# OAIDS: An Ontology-Based Framework for Building an Intelligent Urban Road Traffic Automatic Incident Detection System

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**Abstract.** Handling interoperability of data exchange among road traffic sensor devices, connected vehicles, infrastructure components and heterogeneous traffic management center applications has become an important and basic requirement nowadays. To meet this requirement, this paper proposes an ontology based framework to capture the knowledge domain about traffic automatic incident detection system (AIDS) based on Connected Vehicles (CVs) technology. This ontology addresses the semantic data interoperability needed between different heterogeneous entities constituent this AIDS. This contribution aims at modeling and capturing the semantic of the anomaly information used in the incident detection process and describing the AIDS components, their observations, measurements and communications messages features. First, to achieve this goal, NeOn methodology was adopted. Then, we defined the basic concepts and observations of a traffic sensor and CVs that has been extended to define concepts related to the data sensing and gathering layer of this framework based on ontology concepts. In addition, to ensure data interoperability and identify ontology's restrictions, we used the OWL (Web Ontology Language) language. Furthermore, to build this ontology, we used the OWL under Protégé tool. Finally, OAIDS consisted of 93 concepts and 33 object properties. OntoMetrics was used to confirm the effectiveness of this proposed ontology to carry out the interoperability of CV's sensor data in the urban road AIDS domain.

**Keywords:** Traffic Incident, Automatic Incident Detection System (AIDS), Interoperability, Ontology, Web Ontology Language (OWL), NeOn.

## 1 Introduction

In modern smart cities, an Automatic Incident Detection System (AIDS) is an indispensable component used to improve the performance of transportation systems and to provide suitable and reliable safety services based on the data generated from the movement of smart vehicles on different road infrastructures. Actually, the AIDS contain two major components, which are data sensing, and gathering component, and data processing and incident detection component. The first component ensures the effectiveness of the obtained traffic data quality, while the second component is the more intuitive one to understanding, analyzing, and making decisions about the real-time traffic incident within an efficient transportation system.

However, one of the major requirements of AIDS is the collection and the dissemination of real time data in order to process, monitor, and manage it with heterogeneous components. These requirements can help end users to understand the real-time road situations such as road traffic congestion, closure of lanes due to traffic incidents, travel speed limits and also sharing urgency alert notification information for analysis and monitoring traffic mobility especially on urban areas. To these end, AIDS are based on the following traffic data collection technologies such as intrusive and non intrusive sensors (e.g. Inductive-Loop, Seismic Sensors, Radar, Ultrasound, Wireless Vehicle Identification Sensors and Video Image Processing sensors), and sensors located into connected and autonomous vehicles. Therefore, the data generated from these technologies are heterogeneous in format, structure, semantics, organizations, and accessibility. That makes its implementation and integration by the second AIDS's component without any delay or miscommunication problems a severe challenge. For that, transportation researchers used some communication protocol standards under the initiative technology named Vehicular Ad-Hoc Network (VANET) that is identified as one of the most promising technologies for managing future ITSs data exchange and communication. However, according to the last development research recommendations, this proposition cannot give a complete solution to handling the data interoperability, especially for sensor data.

Actually, the primary challenges for any AIDS based on CV sensor data is how to deliver these data and then transforming it into useful visual representation in unique and standard form? To answer this question, we must first understand the relationships between these CV sensors and others AIDS entities, including road traffic sensors, Road Side Units (RSUs), Traffic Management Center (TMC) and traffic information systems. Unfortunately, sharing and retrieval CVs data represent a challenge. Since this operation needs a greater interoperability among different AIDS entities involved in the transportation system.

One of the simplest ways of tackling this problem is to use Ontology concept. Ontologies defined as "a formal explicit specification of shared conceptualization" [1]. As ontologies provide a common vocabulary in a given domain and allow defining, with different levels of formality, the meaning of terms and the relationships between them. In an intelligent transportation system (ITS), Ontologies can describe the live traffic situation of the movement of CVs and the interaction between ITS infrastructure components and different involved sensors. Such usage can be done across the design of a standardized methodology of conceptual schemes to allow communication and information exchange between different ITS visual monitoring system entities.

Nevertheless, different contributions have been developed in this regard. Researchers have been trying to provide a set of ontologies to describe a specific scenario in Advanced Driving Assistance Systems (ADAS), vehicle sensing system failures, modeling context information utilized pervasive transportation services, prediction of congestion and traffic light signal, and management of traffic situations. However, there has been very few research efforts conducted into using ontology to give a unique semantic interpretation of information collected by the integrated sensors in CVs, RSUs and Traffic Signal Controller (TSCs) to describing the semantic data of anomaly information events in a signalized intersection. In particular, there is a gap to deal with these sensory data in the AIDS field.

