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Multi-agent Highway Toll Collection System

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Preliminary communication

This article describes Highway Electronic Toll Collection (HETC), technologies and interoperability issues, and suggests possible solution to interoperability issues based on multi-agent technology and newly defined HETC ontologies. The RFID (Radio Frequency IDentification) technology is used as a foundation for a HETC system user identification. The unique HETC standards are not defined yet so the problem of HETC systems interoperability related to vehicle class definition and user identification is still unresolved issue. The problem of interoperability is emerging from the implementation of different tolling models among different highway operators. There is a need to define the structure of an adaptable system implementing newly defined HETC ontologies that can be used for toll calculation based on different business solutions. The proposed method results in clear specification and realisation of interoperable HETC.

Key words: Highway Electronic Toll Collection, Interoperability, Multi-agent system, Ontology

1 INTRODUCTION

The field of toll collection system is especially interesting for transit countries as Croatia. The problem of interoperability is emerging with the implementation of different tolling models and different pricing models in neighbouring countries as well in Croatia [1, 2]. There is a need to define the structure of an adaptable system that can be used for toll calculation in different tolling models and different pricing models since highway toll collection system is a set of business rules applied to a customer, with intent to determine the price of services used on the highway. Electronic Toll Collection (ETC) is defined as a technology that allows electronic payment of tolls [3]. Highway ETC (HETC) system determines if a vehicle is registered in a toll payment database, alerts authority of payment violation event and debits customers account. HETC rely on technologies for Automatic Vehicle Identification (AVI) [4], Automatic Vehicle Classification (AVC) [5], and Vehicle Positioning Systems (VPS) [6].

AVI process determines the identity of customers' vehicle subject to tolls. The goal on highway is to record the passage of vehicle trough limited number of toll lanes, gate/plaza areas. Most current AVI systems rely on RFID [7], where an antenna at the lane communicates with an on board unit (OBU) [8] on the vehicle via Dedicated Short Range Communications (DSRC) [9].

AVC process is closely related to AVI process [10]. Customer on highway is charged according to a type of vehicle, making it necessary to distinguish/classify the vehicle passing through the toll lane. Classification parameters are defined by the highway operator authority making it almost impossible to create universal AVC technical solution [11]. In HETC system simplest AVC method is to store the vehicle class in the customer record or on the OBU, and to use the AVI data to determine the vehicle class. Simplest AVC method emphasizes the importance of the VES, where several methods can be used to detect toll violators [12]. VES triggers events like video capturing, security alarm beacon, automatic numeric plate recognition, police alarm. Automatic numeric plate recognition (ANPR) is also known as automatic license plate recognition (ALPR), automatic vehicle identification (AVI), car plate recognition (CPR), license plate recognition (LPR), or electronic number plate (ENP) recognition. ANPR is used for ETC enforcement as well as identification for tolling purposes [13]. ANPR can be observed as a subsystem of a VES. VPS determines the position of the vehicle within a given charge area or network. Charge area can be as small as part of the toll lane road or, as big as city quarter. Technical solution depends of the required functionality. HETC systems can be

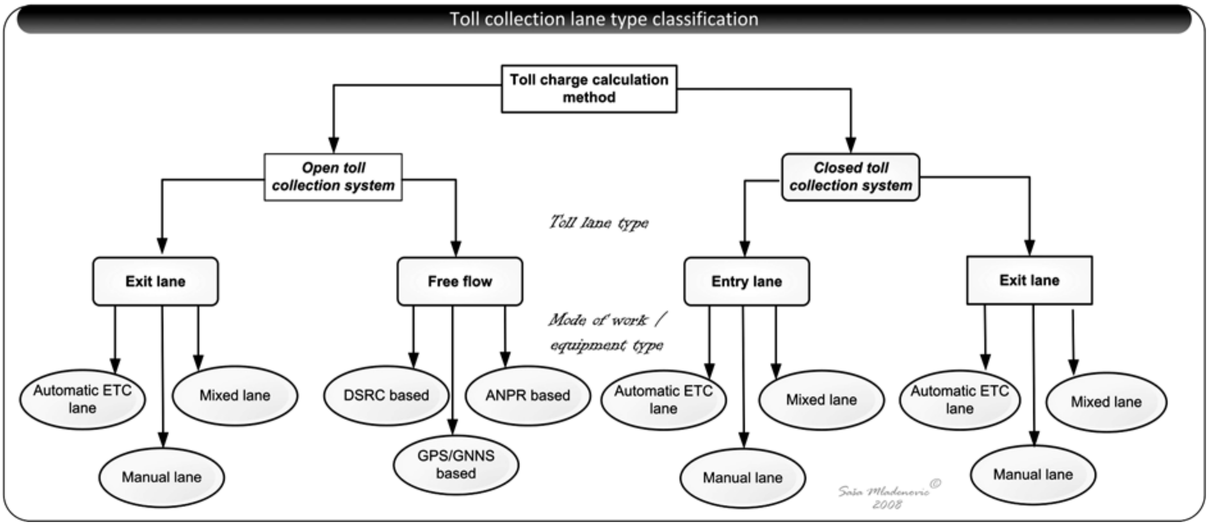

Fig. 1 Toll collection lane type classification

grouped based on payment method and service offered, as shown on Figure 1.

