SCIENTIFIC OASIS

Spectrum of Engineering and Management Sciences

Journal homepage: www.sems-journal.org
ISSN: 3009-3309

An Ontological Model to Enhance Traffic Conditions in Smart City Domain

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ARTICLE INFO

Article history:
Received 22 September 2024
Received in revised form 21 May 2024
Accepted 8 June 2024
Published 9 June 2024

Keywords:
Knowledge Management; Smart City; Ontology; Transportation

ABSTRACT

The rising trend of the increasing interconnection of city services refers to the growing integration and interconnectedness of various urban systems and services through the utilization of technology and data. One of the primary objectives of smart city initiatives is to establish more efficient and sustainable urban environments by optimizing resource utilization and infrastructure. In this paper, we introduce a traffic ontology named "TrafCsOnto," which encompasses a comprehensive range of traffic concepts. The primary aim of this ontology is to address traffic congestion issues within the smart city context. The formalization of this ontology has been carried out using the OWL language and the protégé tool. We endeavor to illustrate the practical application of the traffic ontology through the manipulation of real-world instances and inferences.

1. Introduction

As the global population continues its relentless growth, cities are confronted with a myriad of daunting challenges such as traffic congestion, air pollution, and efficient transportation systems. To combat these pressing issues, many cities are embracing smart city technologies that capitalize on data and connectivity to enhance urban mobility and elevate the quality of life for their residents.

Smart city technologies have the potential to optimize traffic flow, alleviate congestion, and enhance road safety. Nevertheless, the implementation of these technologies is not without its own set of formidable challenges. One of the primary hurdles lies in integrating diverse systems and data sources. Smart city technologies heavily rely on data streams originating from various sources, including traffic sensors, GPS devices, and mobile applications. The integration of these disparate systems demands intricate solutions and necessitates substantial investments in software development.

In this article, we will explore some of the challenges facing smart cities and traffic systems, we will propose traffic ontology to resolve interoperability problems resulting after a collaboration pro-

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https://doi.org/10.31181/sems1120246m

cess between smart city components. The structure of the paper is organized as follows: Section 2 will be the background, Section 3 represents related works, Section 4 designs ontology construction steps, Section 5 will be a discussion and we finish with Section 6 by giving the conclusion and future work.

2. Background

2.1 Smart City Applications

Hall [1] mentioned that “A city that monitors and integrates conditions of all of its critical infrastructures, including roads, bridges, tunnels, rails, subways, airports, seaports, communications, water, power, even major buildings, can better optimize its resources, plan its preventive maintenance activities, and monitor security aspects while maximizing services to its citizens”. A smart city is a domain that covers various aspects of urban development and management, leveraging technology and data-driven solutions to improve the quality of life for residents and enhance sustainability. Here are the smart city functions defined by Batty et al. [2] and similarly by Albino et al. [3]:

i. *Smart economy* – Tackles the competitiveness of cities in terms of productivity. Transportation availability has an impact on activities accessibility.
ii. *Smart people* – Tackles social issues and human capital, no matter how diverse, creative, and educated. The equity of transportation systems may affects the diversity of the population. The system also provides many opportunities for people to track educational and learning activities.
iii. *Smart governance* – This includes the use of technology to improve communication and engagement between citizens and their government.
iv. *Smart environment* – Attend to have sustainable resource management in order to reduce pollution caused by various means of transport.
v. *Smart living* – Addresses education and cultural facilities, safe living conditions, and general tourist appeal. Mobility has an impact on safety, healthy living across active transit options, and their availability to destinations.
vi. *Smart mobility* – Deals with the traffic.

Smart city applications encompass the utilization of cutting-edge technologies to augment the well-being of citizens, elevate the quality of urban services, and foster urban advancement [4]. Below are presented several instances of smart city applications [5]:

i. *Intelligent transportation systems* – These systems use sensors, cameras, and other technologies to manage traffic flow, reduce congestion, and enhance safety on the roads.
ii. *Smart parking* – Smart parking systems use sensors and data analytics to help drivers find available parking spots quickly and efficiently, reducing traffic congestion and carbon emissions.
iii. *Smart waste management* – IoT sensors can monitor waste levels in bins and optimize collection schedules, resulting in more efficient waste management and reduced pollution.
iv. *Energy management* – Smart energy systems use sensors and data analytics to optimize energy consumption, reduce carbon emissions, and lower energy bills.

v. *Smart buildings* – Smart building systems use sensors and automation to optimize energy use, reduce maintenance costs, and enhance occupant comfort.
vi. *Public safety* – Smart city applications such as video surveillance and facial recognition can enhance public safety and help law enforcement agencies respond more effectively to emergencies.
vii. *Environmental monitoring* – Smart applications can monitor air and water quality, weather conditions, and other environmental factors to help policymakers make informed decisions and protect public health.
viii. *Citizen engagement* – Smart city applications can enable citizens to participate in urban planning and decision-making through online platforms, mobile applications, and other digital tools.

Smart city is a large domain that encompasses different kinds of applications that are developed to ensure its sustainability and answer to citizens' requirements. In the next subsection, we will explore how knowledge is managed in smart cities.

2.2 Knowledge Management in the Context of Smart Cities

Knowledge management was defined as a process that "involves the people, process, culture, and enabling technologies necessary to capture, manage, share, and find information" [6]. As reported in [7], knowledge is the main factor in the establishment of cities. In fact, knowledge has a strong influence on the economy, society, and culture of a city.