In spite of this, a new approach based on the concept of ontology is therefore needed to tackle the problem of incident traffic data exchange on the whole transportation network. Taking all this into account, our paper aim is to focus on fill this gap by implementing a unified ontology under traffic incident cases. This is to achieve the mounting need to serve CV's Basic Safety Message Data (BSM) data in real-time and to provide a detailed description about the knowledge data in this type of system.

As a solution, the contributions of this work can be summarized as follows:

First, describe the OAIDS ontology structure; Second, Adopt the NeOn Methodology to build OAIDS ontology. Finally, developed and modeled the anomaly traffic information and its specifications according to the OAIDS Ontology.

The paper is organized as follows: Sec 2 discusses the state of the art of different proposed ITS ontologies based on sensor data. We introduce our proposed ontology and its empirical evaluation in Sec 3. Finally, we conclude our paper in Sec 4.

## 2 Related Works

In this section, we review the literature related to the main proposed ontologies in the context of ITS.

In [2], authors proposed a new ontology to improve the driving environment through a traffic sensor network. To describe the different concepts involved in the road traffic scenario, such as vehicles, infrastructure elements, sensors, and driver behaviors; and also the relationships between them, Semantic Sensor Network (SSN) ontology is applied. To validate this proposed ontology, authors used Web Ontology Language- Resource Description Framework (OWL-RDF) language and the Protégé tool. The results obtained confirmed the greater decision-making capability to know the overall traffic situation at all times, instead of having only a partial view.

By using the same ontology that is SSN, authors in [3] tried to manage the sensor information to perform the automatic traffic light settings allowing to predict and avoid traffic accidents and the routing optimization. The authors used RDF concept to mapping sensor data into SSN ontology. However, authors suggested to improve the mapping process by reducing the human intervention in the semantic annotation. Other ontology to support road traffic assistance transportation management applications is also proposed in [4]. The concepts of this ontology are related to vehicles and the elements related to road infrastructure. In term implementation, they used OWL-RDF language using the protégé tool and SPARQL query language.

Authors in [5] introduced a visualization oriented ontology that formalizes the knowledge about urban mobility events and visualization techniques. OWL is used to develop this ontology. Allow the semantic annotation of urban mobility events is the main advantage of using this ontology.

Adaptive I-parking system ontology is also discussed in [6] for building adaptation services for I-parking system's user interface. First, authors identified the concepts of this ontology and grouped it as environment, device, user interface and service intelligent parking concepts. Then, they used OWL to define restrictions between these concepts. Moreover, the adaption rules are identified by using the SWRL. Finally, Protégé tool is used to develop this ontology.

In 2017, authors proposed two ontologies to describe the safe driving for Advanced Driver Assistance Systems [7]. The first is for autonomous vehicles and the second is for the knowledge base that integrated map, car and control ontologies. The RDF is used to convert senor data, while C-SPARQL Query Engine is used to observe it. Moreover, the SWRL rule is used as a reasoning method. Experimental results prove the capability of this proposition to enhance real-time decision making systems.

New ontology for traffic event using autonomous vehicles is presented also in [8]. An annotation for predicting future traffic accidents is also developed. Protégé tool is used to visualize the structure of this annotation. Their results confirmed that accident occurrence depending on varies traffic environment scenarios.

In [9], authors proposed the SSN ontology to manage the sensor information in an ITS. Their objective was to develop a semantic integrator module to map sensor data to SSN ontology in automatic way. For this, they used RDF to translate and mapping senor data to SSN. For validation goal, the semantic integration system was applied as part of an automatic traffic light settings application, to predict traffic accidents and perform routing optimization on ITS. Using machine learning with rule based system is suggested to enhance the semantic annotation process.

In [10-11], authors presented vehicle signal specification ontology (VSSO).To this end, they used the concepts of Sensor, Observation, Sample, and Actuator (SOSA) and SSN ontology in order to represent observation of car signals. Comparison results of integration of VSSO, SOSA/SSN and STEP to other ontologies demonstrates it effectiveness in term sensor coverage, semantics, trajectory enrichments metrics.

VANETs is another ITS domain where researchers developed a specific ontology named Messaging Ontology for VAnets (MOVA) to support multi-hop message dissemination over VANETs as presented in [12]. The objective of this ontology is to enhance performance of VANETs in order to disseminate messages between vehicles, especially for traffic safety related services. OWL and Protégé tool are used to design and organize the information transmitted between vehicles.

