An Architectural Model for Intelligent Cities using Collaborative Spatial Data Infrastructures

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Abstract: Smart cities make intense use of information technologies to capture data in real time in order to automate urban management and social actions. However, the implementation of this concept is hindered by its complexity and limitations in cities. Using a model that contains the basic concepts of a smart city ensures such basic concepts will be approached during specification, besides facilitating communication among designers and allowing the evolution of a smart city to be followed. The International Cartographic Association (ICA) has developed a formal model for Spatial Data Infrastructure (SDI) using the Enterprise, Information, and Computation viewpoints of the Reference Model for Open Distributed Processing (RM-ODP) framework. Assuming that an SDI and volunteered geographic data (VGI) are key parts of a smart city, this study adapts ICA's formal model for SDI with basic concepts that a smart city must have. The adapted model was applied in the specification of the Enterprise viewpoint of a system to reduce traffic congestion. The specification enabled exemplifying the importance of SDI and VGI in the context of a basic architecture for the implementation of applications aiming to turn small and medium-sized cities into smart.

1 INTRODUCTION

The urbanization process has sped up in recent years and the World Health Organization (WHO) estimates there are currently over 7 billion people in the world (Organization et al., 2016). According to the United Nations (UN), half of this population lives in urban areas and this number is expected to reach 70% by 2050 (Seto et al., 2012).

Many urban centers are not properly prepared to handle an expressive increase in the number of people. The main services such as safety, water, sewage, transportation, and education, when they do exist, are deficient. Such issues require measures to be taken in order to ameliorate the situation.

In recent decades, governments, universities, and businesses have increased investments to create solutions that align technology and sustainable development. In this context, a new concept was developed, called smart cities (Caragliu et al., 2011); (Pérez-Martínez et al., 2013).

Some initiatives, such as in (Pérez Pérez et al., 2013) and (Kyriazopoulou, 2015), aim to create smart services and applications that allow cities to become more sustainable and citizens to have access to better, more efficient services. In Brazil, small and medium-sized cities receive less financial resources than large cities. That does not prevent these smaller cities from turning into smart cities. Thus, more incentive and investment are required from all involved in the creation of smart services for the cities.

Smart cities use information and communication technologies (ICTs) as crucial tools to "detect, analyze, and integrate base data and information to execute the cities" (Su et al., 2011). Developing smart cities is a complex activity since it involves several areas and the interest of different parties. The identification and collaboration of actors in a smart city allow the basic concepts of the literature to be contemplated during the specification process, which helps the city's transformation and evolution.

The Open Geospatial Consortium (OGC) defines a smart city as "the integration of physical, digital, and human systems to develop urban areas aiming to create a more prosperous, sustainable, and inclusive future" (Percivall et al., 2015). Using this definition as a starting point, the use of spatial data infrastruc-

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ture (SDI) combined with volunteered geographic information (VGI) can help transform and maintain a smart city.

The formal model for SDI of the International Cartographic Association (ICA), developed by (Hjelmager et al., 2008) and later extended by (Cooper et al., 2011), (Béjar et al., 2012) and (Cooper et al., 2013), allows an SDI to be specified independently of technologies, implementations, or policies (Oliveira and Lisboa Filho, 2015). The positive results of those proposals allow this study to verify which changes are required for a new heading, namely, smart cities. This new approach is based on the extension of the formal model for SDI including the VGI component proposed by (Cooper et al., 2011).

The present study proposes a collaborative architectural model that combines SDI and VGI from the Enterprise viewpoint of ISO/IEC 10746, Reference Model for Open Distributed Processing (RM-ODP), in order to allow small and medium-sized cities to start their transformation into smart cities.

The remaining of the paper is structured as follows: Section 2 presents relevant works for the development of the research. Section 3 presents the theory basis of this research, such as the contextualization of the RM-ODP framework, the requirements for the development of smart systems, and which domains and indicators the systems may comprehend in a smart city. Section 4 contains the specification of the Enterprise viewpoint of RM-ODP. Section 5 discusses the results reached, while Section 6 presents some final considerations of the study.