Open toll collection system can be defined as a closed toll collection system with exactly one virtual entry point defined. The same logic is applied to free flow system. Regarding equipment used on the toll lane we make difference only between automatic ETC and manual lane, and we define mixed lane as a combination of automatic ETC and manual lane. In this way the architecture of the HETC system has been simplified. To understand better the HETC automatic ETC implementation problem it is enough to point out the visitor/tourists charging problem. Visitors/tourists may posses OBU purchased from one highway authority. They expect OBU to be valid on all toll highways they can access, regardless the highway authority. Without interoperability it is not possible to use one OBU and drive trough highways operated by different toll operators. One option is to let visitors/tourists drive for free or to make them purchase vignette. Vignette system is the time-proportional lump sum system that becomes uneconomic and inefficient due to the rapid expansion of the motorway networks. The system is not suitable for operating, maintaining, and reconstructing. Travellers are dissatisfied with having to purchase vignettes valid for several hundred kilometers and often several days and weeks in order to travel just a section of the motorway, like recently observed in the case of Slovenia [14]. For transit or tourist destination country, like Croatia, none of the proposed solutions is acceptable. This article introduces a multi-agent technology as another possible solution for the interoperability problem between different HETC operators. The solution includes a multi-agent system architecture and newly defined highway toll collection system ontology as a foundation of the HETC multi-agent system. The proposed solution can be implemented on top of an existing HETC system providing interoperability via ontology mapping.

2 CROATIAN HETC SYSTEMS

Taking into account specific situation in Croatia, mixed toll collection system is used. When using manual toll collection part of the system, the operator is minimising the risk of letting the driver pass trough without payment. Another point is that typical user is still not accustomed to use fully automatic payment lane, resulting in queues forming without obvious reason. In Croatia the AZM (Autocesta Zagreb-Macelj) has implemented automatic payment lanes where the mentioned behaviour of users has been observed on site during our investigation [15]. ARZ (Autocesta Rijeka-Zagreb) and HAC (Hrvatske autoceste) have implemented ETC (Electronic toll collection) lanes as method to enable automatic toll collection on the plaza, but with specific payment media (OBU, contactless smartcard). Typical configuration of the manual toll lane in Croatia is shown on Figure 2.

The manual toll lane is upgraded to ETC lane by adding peripheral equipment required for electronic tolling. Two different RFID technologies are in use: SMART card and DSCR based OBU. The goal of the operator is to increase the volume of cashless payment in the total turnover and toll rev-