In 2020, several ontologies in ITS domain are proposed. First, authors in [13] developed a new Connected Traffic Data Ontology (CTDO) on the foundations of SOSA ontology. The aim of this contribution is to provide a suitable ontology for large volumes of time-sensitive data coming from multi-sensory on connected vehicles. Authors used Semantic Web technologies (SWT) and RDF to support the operation of CAVs within urban roads. BSMs data are used to translate CVs data onto SOSA ontology based on three sensors integrated on CVs (i.e. speed sensor, acceleration sensor, and position sensor). To validate this contribution, Apache Jenna Fuseki and SPARQL queries are used. The results obtained demonstrate the effectiveness of CTDO in term query response time compared to SSN ontology. Secondly, authors in [14] proposed ontology for integration and visualization of urban mobility data. This ontology is named as Visualization-oriented Urban Mobility Ontology (VUMO). The objective of this ontology is to lay the semantic foundation for integrating S-T urban mobility data from heterogeneous sources, and building knowledge-assisted visualization tools based on a formal knowledge representation model for describing ITS instance data, analytical tasks, and annotating visualization techniques and expert knowledge. Thirdly, the work [15] presented ontology to understanding the common terms used in the transport system. For this, authors used Multi-Agent systems (SMA) coupled with semantic web in order to help decision-making and improve the management in the context of urban mobility. To implement this ontology, they used Protégé, OWL 2 Web Ontology Language and RDF. Finally, route suggestion system is another aspect to model it by ontology as presented in [16]. In this contribution, researchers tried to develop architecture called Ontology-based Route Suggestion by using the OWL with realistic data. In this regard, they used three main phases; semantic search, inference engine, and starting the engine. To validate this ontology, SWRL is used to develop semantic rules and Protégé tool.

In sum, although there was a vast literature on ontology based ITS, there is no actual ontology for an urban AIDS that use the concept of CVs. Consequently, there is a dire need for finding an efficient solution that can achieve the visual analysis of a real time traffic incident detection based on unified concepts and knowledge. For thus, our system focuses on the development of a novel ontology to assist TMC authorities and drivers to use a traffic data monitoring and visualization system based on ontology principles and data semantic interoperability.

## 3 Proposed Ontology Framework

In our solution, we propose creating domain ontology for Automatic Incident Detection System based on the CV technology. The ontology is called “Ontology for Automatic Incident Detection System” (OAIDS). More details about the conception of this ontology are given below.

### 3.1 AIDS Structure

Since an AIDS consists of a number of heterogeneous components, it is important to define a shared representation of the exchanged information. In addition, each component has a direct/indirect impact on the other components and on the overall system. For that OAIDS would provide a structure that is flexible, and that naturally organizes the information in multidimensional ways. We divide the functional architecture of our proposed approach in four layers as shown in Fig.1. These interconnected layers are (1) traffic data collection (TDC) layered, (2) traffic data preprocessing and storage (TDPS) layered, (3) traffic data analytic (TDA) layered and (4) Incident data alarm visualization (IDAV) layered, respectively where each has its own data control layer and data distribution layer. The data control layer is responsible for the management of data and its operations branch, and the data distribution layer is the responsible for the data circulation between the layers. In our approach, these four layers are interconnected and they can collaborate with each other to provide a real-time incident data for road traffic management efficiency and safety. In the following subsections we provide further details of these layers.

The TDC layer consists of intrusive and non intrusive sensors with connected vehicles in a road infrastructure. The TDPS consists of a data acquisition and data storage services. TDA consists of a set of services, which have the goal of detection of data anomaly from normal and then the detection of incident. The last layer, which is IDAV is contained two services; the first for the distribution of incident alarm notification to end users and the second for the prevention of route suggestion.

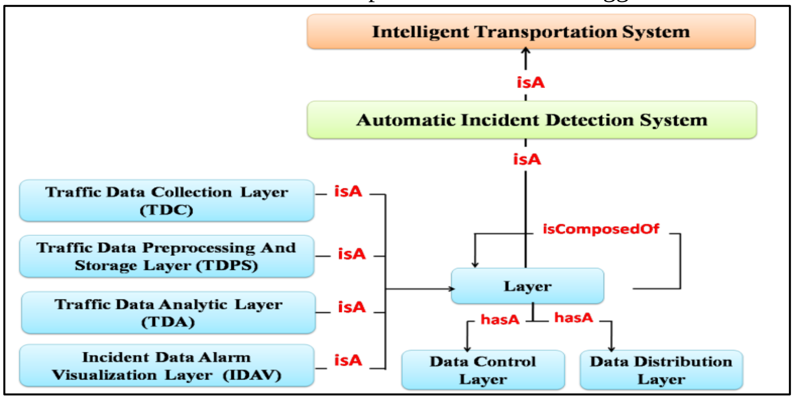


**Fig.1**. The AIDS skeleton structure.

### 3.2 OAIDS Development

In this subsection, we describe our proposed ontology structure in detail using the methodological guidelines proposed in NeOn methodology [17].