2 RELATED WORKS

Cooper et al. (2011) developed a formal SDI model including VGI. This model arose from previous works targeting only SDI considering different viewpoints (Enterprise and Information) of the RM-ODP framework (Hjelmager et al., 2008). The integration of VGI into the model is justified by the increasing cost of official mapping programs and by the large availability of citizen-generated data.

Pérez Pérez et al. (2013) proposed the use of SDI as the central axis around which smart services can be built in a city. The proposal is based on the experience in developing the SDI in the city of Zaragoza, Spain (IDEZar) (Fernández et al., 2006). The proposal allows a series of smart services and products to be created for this city.

Kyriazopoulou (2015) presents a literature study on the architectures and requirements for the development of smart cities. Some requirements, such as data collection, processing, and streaming, are the most common among the 41 projects analyzed. Other requirements, such as data security, were found in only two projects.

This paper describes the creation of an architectural model combining SDI and VGI for the development of smart cities. To that end, the requirements must be analyzed based on different viewpoints in order to meet the needs of the city.

3 THEORETICAL FRAMEWORK

3.1 Combining SDI with VGI for the ISO Reference Model for Open Distributed Processing (RM-ODP)

Architectures for smart cities can be built based on different viewpoints. RM-ODP is a framework that aids the development of any type of system, preferentially large and complex ones (Da Silva et al., 2013). The framework defines and deals with five viewpoints: The Enterprise viewpoint (EV) defines the system's purpose, scope, and policy; the Information viewpoint (IV) defines data semantics and interaction in the system; the Computation viewpoint (CV) "allows breaking the system down into a set of services that interact through interfaces," except for distribution; the Engineering viewpoint (NV) defines the tools and features needed for the interaction of different services and data in the system; and the Technology viewpoint (TV) defines the technologies to implement the system (Hjelmager et al., 2008). Figure 1 illustrates the five viewpoints in RM-ODP, highlighting the EV approached in this study. Specifying the EV is the first step in the creation of a model that combines SDI with VGI for smart cities.

According to (Hjelmager et al., 2008) and

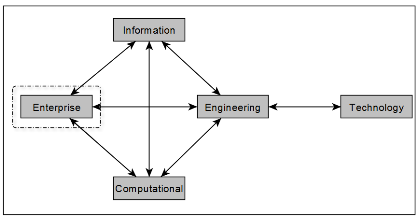

Figure 1: Viewpoints of the RM-ODP framework – adapted from (Hjelmager et al., 2008).

(Linington et al., 2011), the EV refers to any type of more abstract activity in the development of a system, such as the specification of system requirements, policies, high-level components, etc. In the EV, the actors (stakeholders) interested in the success of the system are specified, whether users, contributors, or developers of the system. Moreover, the EV must show the purpose of the system, the system requirements, and the types of relations the actors have with the system.

System development is subjected to some restrictions, which may arise from business processes, which are interconnected tasks to provide products or services, and organizational norms, such as agreements, partnerships, security policies, etc. In order to combine different restrictions, EV specification consists in an inter-related set of communities (Linington et al., 2011).

The communities, working under a contract, define the behaviors of the sets of participants to achieve a specific goal. The contract expresses the obligations of those involved in the system, besides the conditions of the system itself such as security and efficiency. Figure 2 illustrates the elements involved in the specification of a community in relation to the "Phone Repair" event. Normally, the behavior of this community is defined by a composition of processes. The process resulting from this composition is represented as a UML activity for ODP systems by the stereotype $\ll EV\_Process \gg$. This process is also specified by community roles. The roles define how objects (communities, actors, etc.) must behave and interact to reach a goal. In order to define a role in the ODP nomenclature, the stereotype $\ll EV\_Role \gg$ is used.

The EV policies are represented by rules or restrictions in the system creation process. They may be modified to fit certain needs during the creation process.