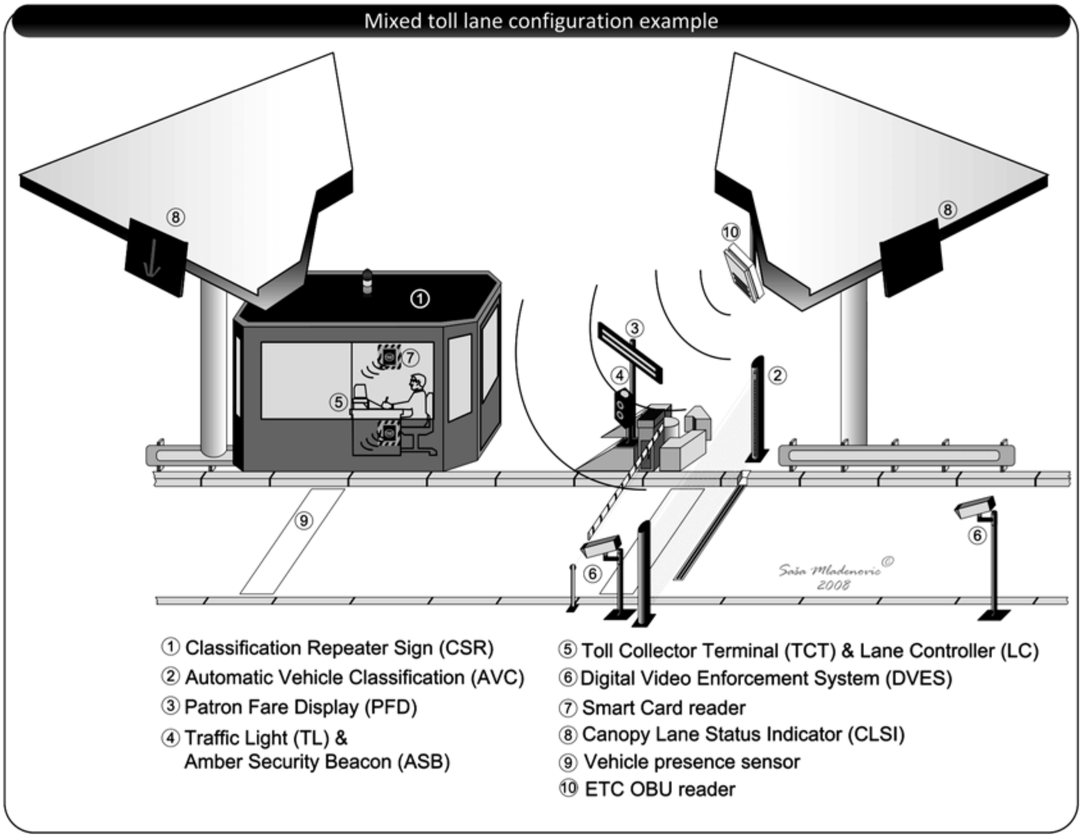

Fig. 2 Manual toll lane, Croatia

enue from 16% in 2007 to 30% in 2008. ETC shortens the payment waiting time and increases traffic flow through the plaza.

There are four operators of tolled roads in Croatia. Distribution of road length under the supervision of the company and the traffic for the year 2007 is presented in Figure 3.

Major operator of highway in Croatia is Hrvatske autoceste d.o.o. (HAC). HAC is the leading company in Croatia when it comes to novel implementation of HETC. To understand better the overall HETC problematic in Croatia, Figure 4 shows Croatian highways network. It is clear from the Figure 4 that A1 highway is operated by both HAC and ARZ. HTCS (Highway toll collection system) is different for each operator. Bilateral interoperability agreement for RFID payment media is signed between ARZ and HAC [2]. The rest of operators are still to join the initiative. Regardless of the fact that both operators are using DSRC microwave at 5.8 GHz OBU, as standardized by the

Distribution of road length and traffic per Croatian concession companies in 2007

	Company	Highway length (km)	Number of Light vehicles in 2007	Number of Heavy vehicles in 2007
1	HAC d.o.o.	780	27,468,537	3,908,210
2	ARZ d.d.	179	12,069,014	1,893,629
3	BINAIstra d.d.	145	4,502,102	461,029
4	AZM d.d.	60	5,848,134	729,005
	Total	1,163	49,887,787	6,991,873

Fig. 3 Distribution of road length and traffic per Croatian concession companies in 2007

Fig. 4 Croatian highways network map

Comité Européen de Normalisation the interoperability is not guaranteed since the application level is different.

In HAC and ARZ HETC system the application level is realized in TIS and PISTA standards. Both standards are supported in European CESARE/CARDME/PISTA [16] standardization procedure since they are already widely use by numerous European highway operators. Data structure at the application level in different standards is not unified. Different data structure can be interpreted like different »languages«. All languages use phonemes, have a grammar, sentence structure, but if one speaks English and another speak Chinese they cannot understand each other. Every operator can read data that other operator created, on the physical level, but it does not understand it. Interoperability is reached by signed interoperability agreements in which operators exchange data structure and data meaning. Each operator reads data on the physical level. If the data is in other operator format it is translated from the external data structure and data meaning to internal data structure and data meaning according to the interoperability Agreement. Currently, ARZ and HAC have defined set of business rules to support roaming of the ETC users. User is allowed to go if it is found on the common authorized users list. Clearing procedure is carried out mutually by highway operators. That is not complicated if only two highway operators are in stake. But what if all Europe operators would agree on interoperability? It is possible to form single European clearing house that will serve as authorization authority for all HETC users and operators. Technical solution should take into account highly distributed nature of the problem as well as need for constant change in tolling policy. Technology that is good candidate for the solution is multi-agent software paradigm [17].

RFID technology is foundation of HETC systems. The HETC system is able to determine if a car is registered in a toll payment program, alerts enforcers of toll payment violations, and debits the participating account. ETC minimizes vehicle wait time at toll plazas and reduces toll-plaza operating costs. The sever problem is absence of the unique standards for used RFID systems. Even if the used RFID system are compliant the RFID tags carried information can have different structure and meaning. That causes the interoperability problem among highway operators.