Knowledge management holds utmost significance in the advancement and operationalization of smart cities. The prosperity of smart cities is heavily reliant on harnessing technology to amass and scrutinize data from myriad origins, intending to enhance the well-being of their populace. This necessitates the adoption of a meticulously structured methodology to effectively administer knowledge and information, guaranteeing the precision, dependability, and pertinence of the accumulated data, harmonized with the unique requisites of the city. Here are some key aspects of knowledge management in smart cities [8]:

i. *Data governance* – The first step in managing knowledge in smart cities is to establish a data governance framework that defines how data is collected, stored, and shared. This includes establishing data ownership, defining data standards, and developing protocols for data sharing and access.
ii. *Data analytics* – Smart cities generate vast amounts of data from various sources, including sensors, IoT devices, social media, and mobile applications. Effective knowledge management requires the use of data analytics tools to identify patterns, trends and insights from the data.
iii. *Collaborative platforms* – Smart cities require collaboration among various stakeholders, including citizens, businesses, and government agencies. Knowledge management platforms such as collaborative decision-making tools and knowledge-sharing platforms can facilitate collaboration and knowledge sharing.
iv. *Citizen engagement* – Knowledge management in smart cities involves engaging citizens in the collection, analysis, and use of the data. This includes developing citizen-centric platforms and accessing information about city services and initiatives.
v. *Continuous improvement* – Smart cities are dynamic environments that require continuous improvement. Effective knowledge management requires the use of feedback

mechanisms to monitor performance, identify areas for improvement, and make data-driven decisions to improve city services and initiatives.

Overall, knowledge management is essential for the successful development and operation of smart cities. By leveraging technology and data to improve decision-making, enhance citizen engagement, and address complex urban challenges so that cities can create more sustainable, livable, and resilient urban environments. In contrast, the collaboration between each component is still a difficult challenge. This topic will be addressed in the subsequent section, wherein we will undertake an extensive survey encompassing the prevailing ontologies within the domain of smart cities at large. Moreover, we will delve into the specific realm of traffic ontologies, delving deeper into their intricacies and nuances.

3. Related Works

3.1 Smart City Ontologies

Ontologies serve as a valuable instrument for representing semantic Web data, facilitating knowledge organization and exploration of relationships. Within this context, Gruber [9] defined that “an ontology is an explicit and formal specification of a conceptualization of a domain of interest”. A smart city ontology, accordingly, embodies a formal representation of knowledge within the smart city realm, employing concepts, properties, and their interrelationships. These ontologies are utilized to describe and structure knowledge methodically and coherently, thereby enabling more efficient and effective information management and sharing. To further elucidate, a comparative table detailing the most prominent smart city ontologies is presented below.

Table 1
Smart city ontologies

Ontology	Focus	Data model	Development	Key features
SmartCity ontology	**Various smart city domains such as transportation and governance**	**OWL**	**Ontology development kit**	**Modular design, extensibility**
CityPulse ontology	**Sensor data in smart city domains such as traffic and air quality**	**RDF**	**Not specified**	**Real-time data processing and analysis**
SAREF4City ontology	**IoT devices and systems in smart cities**	**OWL**	**Ontology development kit**	**Integration of IoT devices and systems**
Smart-M3 ontology	**Interoperability between smart city systems**	**OWL, RDF**	**Ontology development kit**	**Support for data and information exchange**
ISO/IEC 30182 ontology	**Standard for ontologies in smart city domains**	**Not specified**	**Not specified**	**Interoperability and standardization**

In conclusion, Table 1 provides a comprehensive overview of various smart city ontologies, highlighting their key characteristics, features, and relevance within the context of smart cities. By examining these ontologies, we gained valuable insights into the diverse approaches and conceptualizations employed in the representation and management of knowledge in smart city domains.

Moving forward, we will now shift our focus to a specific subset of smart city ontologies; i.e. traffic ontologies. In the subsequent subsection, we will delve deeper into the realm of traffic ontologies, exploring their unique characteristics, applications, and contributions to the field of smart city transportation systems. We will examine the role of traffic ontologies in improving traffic management, enhancing mobility, and optimizing transportation infrastructure within the smart city context. By narrowing our focus to traffic ontologies, we aim to provide a more targeted and detailed analysis of this specific domain within the broader smart city landscape. We will explore the existing traffic ontologies, evaluate their strengths and limitations, and discuss their potential for integration and interoperability with other smart city components

3.2 Traffic Ontologies in Smart City Domain

As part of our research work, we were interested in the field of traffic in smart cities and we built a traffic ontology that we called "TrafCsOnto". Before presenting the steps we followed for the construction of our ontology, let us give an overview of the existing ontologies.

Traffic ontologies, in essence, serve as meticulously structured representations of knowledge that revolve around the intricate dynamics of traffic and transportation systems. They serve as a means to model and organize a vast array of information pertaining to various traffic-related concepts, including but not limited to vehicles, road networks, traffic flow patterns, and congestion dynamics. The application of traffic ontologies spans a broad spectrum, finding utility in diverse domains such as transportation systems optimization, traffic simulation, and in-depth traffic analysis.

In the subsequent section, denoted as Section 4, we shall expound upon a compelling use case that demonstrates the practicality and efficacy of our traffic ontology, shedding light on its potential to enhance traffic management practices within the context of smart cities. By presenting this use case, we hope to showcase the real-world applicability and value that "TrafCsOnto" brings to the field, thereby reinforcing its significance as a valuable asset in the quest for efficient, sustainable, and future-oriented urban transportation systems.