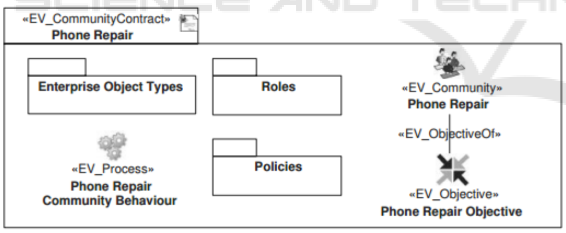

Figure 2: Specification of a community (Linington et al., 2011).

The actors identified by (Hjelmager et al., 2008) take up different roles in the system: The Producer is "responsible for producing data or services for the system"; the Policy Maker is "responsible for defining the policies and involvements in the system"; the Provider is "responsible for providing data or services to system users"; the Broker is "responsible for the negotiations between the User and the Provider, besides maintaining and publishing metadata records collected from Producers and Providers, and for creating catalogs and rendering services based on those catalogs"; the Value Added Reseller (VAR) is "responsible for adding new resources to the products, making them available as new products"; and the End User uses the system for his or her purposes.

Cooper et al. (2011) extended the model by (Hjelmager et al., 2008) in order to include the VGI component since the original actors did not fulfill the representation of the roles in the original proposal. The actors were specialized into "subactors" each of which may take up several roles simultaneously in an SDI that uses VGI. The virtual applications for data sharing that arose with the evolution of the internet and the increase in mapping costs motivated the inclusion of VGI in SDI.

The Producer was classified into four groups: Status, Motivation, Role, and Skill. The group Status has four actors: The Official Mapping Agency, organization responsible for consistently acquiring, mapping, and producing data; the Commercial Mapping Agency, entity that commercializes data and products for profit; the Community Interest, a group of contributors that greatly contribute with small-scale data production of a delimited or global area, particularly through the VGI; and the Crowd Source, anyone who whishes to contribute data according to specifications predefined by the SDI.

The Motivation group is formed by three actors according to the motivation of each one to produce data to the SDI: The Special Interest actor will produce data or information for his or her own interest, such as reporting the number of cases of Dengue fever in the neighborhood or the number of potholes in the asphalt of his or her street; The Economic actor will produce data with financial purpose, whether by commercializing or using them; and the Process actor will produce data with interest in the mode of data capture. For instance, a teacher who transmits the knowledge in data production to his or her pupils.

The group Role is specialized into four actors, each one playing a role in data production or geospatial services: The Captor of Raw Data, responsible for producing, describing, and categorizing geospatial data such as georeferenced images or vector and matrix data; the Submitter of Revision Notice, responsible for reviewing or correcting data in an SDI. This activity includes mainly citizen participation through the SDI for immediate improvement of data; the Passive Producer; responsible for producing data through mobile devices such as cellular phones, tablets, and automotive satellite navigation devices that are tracked by a service provider that monitors traffic flow, network congestion, etc., which may raise privacy-related issues; and the Database Administrator, responsible for ensuring consistency, creation, and verification of the database rules, i.e., that all specifications will be respected.

The last group, Skills, was specialized into five actors according to their skill level to produce geospatial services and data: The Neophyte, despite having "no formal knowledge" on the matter, has availability and interest in contributing with data and opinions; the Interested Amateur, interested in a given subject who seeks knowledge in the literature or from colleagues and specialists in producing geospatial data; the Expert Amateur, experienced in the matter, but whose main source of income is not data production; the Expert Professional, who has knowledge and theory/practical grounds in the production and commercialization of geospatial data, activities that are his or her main source of income; and the Expert Authority, a renowned producer of quality data and services with broad theoretical and practical knowledge in the area. Any mistake may cause him or her to be questioned (Cooper et al., 2011).

The actors and their specializations play a key role in combining a VGI with IDE. However, that does not fulfill the needs for the development of smart cities.

3.2 Requirements of a Smart City

The requirements are fundamental pieces for the construction of systems for a smart city (Kyriazopoulou, 2015). They are primordial in order to integrate functionalities that aim to meet the needs of the city, particularly of the citizens.