3 ONTOLOGY

The proposed system exploits characteristics of multi-agent technology to provide interoperability between different tolling solutions. The obvious problem is lack of unified vehicle classification table, used for toll calculation. This problem can be solved with highway toll collection system ontology proposed in this article. Ontology is »conditio sine qua non« for a multi-agent system, therefore highway toll collection system ontology is proposed in this article. The ontology integrates existing vehicle classification standards used for tolling.

In the early 1990's, an effort to create interoperability standards identified a technology stack that called out the ontology layer as a standard component of knowledge systems [18]. A widely cited web page and paper [19] associated with that effort is credited with a deliberate definition of ontology as a technical term in computer science. The paper defines ontology as an »explicit specification of a conceptualization«, which is, in turn, »the objects, concepts, and other entities that are presumed to exist in some area of interest and the relationships that hold among them«.

Ontologies are used in artificial intelligence, the Semantic Web, software engineering, biomedical informatics, library science, and information architecture as a form of knowledge representation about the world or some part of it. Common components of ontologies include: individuals, classes, attributes, relations, function terms, restrictions, rules, axioms and events [18]. Ontologies are used for integrating heterogeneous databases, enabling interoperability among different systems, and specifying interfaces to independent, knowledge-based services. In case of HETC system one of the most important databases is vehicle class definition database that is used to calculate the toll. To begin to solve the interoperability problem imperative is to define attributes used by different operators for vehicle class definition since physical interoperability is mandatory. Like it is stated in the second section, ARZ and HAC use DSRC microwave at 5.8 GHz OBU, but the OBU data differs. Because vehicle class is foundation for the highway tolling, it is necessary for all highway operators to be able to correctly identify vehicle class according to OBU data. In the Figure 5 attributes used by operators in different countries are presented.

Analysis of existing vehicle classifications, presented in the Figure 5, is needed to conclude which attributes are relevant to the toll vehicle class ontology. Such analysis, that would enable mapping from one vehicle classification to another, is not done yet. The key elements are class attributes and attribute values. The toll vehicle class ontology is

Country	No of classes	Class attributes			
		weight	number of axles	height on the first axle	vehicle length
Austria	4	attribute values	attribute values	attribute values	
		Class 1 - <= 3,5 t Class 2 – > 3,5 t Class 3 – > 3,5 t Class 4 – > 3,5 t	Class 2 – 2 axles Class 3 – 3 axles Class 4 – >=4 axles		
Bosnia and Herzegovina		attribute values	attribute values	attribute values	attribute values
			Class 1 – 2 axles Class 2 – >2 axles Class 3 – 2 or 3 axles Class 4 - >3 axles	Class 1 - <=1,3m Class 2 - <=1,3m Class 3 - >1,3m Class 4 - >1,3m	
Croatia	4	attribute values	attribute values	attribute values	
			Class 1 – 2 axles Class 2 – >2 axles Class 3 – 2 or 3 axles Class 4 - >3 axles	Class 1 - <=1,3m Class 2 - <=1,3m Class 3 - >1,3m Class 4 - >1,3m	
France	5	attribute values	attribute values	attribute values	attribute values
Class 5 is descriptive mottos, side-car, trikes		Class 1 - <= 3,5 t Class 2 - <= 3,5 t Class 3 - > 3,5 t Class 4 - > 3,5 t	Class 3 – 2 axles Class 4 – >2 axles		Class 1 - <=2m Cl. 2 - >2m <=3m Class 3 - >= 3m Class 4 - >= 3m
Italy	2	attribute values	attribute values	attribute values	attribute values
			Class A – 2 axles Class B – 2 axles Class B – >2 axles	Class A - <=1,3m Class B - >1,3m	
Slovenia	4	attribute values	attribute values	attribute values	
		Class 1 - <= 3,5 t Class 2 - <= 3,5 t Class 3 - > 3,5 t Class 4 - > 3,5 t	Class 1 – 2 axles Class 2 – >2 axles Class 3 – 2 or 3 axles Class 4 - >3 axles	Class 1 - <=1,3m Class 2 - <=1,3m Class 3 - >1,3m Class 4 - >1,3m	
Serbia	4	attribute values	attribute values	attribute values	
			Class 1 – 2 axles Class 2 – >2 axles Class 3 – 2 or 3 axles Class 4 - >3 axles	Class 1 - <=1,3m Class 2 - <=1,3m Class 3 - >1,3m Class 4 - >1,3m	