Fernandez et al. [11] proposed a framework that entailed an ontology-based architecture devised to facilitate the development and implementation of intelligent transportation systems (ITS). This framework served as a blueprint for designing and deploying ITS applications, harnessing the power of ontologies to effectively represent and encapsulate the vast array of knowledge and information pertaining to the transportation domain. Within the realm of ITS, an ontology assumes the role of a comprehensive representation, encompassing diverse components of the transportation system, such as vehicles, road infrastructure, traffic flow dynamics, and transportation policies.

This architecture is underpinned by a multi-layered structure, comprising distinct layers that collaboratively contribute to the functioning of the ITS. The data layer serves as a repository for managing and storing transportation-related data, encompassing variables such as traffic flow patterns, weather conditions, and real-time vehicle locations. The knowledge layer, on the other hand, leverages the potential of ontologies to encapsulate and organize the knowledge, rules, and regulations pertinent to the transportation domain. By virtue of this layer, the framework gains the ability to reason and infer new knowledge based on the existing knowledge base, thanks to the capabilities provided by the inference layer. Lastly, the user interface layer serves as a user-friendly gateway, affording seamless access and interaction with the ITS applications, thereby enhancing usability and user experience. Through the intricate orchestration of these layers, the ontology-based architecture for intelligent transportation systems strives to create a robust and efficient framework that fosters the advancement and evolution of transportation technologies. By harnessing the power of ontologies, this architecture offers a structured and organized approach to manage and exploit the wealth of knowledge and information associated with transportation, ultimately aiming to optimize transportation systems, improve traffic management, and enhance the overall user experience within the realm of intelligent transportation.

ITS plays a crucial role in the context of smart cities. However, they often lack the necessary context required by road users and network managers to make informed decisions. These systems must be capable of gathering data from diverse and disparate sources and analyzing it effectively, providing timely information to relevant stakeholders.

Abberley et al. [12] focused on leveraging Big Data analytics to gain insights into road accidents, a significant contributor to non-recurrent traffic congestion. The objective was to develop a model that captured the semantic aspects of road accidents within an ontology. By utilizing the capabilities of the ontology, specific dimensions and Big Data sources were selectively chosen to populate a comprehensive model of non-recurrent congestion. Initial analysis of the extensive Big Data collected from two distinct sensor types in Greater Manchester, UK, was conducted to ascertain the feasibility of identifying clusters based on journey time and traffic volumes. By employing sophisticated Big Data analytics techniques and harnessing the power of ontologies, this research aimed to enhance our understanding of road accidents and their impact on traffic congestion. The ultimate goal was to facilitate informed decision-making processes by providing relevant stakeholders with valuable insights and actionable information derived from the comprehensive analysis of Big Data. Through this approach, the authors strived to improve the management and mitigation of non-recurrent congestion, contributing to the overall efficiency and sustainability of urban transportation systems within the context of smart cities.

Syzdykbayev et al. [13] presented an ontology specifically tailored for collaborative navigation within the context of autonomous cars, drivers, and pedestrians in smart cities. This ontology served as a comprehensive representation of the pertinent concepts, relationships, and rules associated with navigation in a collaborative setting. It encompassed a wide range of concepts, including traffic rules, road conditions, vehicle and pedestrian behavior, as well as communication protocols. By employing that ontology, effective communication and coordination among diverse actors within the collaborative navigation environment could be achieved. Moreover, it could serve as the foundation for the development of intelligent navigation systems that aim to alleviate traffic congestion, enhance safety measures, and improve overall transportation efficiency within smart cities. The article emphasized the significant role of ontologies in fostering interoperability and standardization across smart city systems. The proposed ontology for collaborative navigation was poised to facilitate the creation of advanced transportation systems that benefit both drivers and pedestrians alike. Through its structured representation and incorporation of relevant knowledge, the ontology empowered the development of intelligent transportation solutions capable of addressing the unique challenges and complexities of navigation in smart cities.

De Oliveira et al. [14] discussed the use of transportation ontologies for personalizing user interfaces in transportation-related applications. This article suggested that transportation ontologies could be used to personalize user interfaces by displaying relevant information and options to users based on their preferences. For example, if the user prefers to take public transit, the user interface can display information about nearby transit stops, routes, and schedules. If the user prefers to drive the user interface can display information about nearby parking options and traffic conditions. By using transportation ontology for content personalization, transportation-related applications can improve the user experience and provide more relevant information to users. This can help users make better transportation decisions and ultimately lead to more efficient and sustainable transportation systems. This work emphasizes the importance of standardization and interoperability in transportation systems and suggests that transportation ontologies can play a key role in enabling this. By using transportation ontologies, transportation-related applications can share data and work together to improve the overall transportation experience for users.

Houda et al. [15] presented a public transportation ontology that aimed to support user travel planning. This ontological model included concepts related to public transportation such as transportation mode (e.g. bus and train), transportation stops (e.g. stations and bus stops), and schedules. The ontology was designed to be machine-readable. This allowed for the development of applications that could use ontology to help users plan their public journeys. This model was developed by analyzing existing public transportation data sources, such as schedules and route maps, and extracting the relevant concepts and relationships. The authors also consulted with domain experts to ensure the ontology was comprehensive and accurate.