Kyriazopoulou (2015) identified a set of requirements commonly found in the literature to implement a smart model or applications for cities. Below, a brief description of some requirements is presented:

Data Collection is a basic activity in a smart city. This activity must handle data of different types and dimensions to allow analyses for the identification of problems to enable improvements. Different sources can be used for data collection. For example, physical systems that capture real-time data such as seismographs, radars, pluviometers, among others. Another form of contribution is citizen participation through applications with VGI support;

Data Streaming and Processing concerns the capacity of accessing the data and analyzing transmission flows from the distributed data collection sources;

Data Security is one of the most important requirements. The systems must not allow access to confidential citizen data. To ensure the protection of such data, encryption techniques, authentication mechanisms, and access control can be used;

Monitoring smart cities in real time is essential to estimate and predict situations for immediate decision-making. Mobile technologies, radio-frequency identification (RFID) networks, and smart devices are the main facilitators for this requirement;

Heterogeneity concerns the capacity of dealing with different devices and different flows of information in a smart city;

Adaptation concerns the capacity of reaction or change in the occurrence of a given event and can be achieved with the use of sensors, prediction techniques, and data-mining;

Sustainability concerns social aspects, such as providing services in transportation, healthcare, safety, education, etc.; financial aspects such as investments, job creation, etc.; and environmental aspects related to energy efficiency and natural resources management. Those aspects must be supported by the ICTs;

Interoperability concerns the capacity of simultaneous "interaction" among different connected devices. This interaction is facilitated with the use of protocols and standards that allow information sharing.

It is a fact that those requirements may not represent all needs since cities have different issues, characteristics, and resources. The fact those requirements were extracted from a technical standpoint and do not consider citizen needs or preferences is also questionable. A smart city application will hardly ever meet all requirements needed, even because the needs might change over time.

3.3 Domains and Indicators

According to (Giffinger et al., 2007), indicators are essential to identify deficient areas in a city. Data such as unemployment rate, carbon dioxide (CO_2) levels, number of homicides, and many others may be useful to create smart applications and speed up the public administration's decision-making process.

The document "ISO/DIS 37120 Sustainable development and resilience in cities – Indicators for city services e quality of life" lists a series of indicators along with a method to evaluate each one. The indicators are grouped into themes or areas of interest that may also be called domains, namely: Economy, Education, Energy, Environment, Recreation, Safety, Shelter, Solid Waste, Telecommunications and Innovation, Finance, Fire and Emergency Response, Governance, Health, Transportation, Urban Planning, Wastewater, and Water and Sanitation (ISO/DIS 37120, 2013). Each domain has two groups of indicators: Core indicators, defined as fundamental, and supporting indicators, defined as recommended. Both are used to demonstrate the performance in rendering of services and quality of life of the city. To exemplify, this paper approaches the domain Transportation.

A city's transportation network provides a view of vehicle traffic and the flexibility of transportation systems. Although small and medium-sized cities usually do not have as many vehicles as large ones, the problems faced with traffic may be the same. The indicators are highly important to measure the performance of a city. It is important to point out that not all fundamental and functional indicators may be relevant to a given city. Likewise, a city may have relevant indicators that are not described in (ISO/DIS 37120, 2013).

4 PROPOSED MODEL

The key "ecosystem" for the development of this research is smart cities, where the several domains are found, which, in turn, are observed by means of indicators. The model must incorporate ICTs that detect key information that shall later be analyzed and integrated into the system. A network of sensors is the main instrument to detect events in a smart city. The complexity to develop a smart city is mainly due to the different views and perspectives that may be taken into account, besides the different interested persons and the city needs. According to (ISO/DIS 37120, 2013), this complexity may be represented by models using modeling techniques and formalisms such as the one by ISO/IEC 19505 Information Technology – Management Group Unified Modeling Language (OMG UML). The examples presented in this section are based on the administrative structure and regulation agencies of Brazil.

4.1 Purpose and Objectives

The purpose of this study is to allow small and medium-sized cities to create smart services and applications to provide better conditions and quality of life to citizens. The use of SDI and VGI is very important to obtain geospatial data and information. These may integrate applications to create a collaborative environment of mutual benefit.