Fig. 5 Vehicle classification definition used for toll calculation in different countries

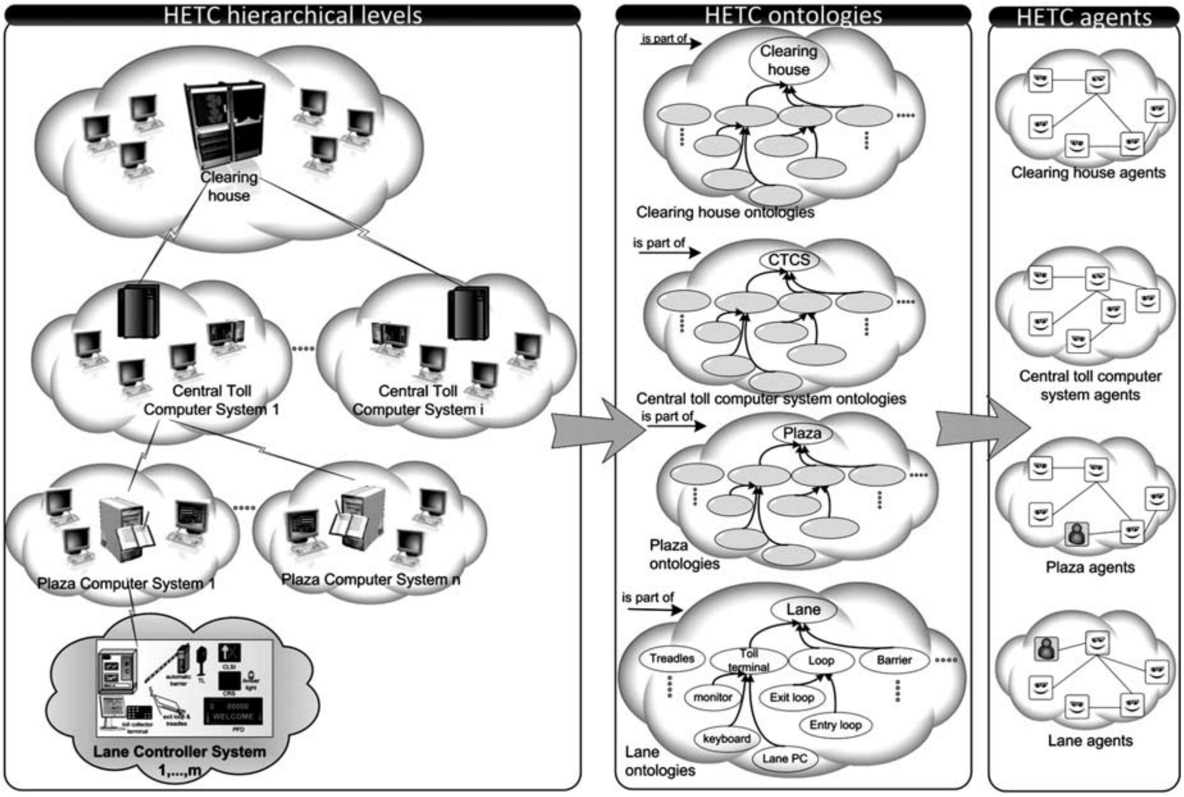

Fig. 6 HETC architecture, equivalent ontologies and multi-agent system implementing ontologies