The following is a comparative table that presents the traffic ontologies:

Table 2
Comparative table about existing traffic ontologies in smart cities

Ref.	Ontology/uses cases	Concepts	Relations	Limitations
[11]	**– Traffic management and monitoring – Incident detection and response – Travel time estimation and route planning – Intelligent traffic signal control – Intelligent driver assistance**	**– Road network: road, intersections, and bridges – Transportation modes: cars, buses, and bicycles – Traffic management: traffic signals, traffic signs, and road markings – Transportation infrastructure: parking facilities, bus stops, and train stations. – Travel demand: trip origins, travel modes, and travel times**	**– HasRoute (transport mode, road network) – HasConnection (road segment, road intersection) – HasGeometry (road segment, spatial geometry) – HasCapacity (transportation mode, capacity) – HasSpeed (transportation mode, speed) – HasTrip (trip, origin/destination point)**	**– The developed ontology does not include enough details on the behavior of individual vehicles or drivers – This ontological model does not cover certain types of transportation, infrastructure, or modes of transportation (public transit, pedestrian traffic)**
[12]	**– Congestion prediction – Traffic management and control – Emergency response and incident management – Public transportation optimization – Infrastructure planning and expansion – Data-driven policy making – Travel demand management**	**– Smart city: smart transportation, smart building, smart energy – Sensor: traffic sensors, weather sensors, air quality sensors – Data: traffic data, energy consumption data, weather data – Analytics: data mining, machine learning, statistical analysis – Application: traffic management systems, energy management systems, emergency response systems – Citizen: resident, visitor, business owner – Service: transportation service, energy service, emergency service**	**– Collects (sensor, data) – Analyses (data, analytics) – Uses (analytics, data) – Provides (service, citizen) – Consumes (citizen, service) – Requires (sensor, data or service)**	**– The ontology mainly focuses on the road network and does not consider other transportation modes such as public transportation and cycling – Some important concepts and relations such as road congestion and accidents are not taken into consideration – This model does not fully capture the spatiotemporal aspects of traffic**

Table 2 *continued*

Ref.	Ontology/uses cases	Concepts	Relations	Limitations
[13]	– Intersection management (collaboration between cars, drivers, and pedestrians needs to coordinate their movement) – Efficient traffic flow – Autonomous vehicle coordination – Driver-assisted navigation – Shared mobility services –Pedestrian-friendly navigation	– Autonomous cars (electric, hybrid, self-driving) – Driver (human, child, elderly) – Road infrastructure (traffic lights, crosswalks, pedestrian bridges) – Traffic rules (speed limit, lane change rules) – Road conditions (congested traffic, construction zones, weather conditions) – Communication protocols – Navigation actions (lane change, turn-left, turn-right) – Collaborative navigation	– Has operator (autonomous cars, operator) – Has pedestrian (driver, pedestrian) – Uses infrastructure (entities, road infrastructure) – Flow rules (autonomous cars use traffic lights to navigate) – Depends on conditions (entities, navigation road congestions) – Communicates with (communication between entities) – Collaborates with (collaboration between entities during navigation)	– Lack of concepts related to incidents that occur during navigation that can provide valuable information for collaborative navigation systems – Lack of road hazards such as obstacles, conditions like construction zones, and slippery surfaces – The absence of network attributes such as road types (highway, local roads, speed limit, lane configurations, and classifications
[14]	– Personalized trip planning – Real-time transit information – Customized navigation and directions – Context-aware notifications – Personalized fare calculation – Points of interest recommendations	– Vehicle (cars, buses, trains, bicycles, airplanes) – Route – Stop/station – Schedule – Traffic conditions – Navigation – Public transportation – Personalized preferences – Fare and payment – Geo-location	– Has route (vehicle/user, route) – Stops at (vehicle, stop/station) – Follows (vehicle/user, vehicle) – Has schedule (route/stop, schedule) – Has traffic condition (route, traffic conditions) – Offers services (stop/station, transportation service) – Uses payment method (user, payment method)	– Lack of real-time traffic information (congestion levels, incidents, road closures) – Modelling and capturing the interrelationships between different modes of transportation, especially in the context of traffic is complex
[15]	– Trip planning and routing – Real-time transit updates – Fare calculation and ticketing – Multimodal journey planning – Travel history and recommendations	– User – Trip – Location – Public transportation mode – Route – Stop/station – Fare – Real-time-updates – Accessibility	– Has trip (user, trip) – Has origin (trip, location) – Has destination (trip, location) – Uses transportation mode (trip, transportation mode) – Follows route (trip, route) – Passes through (route, stops/stations) – Has schedule (route/stop, schedule)	– Lack of interrelation between different modes of transportation – Concepts related to real-time information such as service alerts, schedule changes, and alternative road suggestions may be missing

The integration of traffic ontologies with smart city ontologies facilitates cross-domain analysis and decision-making. It allows cities to consider the interactions and interdependencies between traffic, energy, environment, public services, and other aspects of urban life. This integration supports more comprehensive and integrated approaches to addressing traffic congestion, such as developing policies that promote sustainable transportation modes, optimizing urban planning to minimize traffic bottlenecks, or leveraging technology for dynamic traffic management.

In summary, traffic ontologies and smart city ontologies are interconnected, with traffic ontologies providing specialized knowledge and information for traffic and transportation systems while being integrated into the broader smart city context. This integration enables cities to leverage the power of ontologies to effectively manage traffic congestion and create more efficient, sustainable, and livable urban environments.

Based on the previous research we are trying to develop an enriched traffic ontology named “TrafCsOnto” dedicated to enhancing traffic conditions in the smart city domain and integrating into smart city platforms.