**The NeOn Methodology Framework.** The NeOn methodology is one of the proven methods for ontology engineering.“It is a scenario-based methodology that provides accurate details about key aspects of the ontology engineering process, paying special attention to the reuse and reengineering of ontological and non-ontological resources. This framework is founded on four pillars: (1) a glossary of processes and activities; (2) a set of nine scenarios for building ontologies and ontology networks; (3) two modes of organizing ontology developments, called ontology life-cycle models; and (4) a set of precise methodological guidelines for performing specific processes and activities” (p.110) [18-19].

**The Proposed AIDS Ontology.** The proposed method for building OAIDS is illustrated in Fig.2. A detailed description of each component of the proposed method is presented next.

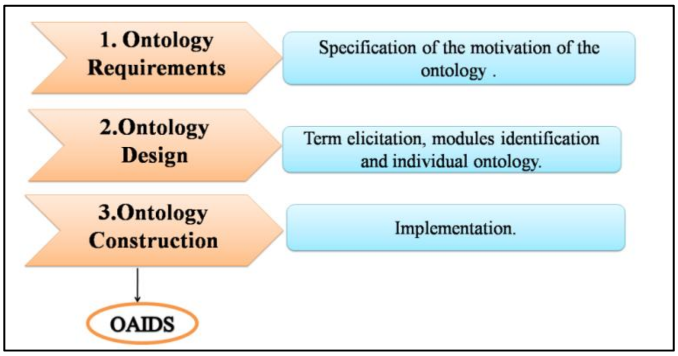


**Fig.2**. Phases and procedures used for the proposed methodology of OAIDS.

*Ontology Requirements*. In this phase, we used ORSD (Ontology Requirements Specification Documents) to describe the purpose of building the ontology, the scope covered by this ontology, the intended uses, the end users who may use this ontology, and then, the functional and non-functional requirements that the ontology should perform. And also, the glossary of terms that will be formally represented in the ontology by means of concepts, attributes and relations. The output of these tasks is the OAIDS ontology (see Table 1 for more detail).

*Ontology Design.* This phase consists in organizing Automatic Incident Detection domain knowledge (concepts and relationships) in a shared and conceptual model. First, we define the concepts classification trees. Then, we identify Class Attributes and restrictions. Finally, we identify the Instances.

- Identification of Concepts**:** To cope with the multi-objective aspect of an AIDS, we present the knowledge in our ontology as 8 groups of concepts (See Fig.3.), each covering an objective aspect, namely: (1) infrastructure, (2) vehicle, (3) detector (4) network, (5) information, (6) incident, (7) service and (Person). Those concepts are the key for conceiving real time incident detection. However, the symbol (+) in this figure means that exists another sub division in each concept.
- Identification of restrictions, object properties and definition of instances (individuals): Fig.4 illustrates the main OAIDS data property, object property and instances used to describe our ontology.

*Ontology Construction.* We have designed and implemented our proposed OAIDS ontology using Protégé 5.2.0 tool. The designed ontology is extracted in OWL 2 format. For purpose of sharing and reusing, the ontology open source is available at: https://github.com/SAMIAHCC/OAIDS/tree/V1.

The resulting ontology system is composed of 931 axioms, 93 classes, 33 object properties, 73 data properties, and 47 individuals. The level of Data Logic (DL) expressivity is ALEHQ (D). In addition, OntoMetric web-based tool [20] is used to validate and display statistics about ontology metrics as shown in Table 2.

To sum, OAIDS evaluation shows acceptable measures to validate the effectiveness of this ontology. However, inconsistency, incompleteness and redundancy measures are required to be addressed to give more accurate evaluation in the future.