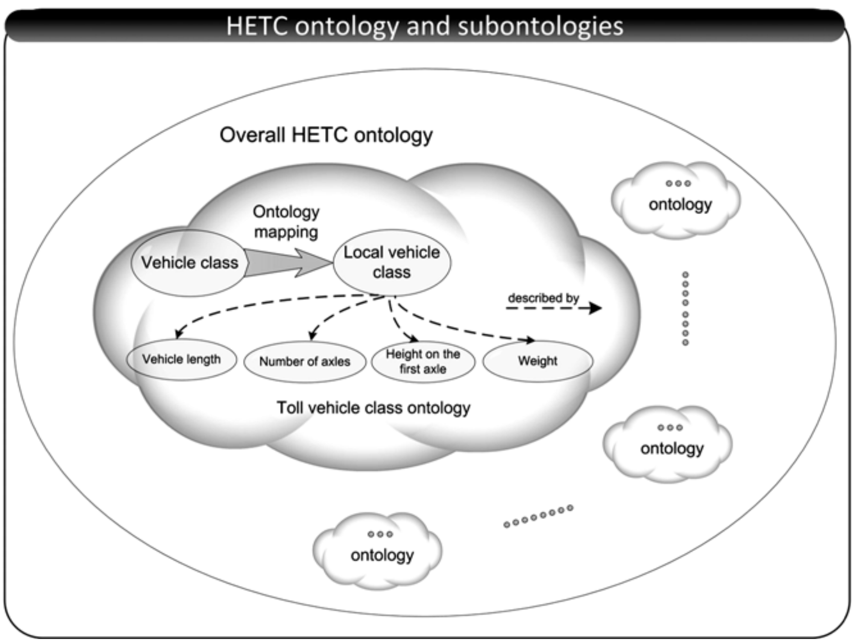

Fig. 7 HETC ontology and subontologies

not the only ontology needed in a HETC system. Different levels, functionalities and modules mentioned in the first chapter require they own ontology. Creation of a centralized ontology is not efficient. HETC system is modular. Described modules are AVI, VES, … and others. HETC system is also hierarchical. The lane level does not have the same functionality as plaza level. The plaza level does not have the same functionality as clearing house level. Figure 6. represents HETC architecture and equivalent ontologies and finally multi-agent system implementing defined ontologies. The multi-agent system is on the top of the existing HETC system placed there to support interoperability among different HETC systems. HETC system is also highly distributed. Usually multiple lanes and multiple plazas exist in the same HETC. Not to mention distribution of different interconnected HETC systems. One HETC can use same module as other. It can be the same on the lane level as other HETC system, but different on the plaza level. Because of that, centralized ontology is not efficient and will not provide interoperability solution.

The toll vehicle class ontology is observed as a subontology of the overall HETC ontology at the lane level. The interoperability is done via ontology mapping among two HETC systems, which needs also to be identified together with ontologies.

The toll vehicle class subontology is the core of toll payment agent in the HETC system, which is focused in the research, but other subontologies also have to be identified. The relation between overall HETC ontology and subontologies is presented in Figure 7.

The ontology and subontologies relation is defined mathematical:

(1) If the overall HETC ontology, set of HETC objects, classes, rules, etc., is marked as O and subontology is marked as O′ then $O' \subseteq O$ [20].

The overall ontology is designed by identifying and designing all subontologies.

4 MULTI-AGENT SYSTEM ARCHITECTURE

A multi-agent system is a network of entities working together on solving the problem that is beyond the agent individual solving capabilities and knowledge [21]. It is assembly of autonomous agents, acting and working independently from each other, but also communicating and collaborating when agent objectives cannot be fulfilled without interactions with other agents. The agent interaction is the main issue concerning multi-agent systems [21]. An interaction is a chain of agent's actions pursued in the dynamic connection with other agents. The interaction influences the future agent behavior. Since the interaction demands some kind of a collective knowledge and a vocabulary each agent implementation domain requires the definition of its joint ontology. Agents need to share common ontology, because ontology provides the domain knowledge basic structure. That basic structure contains a set of concepts and terms for describing a certain domain. Agents need to share a common agent communication language (ACL) and a common ontology to be able to communicate, interact and cooperate [20]. Agent communication language is a language with precisely defined syntax and semantics. ACL is basic requirement for the inter-agent communication. FIPA (Foundation for Intelligent Physical Agents) is an IEEE Computer Society standards organization that defines agent standards, promotes agent-based technology and interoperability of agent standards with other technologies. FIPA also defined the ACL