4. Ontology Construction

Hall [1] mentioned that “A city that monitors and integrates conditions of all of its critical infrastructures, including roads, bridges, tunnels, rails, subways, airports, seaports, communications, water, power, even major buildings, can better optimize its resources, plan its preventive maintenance activities, and monitor security aspects while maximizing services to its citizens”. A smart city is a domain that covers various aspects of urban development and management, leveraging technology and data-driven solutions to improve the quality of life for residents and enhance sustainability. Here are the smart city functions defined by Batty et al. [2] and similarly by Albino et al. [3]:

The ontology development process requires a development methodology that invokes various steps. Noy and McGuiness [16] proposed seven steps in order to develop ontology. So, in our work, we follow these steps. As a first step, we determine the domain and the scope of our ontologies using competency questions [17]:

i. What are congested roads on a specific time?
ii. What are available transport mediums?
iii. What kind of transport will be chosen?
iv. When is the departure time of the chosen kind of transport?
v. When is the arrival time of the chosen kind of transport?

In order to deal with these questions, information and knowledge on transportation systems should be considered. As a second step, we work on determining the taxonomy of our ontology. We reused existing concepts of traffic ontologies such as the taxonomy related to infrastructure [11,18].

The next two steps represent data analysis and class hierarchy definition. In fact, our ontology was created using Protégé tool [19], which is an open source for editing and building. It also supports a variety of ontology languages including RDF, OWL, and XML. It can be customized with plugins to extend its functionality.

“TrafCsOnto” ontology is based on six principal classes which are incident, infrastructure, trajectory, and vehicle (see Figure 1).

The class "incident" within the developed ontology serves to encompass unpleasant events that can lead to traffic problems, including traffic congestion. Previous research lacked concepts related to incidents, which prompted the enrichment of this concept in the ontology. The objective is to cover various types of incidents based on [20].

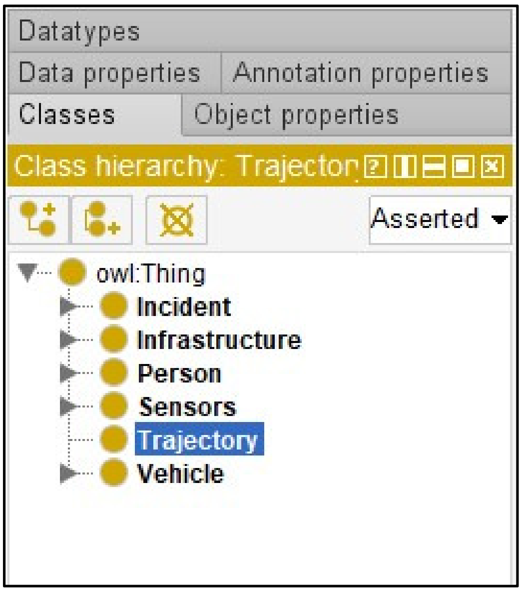

Fig. 1. “TrafCsOnto” global view.

In the developed ontology, the concept of "incident" is divided into "Recurrentincident" and "Nonrecurrentincident". The subclass "Recurrentincident" further includes subclasses such as "ExtremeWeatherConditions" (e.g. floods, blizzards, hurricanes), "ManifestationEvent" (e.g. music concerts, festivals), and "VehicleIncident" (e.g., car collisions, motorbike crashes, traffic violations). These subclasses represent incidents that occur repeatedly or exhibit a predictable pattern. The subclass "Nonrecurrentincident" encompasses subclasses such as "HospitalDeparture" (e.g. Rabta, Hedi Chaker hospitals), "ManifestationEvents" (e.g. women's marches, worker's strikes), "MarketDeparture" (e.g. Carrefour departure, mall of Sfax departure), "PeakHours" (e.g. lunch breaks, school pick-up, and drop-off), "Repair-Works" (e.g. pothole patching, road marking, and signage repainting), "SchoolDeparture", and "SportEvent" (e.g. cycling, marathons). These subclasses represent incidents that occur irregularly or are specific to particular situations or locations.

It is crucial to note that incidents are associated with specific locations, which are subclasses of the "infrastructure" class. Furthermore, incidents are detected through sensors, as illustrated in Figure 2.

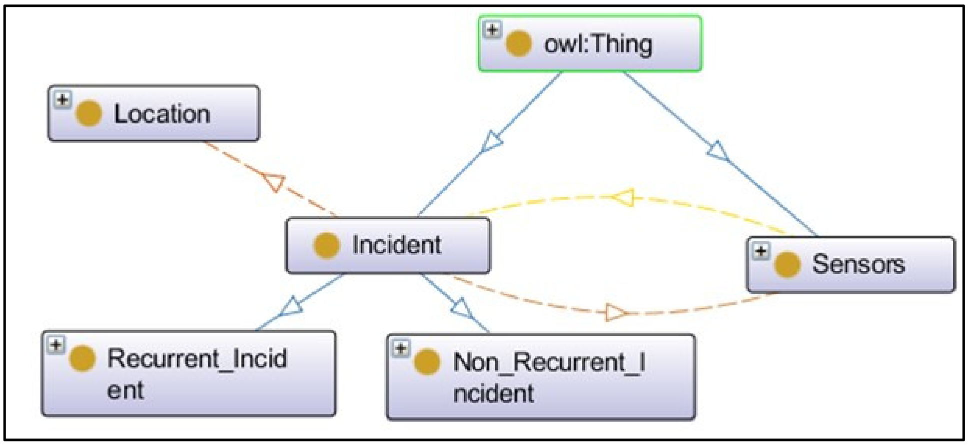

Fig. 2. Class "Incident" and its relations.