The model proposed is based on the Enterprise viewpoint (EV) of RM-ODP. First, the actors and their specializations must be reexamined based on the EV. Among the actors already proposed by (Cooper et al., 2011), a new physical actor was included, called Sensor. It may be considered fundamental for a smart city since it will be responsible for providing real data in real time. Figure 3 shows the inclusion of the new actor in the model with its two specializations: The actor Citizen Sensor, specialized in the group Status from the actor Crowd Source, and the actor Physical Sensor, specialized in the group Role from the actor Passive Producer.

In order to exemplify the EV specification, one

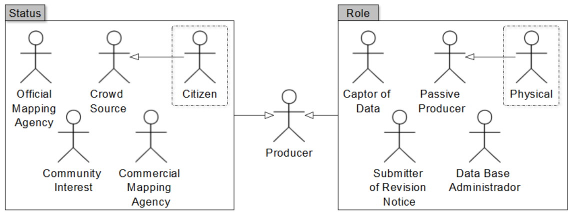

Figure 3: Inclusion of the actor Sensor (Citizen and Physical).

of the most common current problems in cities was chosen: traffic congestion. People waste a lot of time in congestion and often the issue can be solved or ameliorated with smart solutions such as by creating a System for Vehicle Congestion Reduction. The system must support data from different sources and provide real-time information on events on the stretches of road the user intends to travel. This way, the user will be able to decide which route to follow and avoid routes with possible problems.

4.2 Actors

The actor Citizen refers to any individuals who voluntarily contributes (VGI) information through applications installed on or accessed by technological devices such as smartphones, tablets, etc. The actor Physical is a sensor or set of physical sensors responsible for capturing real-time information on a certain space, for example security or traffic cameras.

4.3 Communities and their Behaviors

The flowchart of the administrative structure of a Brazilian city may follow the following hierarchy: secretaries (education, healthcare, transportation, street cleaning), management boards (planning, maintenance, audit, personnel), department (administrative, financial, surveillance), and sectors (property, maintenance, health surveillance). It is important to highlight that the structural distribution may vary according to the municipality.

Besides those entities/organs, the cities may have very important external entities that are not always part of this administrative structure. For example, unions and outsourced companies that provide products or services (e.g., electricity, water). When the vehicle congestion issue is considered, it may involve external entities, for cities in Brazil, such as the National Department of Traffic (Departamento Nacional de Trânsito - DENATRAN), which oversees and rules traffic issues throughout the country, and the National Land Transport Agency (Agência Nacional de Transportes Terrestres - ANTT), responsible for providing appropriate land transport to users.

The National Traffic Code (Código Nacional de Trânsito - CNT) attributes the responsibility of managing traffic to the municipality. Thus, the problem vehicle congestion is the responsibility of each municipality. That means the main community involved with this issue is the Secretary of Traffic and its possible branches (management board, departments, sectors, and divisions).

It can be considered that the following communities are involved in the System for Vehicle Congestion Reduction: municipal secretary of traffic, data analysts, moderators, traffic agents, watchpersons, drivers, passengers, and pedestrians. The roles each one take up are described in the next section.

4.4 Roles, Contracts and Policies

The roles, contracts, and policies presented include activities regarding the objects and communities involved in the system. The system may be split into three units: **Controlling Unit**, **Pacifying Unit**, and **Passive Unit**. Those involved from the three units may have characteristics in common such as supplying information to the system.

The Controlling Unit is responsible for controlling the system and the information received by the users. Those involved in this unit are:

Secretary of Traffic: Responsible for managing and overseeing public passenger transport (e.g., buses, taxis), traffic signs, and the city's fleet. The sector must be able to generate data and historical information such as the number and types of vehicles, areas prone to having some sort of problem (accidents, fallen trees, floods, gridlock, etc.), among others, and store them in an open platform (SDI) accessed by the system. It is the role of this secretary to incentivize the use of the system, presenting the benefits that may be reached. It is also the attribution of the Secretary of Traffic to install and maintain physical sensors to monitor the city;

Data Analyst: Responsible for developing analyses of the data and identifying possible improvements in the system. The analyses may combine different sources of information such as from an SDI and VGI, social media, or sensors, analyzing not only the data produced by the specific application for the vehicle congestion issue;

Moderator: Has the role of following, analyzing, and filtering information provided mainly by the citizens. Information not related to the system's purpose must be withheld so as not to harm the users.