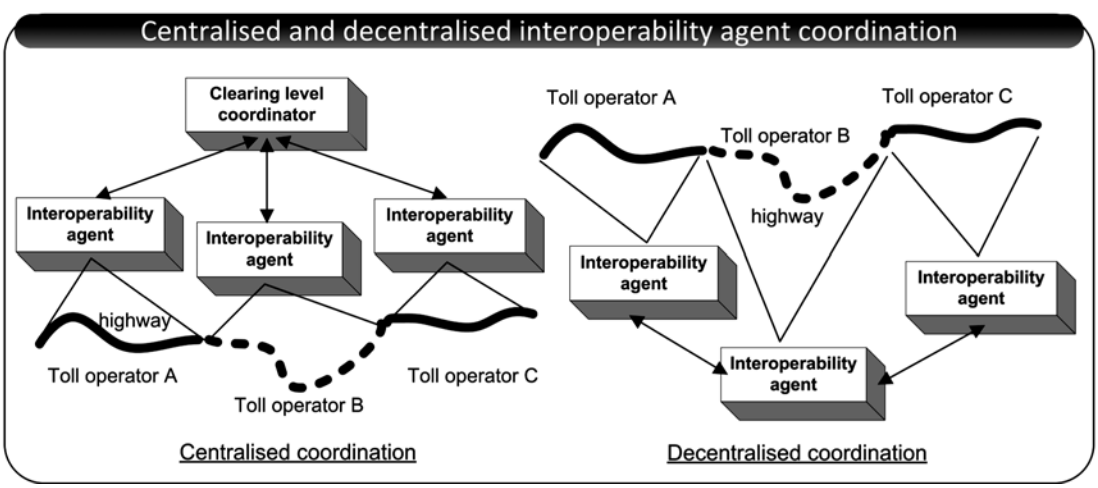

Fig. 8 Centralised and decentralised interoperability agent coordination

standard [22]. The multi-agent approach provides high modularity of the information system necessary in a HETC information system. The HETC information system is hierarchically organized with functionalities defined at the lane level, plaza level, clearing level, etc. According to the HETC hierarchical structure, the HETC MAS is also designed hierarchically with different agents at different HETC levels.

Depending on number of operators involved, centralised or decentralised type of coordination can be used. Centralised coordination is more suitable for clearing house while decentralised coordination is describing the actual clearing system between operators in Croatia. In the following diagram centralised and decentralised coordination between interoperability agents is presented based on [23].

4.1 Agent

Multi-agent system's basic unit is an agent. General agent definition is that an agent is a software system, situated in the environment; it can receive environmental stimulus and can react flexibly and autonomously in pursuing its goals [24]. In artificial intelligence, an intelligent agent (IA) is an entity which can observe and act upon an environment (i.e. it is an agent) and directs its activity towards achieving goals (i.e. it is rational) [25]. Intelligent agents may also use learning and knowledge to help them achieve their goals. Agent may be very simple or very complex: a reflex machine is an intelligent agent, as is a human being, as is a community of human beings working together towards a goal. Russell and Norvig [25] environment properties classification is shown in Table 1. The environment is accessible if an agent can obtain complete, accurate and recent information about the environment. Usually, the environment is inaccessible to a degree. The lower the inaccessibility, the simpler the agent is, and vice versa. If an action has always the same effect, the environment is deterministic. In an episodic environment the agent acts only on its current state, because there is no connection between agent's previous, current or future actions. The static environment changes only under agent action. Other processes, that change the environment, exist in the dynamic environment. The environment will be discrete if it has certain, finite number of states and actions.

Table 1 **Environment properties classification**

accessible vs.	inaccessible
deterministic vs.	nondeterministic
episodic vs.	non-episodic
static vs.	dynamic
discrete vs.	continous

The agent mathematical definition follows [21]. The environment states are described with the set $S=\{s_1, s_2, \ldots\}$. In each moment environment is in the one of the states s_i. The agent action ability is described with the set $A=\{a_1, a_2, \ldots\}$ of actions. Simplified, the agent can be observed as the function *action*: $S \rightarrow A$ mapping the chain of the environment states with the agent actions. This is a simple reactive agent that does not act according to the prior experience. Agent experience can be modeled with the environment states that agent already knows. Environment is defined as the function *environment*: $S \times A \rightarrow \rho(S)$ mapping the current state $s \in S$ and the agent action $a \in A$ to a set of environment states *environment*(s, a) resulting from the agent action a on the environment state s. If the result of one action is just one state the environment is deterministic. The agent and environment interaction can be presented as a *history* defined with h:

$$s_0 \xrightarrow{a_0} s_1 \xrightarrow{a_1} s_2 \xrightarrow{a_2} s_3 \xrightarrow{a_3} \ldots \xrightarrow{a_{n-1}} s_n \xrightarrow{a_n} \ldots$$

where s_0 is initial environment state, a_n is the n^{th} agent action and s_n is the n^{th} environment state.

5 SYSTEM REALISATION

It would be too complicated, expensive and time consuming to change existing toll collection system software to use the new proposed vehicle classification standard. In contrary, the agent will have the knowledge of internal vehicle classification standard, and the capability to translate it to the standard vehicle class. Integration of multi-agent system into existing HETC system requires HETC ontology definition and also HETC processes identification. The payment process is just one of HETC processes. The integration of agent in payment process is explained in next paragraph.