The class "Infrastructure" (Figure 3) plays a fundamental role in the traffic ontology, encompassing various types of infrastructures. We incorporated concepts from [11] and classified them into two classes. The first class is "Location", which includes subclasses such as "Bridge", "RoadIntersection", "Roundabout", "Sidewalks", and "ParkingSpace". The concept of "ParkingSpace" is further divided into "PublicParkingSpace" and "PrivateParkingSpace", enabling us to provide information on parking fees. The second class is "Road", which is categorized into "PavedRoad" and "NonPavedRoad", determining vehicle suitability for each road type. Within the "Station" concept, covering various station types like "BusStation" and "GasStation", we have introduced "ChargingStation" to address the evolving needs of transportation systems in smart cities, specifically catering to electric vehicles and charging infrastructure. The "Lane" subclass is classified into four functional subclasses: "AuxiliaryLane" (e.g. climbing lanes for slower-moving vehicles), "DedicatedLane" (e.g. bicycle lanes and emergency vehicle lanes), "ExpressLane" (e.g. bus rapid transit lanes), and "ReversibleLane" (e.g. reversible center lanes used in urban areas to manage heavy traffic during peak hours). Another significant subclass is "Sign", encompassing various signs, road markings, and traffic lights.

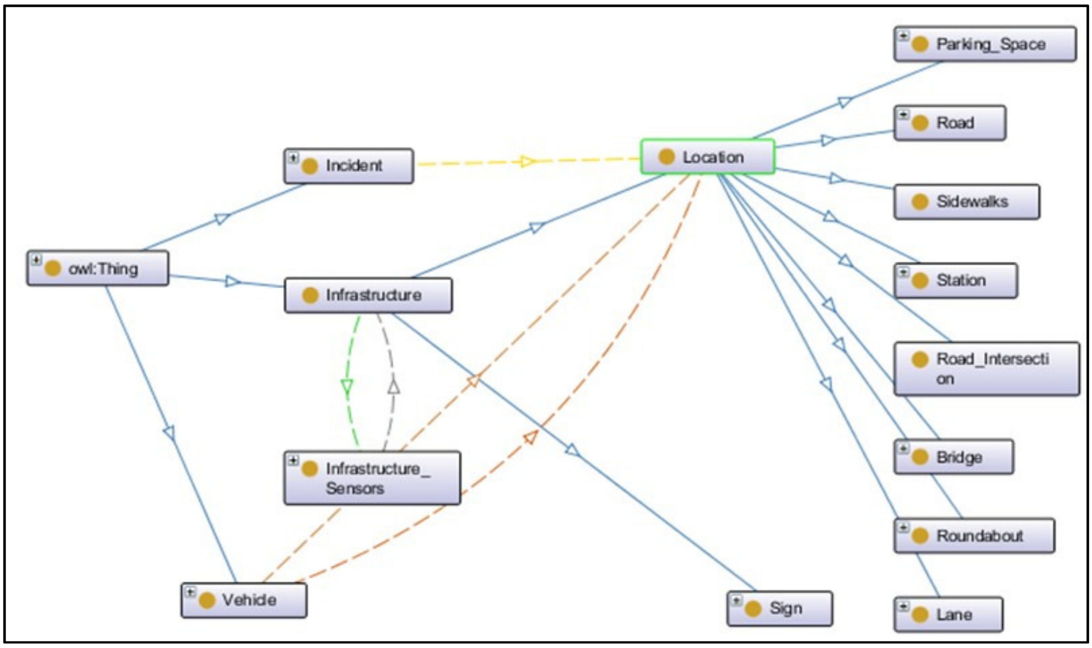

Fig. 3. Class "Infrastructure" and its relations.

Based on the concepts presented in [11] and [15], we propose a specific classification for the class "Person" (Figure 4). This classification comprises subclasses such as "Driver" and "Pedestrian", which further branches into "AdultPedestrian", "ChildPedestrian", "OldPedestrian", and a newly introduced subclass called "VulnerablePedestrian" (e.g. persons with disabilities).

The developed ontologies in the previous works have limitations when it comes to providing real-time information. In our work, we aim to overcome this limitation by expanding the coverage of sensor types. Drawing from [21], we have extended the "Sensor" class into two subclasses: "InVehicleSensor" and "InfrastructureSensor" (Figure 5). The "InVehicleSensor" subclass encompasses sensors that are installed within vehicles. Examples of specific sensors include "TemperatureSensor", "OxygenSensor", and "EngineSpeedSensor". These sensors capture data from various vehicle components and contribute to enhancing the quality of information collected. On the other hand, the "InfrastructureSensor" subclass covers sensors that are installed in different locations within the road infrastructure. This subclass further branches into two subclasses; i.e. "NonIntrusiveSensor" and "IntrusiveSensor". The "NonIntrusiveSensor" subclass includes sensors such as "Infrared", "Ultrasonic", "Video camera", and "AcousticArraySensor". These sensors are deployed in different positions along the road infrastructure and capture data without physically penetrating the road surface. The "Intrusive-Sensor" subclass comprises sensors like "InductiveLoopSensor", "PassiveMagneticSensor", and "PneumaticSensor". These sensors are installed within the pavement of the road infrastructure, allowing for more direct and intrusive data collection.