The Pacifying Unit is responsible for monitoring the system's working environment, i.e., the traffic of vehicles and pedestrians, the streets, etc. In addition, the unit must contribute information to the system. Those involved in this unit must be hired and be identified in the system. They may be represented by:

Traffic Agent: Responsible for "developing activities to improve the quality of life of the population, acting as a facilitator of sustainable urban or road mobility, being guided, among others, by constitutional principles of legality, impersonality, morality, publicity, and efficiency" (DENATRAN, 2010). The agent must report in the system information on any event that may cause congestion (e.g., accidents, floods);

Watchperson: Responsible for following and monitoring using audio/video telecommunications devices such as cameras and microphones. The role also includes providing information of possible events that may impact vehicle flow.

The Passive Unit is made up of the system users that are not mandated to provide information. However, it is essential that those users participate as VGI contributors so that the system does not depend only on information from physical sensors and the pacifying unit. This unit may comprise:

Driver: Able to provide data such as speed and geographic location through on-board systems or satellite navigation installed in the vehicles. This may be crucial to identify possible areas with congestion by comparing the speed of vehicles with the maximum speed allowed in that stretch of road over a certain timeframe;

Passenger: Has the role of contributing information on events that may impact the flow of vehicles through VGI applications installed on or accessed by mobile devices. Situations such as accidents, fallen trees, floods, roadworks, and several others may be reported in the system;

Pedestrian: Has the same role as the passenger, however, not in a vehicle.

The specification of the EV of the System for Vehicle Congestion Reduction is illustrated in Figure 4. Each community is specified by the stereotype $\ll EV\_CommunityContract \gg$, which contains a component stereotyped as $\ll EV\_Community \gg$. Each of the components has its dependence defined by the stereotype $\ll EV\_RefinesAsCommunity \gg$, referring to the classes stereotyped as $\ll EV\_CommunityObject \gg$ (Controlling Unit, Pacifying Unit, and Passive Unit).

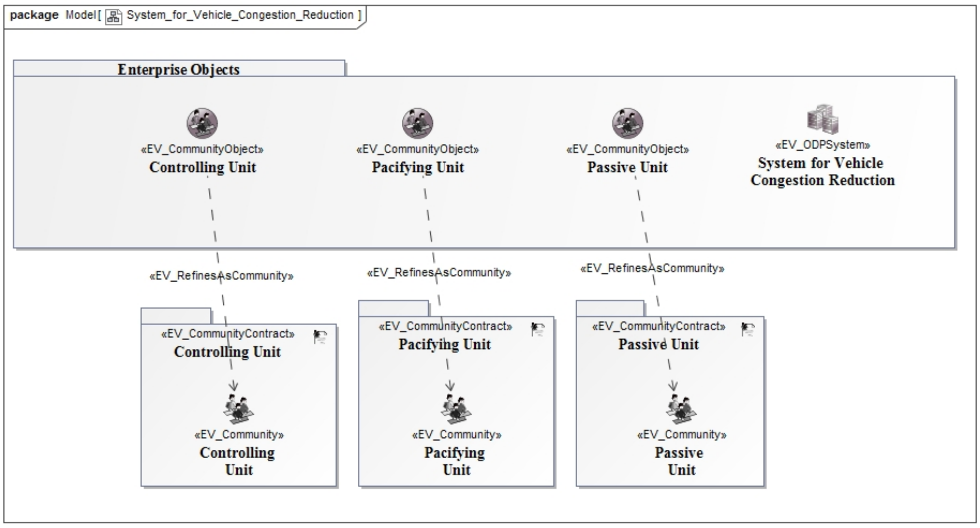

Figure 4: Enterprise specification of the System for Vehicle Congestion Reduction.

