertainty is one of the most fundamental and unavoidable features in the knowledge extraction and reasoning. In order to deal with uncertainty intelligently, we need to be able to represent it and reason it. Information fusion systems (IFS) notionally consist of low-level (data collection, registration, and association in time and space) and high-level information fusion (user coordination, situation awareness and mission control), which require a common ontology for effective communication and data processing. For instance, Fuzzy Logic has been found to be very useful for modelling some common vague concepts in [13], because users usually define their preferences by expressing imprecise definitions.

Almost all approaches proposed in the literature concerns the low-level data fusion using different methods such as probabilistic fusion, evidential belief reasoning, and rough set based fusion. Very few approaches dealt with a high-level data fusion [11, 12]. The URREF ontology is a first step towards this goal as it is intended to provide guidance for defining the actual concepts and criteria that comprise the comprehensive uncertainty evaluation framework being developed by the Evaluation of Technologies for Uncertainty Representation Working Group (ETURWG). Within the URREF, a major task is to formally identify the concepts that are pertinent to the evaluation of uncertainty of an IF system, which is a means to ensure that all evaluations follow the semantic constraints that abide by the same principles of mathematical soundness [14]. [13] examines the main challenges involved in dealing with various forms of uncertainties as well as the need for high-level ontological analysis to assess them properly.

E. Discussion

Regarding our initial motivation, there are several interesting combinations of different ontologies while solving semantic interoperability with the aim to create traffic services. Taking the example of route condition-integrated charging point finding, we are interested in using DATEX II as the format of information providing current route conditions while combining the information with the OCM-based charging stations. DATEX II is useful for developing various types of services and applications, including the following examples:

- Rerouting, network management and traffic management planning. Motorway networks and urban networks are regarded as closely connected.
- Linking traffic management and traffic information systems
- Applications which require intensive information exchanges between individual vehicles and traffic management such as car-to-infrastructure systems.
- Provision of services in the framework of road management with a strong link to network safety or performance like truck parking.

For the purpose of making all the information available in the context of a new service, we need to combine relevantly distributed parts of semantic models, according to ontology fusion, supported by appropriate reasoning procedures.

V. Conclusion

The PSLO framework presented in the paper is in its prototype state, which is to be improved in future work. The first objective to achieve is the integration of the OpenRDF Sesame repository as an O-MI node. The real impact of the interoperability among different IoT data providers will be demonstrated after that a sufficient amount of real-world data can be collected. However, we are convinced that the approach is very promising.

As for the ITS services on the whole, we presented some research ideas such as ontology fusion or semantic annotation of sensor data, as well as their potential contributions to the ontology-enabled traffic information service. The whole range of state-of-the art is still very large to explore completely and not much detailed in this paper. As for the existing ontologies to be integrated in ITS services, a variety of ontologies studied by Open Geospatial Consortium [17] and published standards are to be investigated in parallel.

Acknowledgment

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