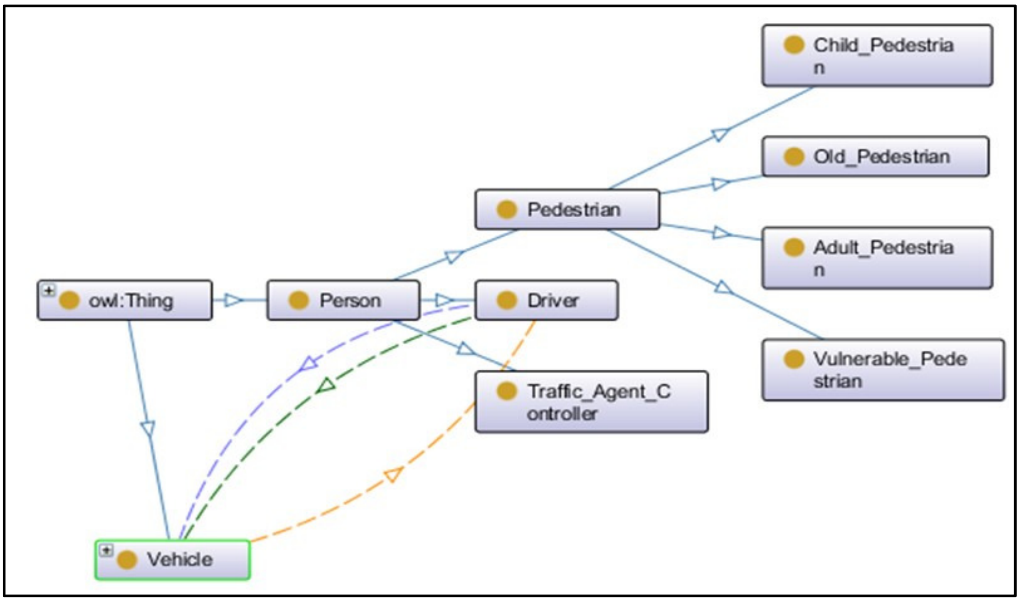

Fig. 4. Class "Person" and its relations.

The relationships between the "Sensor" class and other classes are defined as follows: "InstalledIn" relates the "InfrastructureSensor" to "Infrastructure", indicating the association between the sensor and the infrastructure it is installed in. "Detects" relates the "Sensor" to "Incident", denoting that the sensor is capable of detecting or sensing incidents. "Observes" relates the "Sensor" to "Vehicle", indicating that the sensor can observe or gather data from vehicles. Finally, "IsArrangedIn" relates the "Vehicle" to "InVehicleSensor", signifying that the vehicle has an arrangement of in-vehicle sensors.

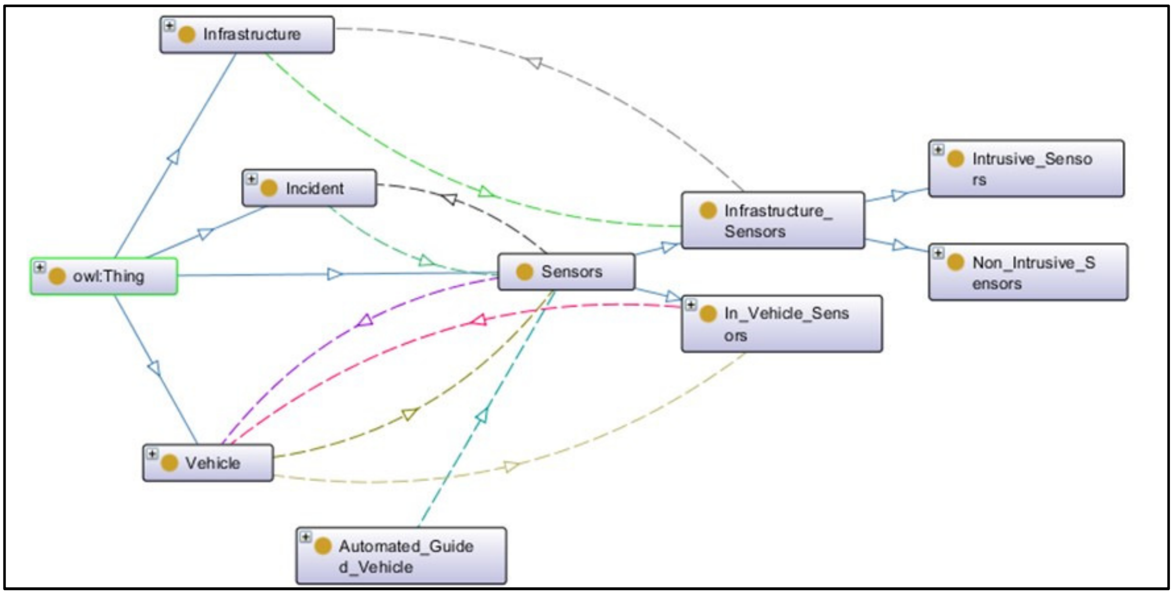

Fig. 5. Class "Sensor" and its relations.

Drawing from reference [11], we have incorporated preexisting vehicle concepts while introducing a novel subclass named "Heavy-weight-vehicle". Our objective is to categorize vehicles based on their weights, as this criterion holds significant significance in the realm of traffic regulation and enforcement. Additionally, weight classification holds the potential to support traffic management and control systems. To illustrate, it enables the establishment of weight-dependent restrictions and the allocation of priority lanes to specific vehicle classes. In real-time traffic management systems, weight information can be leveraged to optimize traffic flow, fine-tune traffic signal timings, and implement toll pricing strategies based on vehicle weight. The vehicle class entails several crucial relationships, such as "IsObservedBy" (sensor, vehicle), "HasPosition" (vehicle, location), "Processes" (vehicle, InVehicleSensor), "IsPropertyOf" (vehicle, driver), and "Drives" (driver, vehicle). These relationships delineate the interactions and dependencies between sensors and vehicles, vehicle location information, the presence of in-vehicle sensors, the association of properties with vehicles (e.g. ownership), and the act of driving by a driver with a specific vehicle. (see Figure 6).