Those classes express the community objects that model the communities as simple objects. The community objects are included in the package "Enterprise Objects." The objects Traffic Agent and Watchperson are examples of those enterprise objects that interact with the system.

It is worth pointing out that the roles of the actors may overlap. For example, the Data Analyst and the Moderator may take up the role of Driver, Passenger, and Pedestrian or a Driver may work as Watchperson or Data Analyst. In fact, an actor may take up another role at a certain moment to further contribute with the system's goal, which is to reduce vehicle congestion in the city.

5 DISCUSSION OF RESULTS

The actor Sensor (Citizen and Physical) introduced in the model may allow for greater system efficiency through the data collected both by physical and human (VGI) sensors. The communities defined may take up several roles in the system. They all have a task in common, i.e., supplying data. It is up to the system user whether to make a decision or not, such as whether he or she should follow a certain route or take another path (if it exists). Figure 5 shows the roles identified regarding the communities involved. The roles specified of each community may share a common goal in the system such as supplying volunteered data (VGI).

Three communities were identified that make up the System for Vehicle Congestion Reduction: Controlling Unit, Pacifying Unit, and Passive Unit. Roles were attributed to the communities regarding their behaviors. As well as a community, the system itself has its role – to reduce vehicle congestion by providing information regarding events that hold up the flow of vehicles through that route. The objects contained in each of the communities have roles concerning the activities of their community.

6 CONCLUSIONS AND FUTURE WORKS

It is concluded that the ICA's original SDI model proposed by (Hjelmager et al., 2008) and its extension developed by (Cooper et al., 2011) are solid enough for the development of an architecture for smart cities. However, due to the complexity of the domain, two new specializations had to be included.

The specification of the System for Vehicle Congestion Reduction exemplified how smart solutions can be developed by combining SDI and VGI. Sensors are key parts in the development of smart cities. Moreover, this combination allows smart applications to be developed in several domains of a city, thus allowing for the transformation of a "common" city into a smart city. This way, a sustainable and efficient environment can be obtained in which the population has better quality of life and is less impacted by the inherent issues of a city (congestion, electric grid or water distribution grid failure). The authors of this study have high expectations towards the use of SDI and VGI in the development of smart cities, which opens a huge space for new researches and technological innovations.

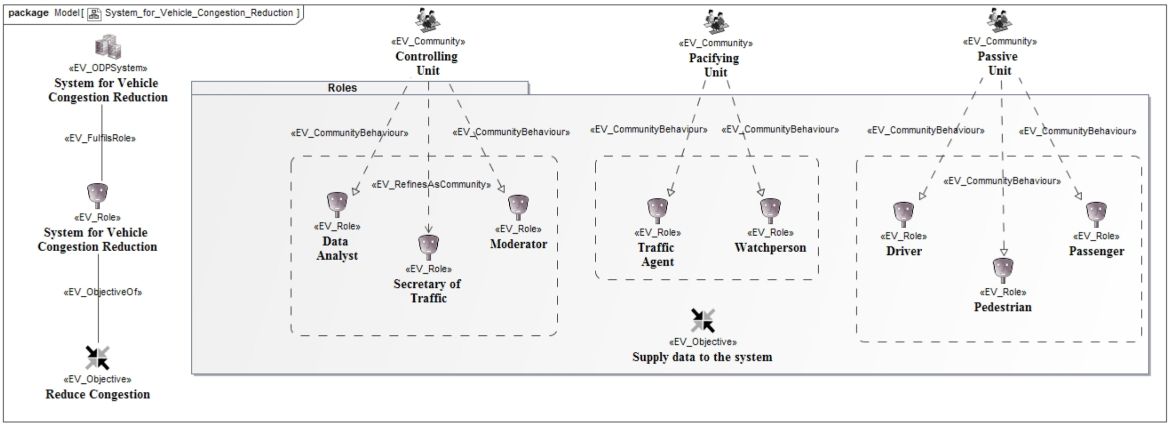

Figure 5: Attribution of community roles.

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