**Table 1**. Summary of the Ontology Requirements Specification Document for OAIDS.

| | |
|---|---|
| Purpose | Representation of the knowledge in the domain of AIDS that can be used by public ITS safety services. |
| Scope | The ontology will on information exchange in AIDS. |
| Implementation & language | The ontology will be implemented in the ontology representation language OWL 2 using Protégé tool. |
| Intended Users | Direct users: transportation researchers who conduct academic research in order to improve incident detection. Software engineering for developing ontology driven information systems.<br>End users: drivers and TMC authorities who are searching incident detection notification. Public or private transportation service which offers services to gather, to analyze and to prepare some data and statistics about the situation of traffic safety. |
| Intended use case | Use case 1: to share a common understanding of traffic data knowledge between different AIDS components such as type of message, format of data, structure of packets. |
| Ontology requirements | What are the major devices used in AIDS?<br>What is the traffic sensor behaviors sent from CVs?<br>What are the main activities for each AIDS component?<br>Which type of VANET messages is used?<br>What types of information are circled in AIDS?<br>What are the symptoms of an incident occurrence on traffic?<br>What is the type of data used to judge the incident detection? |
| Pre-glossary of terms | Traffic, connected vehicle, detectors, signal, message, detection, incident, anomaly, VANET, collecting, analytic, alarm, distribution, intersection, road. |
| Identified questions | What is meant by an incident?<br>Which information is used to define a traffic anomaly data?<br>What are the main factors used to define an incident alarm?<br>Who are the people associated with incident detection?<br>Which mechanisms are used to distribute traffic data from its collecting till to its processing? |

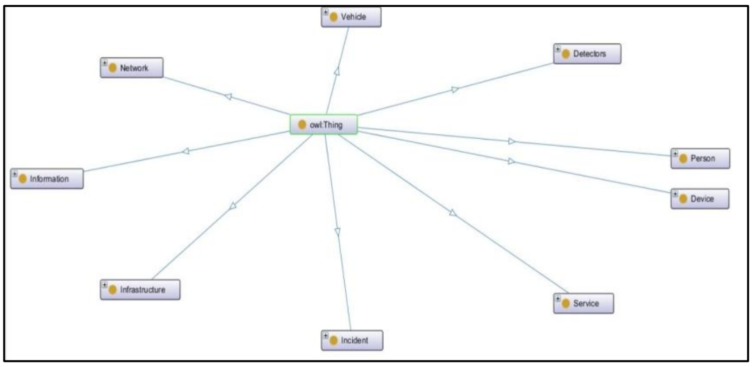


**Fig.3.** Main OAIDS concepts.

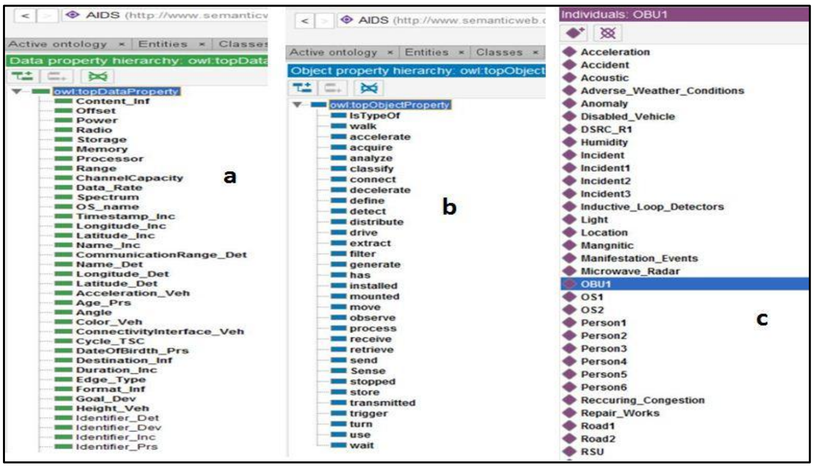


**Fig.4.** (a) OAIDS data property. (b) Object property. (c) Instances.

**Table.2.** General OAIDS ontology metrics.

| Base Metrics | | Graph, Schema & Knowledgebase Metrics | |
|---|---|---|---|
| Axiom | 931 | Absolute sibling cardinality | 93 |
| Logical axiom count | 675 | Absolute depth | 244 |
| Class count | 93 | Absolute breadth | 93 |
| Object property count | 33 | Total number of paths | 93 |
| Data property count | 33 | Attribute richness | 0.784946 |
| Individual count | 74 | Class/ relation ration | 0.794872 |
| Annotation Property | 1 | Average population | 0.505376 |

## 4 Conclusion and future works

Several propositions exist in literature which constructs a domain ontology for different ITS domains. However, none of them explains the AIDS ontology engineering process which might be very helpful for many stakeholders (e.g. ontology developers, domain experts, and end-users) to improve safety and efficiency of transportation networks. In this work, we deal with the development of OAIDS, an ontology representing the domain knowledge specific of AIDS, particularly for the urban areas. It was built by adapting NeOn ontology development methodology. Through this paper, the authors give the comprehensive semantic description of the AIDS domain. It will serve as the semantic knowledge base to facilitate and simplify the development of urban automatic incident detection systems.

In the future, we will extend and re-organize this ontology for representing other AIDS management knowledge and then prove compliance of the world model to the world modeled formally of OAIDS by adding ontology evaluation phase.

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