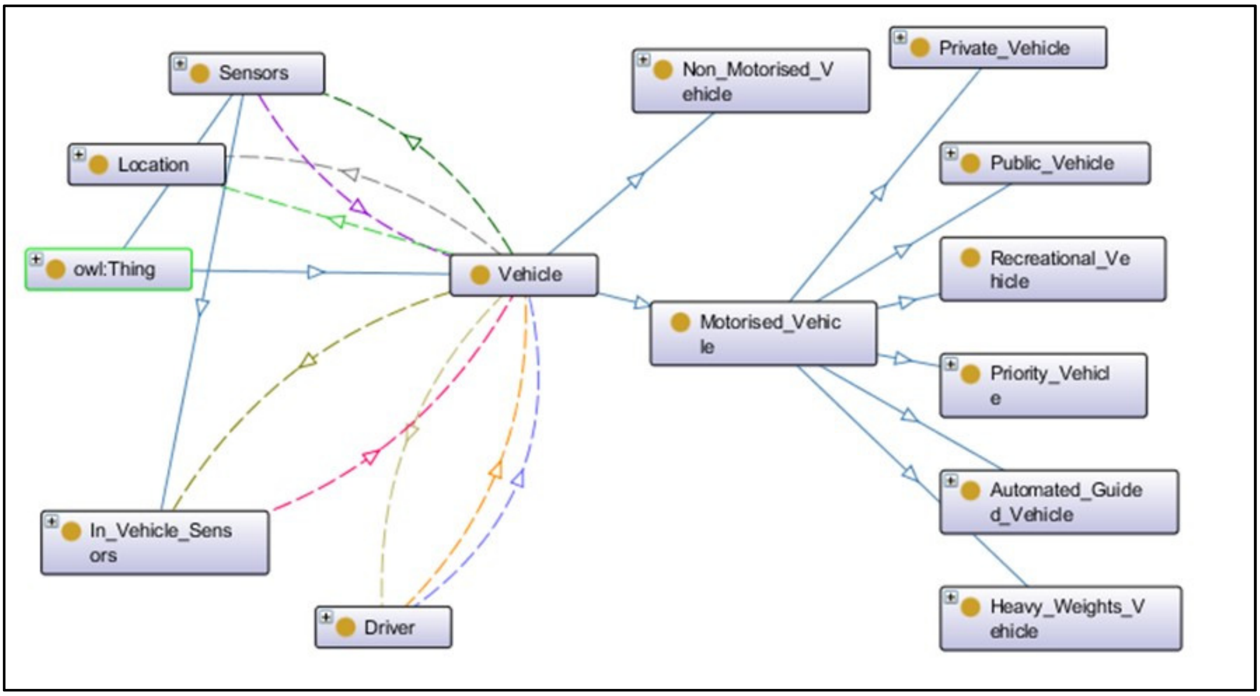

Fig. 6. Class "Vehicle" and its relations.

5. Discussion

The study introduces an ontological model specifically designed to address traffic issues in smart cities. The model aims to enhance the efficiency and effectiveness of transportation systems by utilizing semantic technologies and knowledge representation. One of the major contributions of the proposed ontological model is its ability to integrate heterogeneous data sources and provide a comprehensive view of traffic conditions. By aggregating information from various sensors, transportation authorities, and other relevant sources, the model offers a holistic understanding of the traffic ecosystem. This comprehensive view enables real-time monitoring, prediction of congestion patterns, and identification of potential bottlenecks.

In the presented work we try to have collaboration between all traffic factors. Alos, we try to have detailed classifications of concepts that are missed in the related works such as taking into account vulnerable pedestrians, lane classification, and adding new criteria to classify vehicles according to their weight.

The ontological model facilitates data interoperability and integration across different smart city applications. It establishes a common vocabulary and standardized representation of traffic-related concepts, enabling seamless communication and collaboration between various systems. This interoperability leads to improved coordination among different stakeholders, including traffic management authorities, urban planners, and transportation service providers. In contrast, obtaining real-time data for an ontological model to enhance traffic conditions is a challenging task. The availability and accessibility of such data from various sources are inconsistent, making integration complex. Ensuring data quality, addressing privacy concerns, and handling the scalability of real-time data further contribute to the complexity. Overcoming these challenges requires collaborative efforts and advanced technologies to ensure accurate and timely data for effective traffic management and decision-making in smart cities.

6. Conclusion

In the aforementioned paper, our contribution lies in the proposal of an ontological model. This model serves as a foundation for describing the essential elements of the environment required to enhance traffic conditions within the domain of smart cities. The paper not only presents the ontological model but also puts forth potential directions for further research based on this model.

As part of future work, we aim to establish a relationship between our ontology and upper-level ontology such as DOLCE. This integration will allow for a more comprehensive and interconnected representation of knowledge. Additionally, it would be intriguing to explore the integration of this ontology within a process for constructing an ontological database tailored to real-time applications, particularly in the context of smart city platforms. By delving into these areas, we can extend the capabilities of our ontological model, ensuring its applicability in various domains and its suitability for real-time scenarios in smart city environments.

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