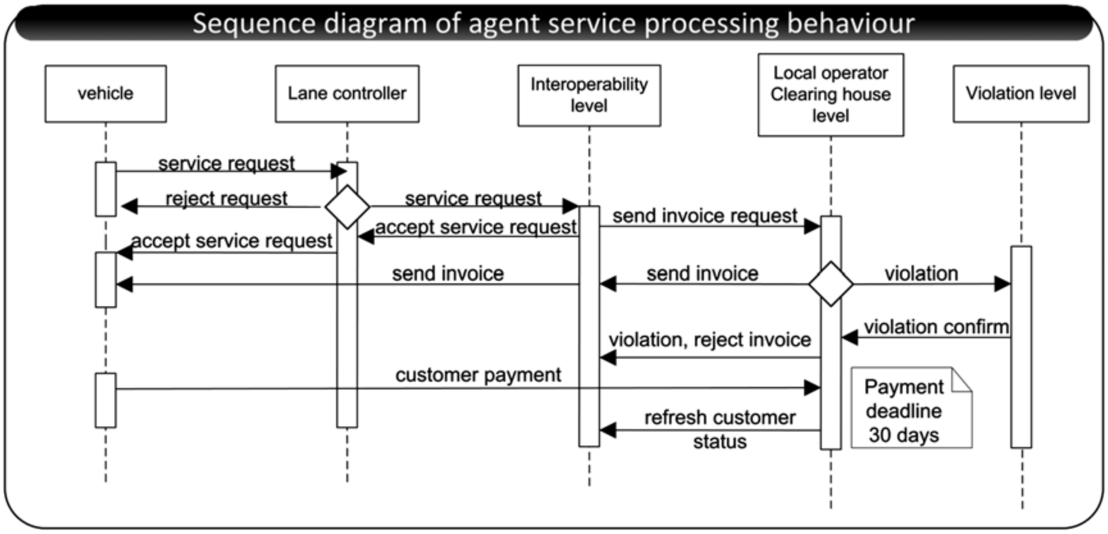

Fig. 9 Service processing agent behaviour sequence diagram

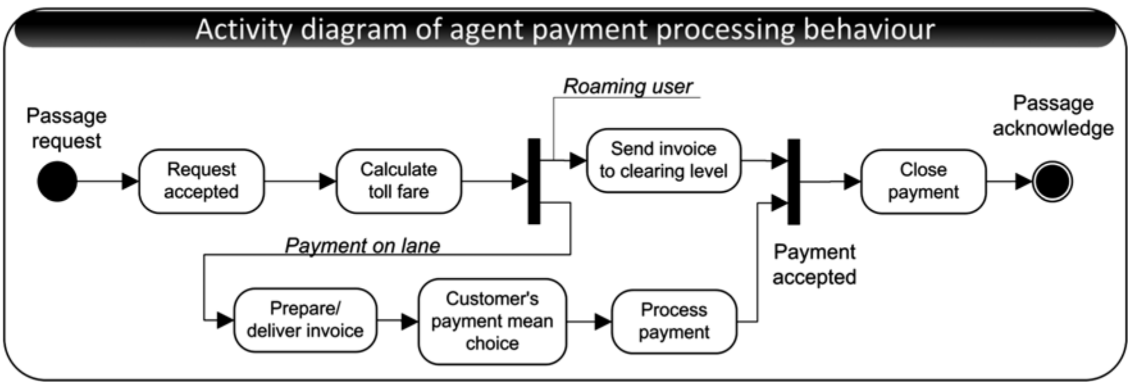

Fig. 10 Payment processing agent behaviour activity diagram

The vehicle identified by the toll collection system is treated as customer. Customer is requesting a payment type service depending on the payment mean available. The goal of the toll collection system operator is to minimise the waiting time on the lane but also to minimise the risk of non paid passage. Following diagrams depicts the payment processing that take place within a Service request agent (based on [25]).

Lane System is suite of software modules providing real-time control, monitoring, and management of the devices used in toll collection systems. Entry lane is specific to entry point of the closed toll collection system, where the user has to take a ticket. Exit lane is specific to exit point of the toll collection system, where the user has to pay for the service consumed. The gathered information is cantered in one place. This architecture is applied to the multi-agent system. Each entry/exit point is represented as a multi-layered multi-agent system. Communication with other points, including the central information repository is routed through main processing agent. Existing software modules are modelled with a specific agent (camera agent, AVCS agent, ...). The central information repository is also modelled with data agent.

6 CONCLUSION

HETC system is hierarchical, modular information system for highway electronic toll collection. Growth of roads under toll collection is constant in Croatia. Electronic toll collection is more efficient, less time and man power consuming, so operators prefer electronic over manual toll collection. The problem arises when a customer wants to travel across roads operated by different operators. Different operators use different tolling models and different pricing models. The physical interoperability is implied. It relates to RFID physical interoperability (i.e. communication among RFID device goes on 5.8 GHz) since RFID technology is foundation of the HETC system. But this does not guarantee the overall interoperability. Operators usually use different data formats. Vehicle classification, as the main pricing element, is also different. Different standards exist (TIS, PISTA,..) and are widely implemented over Europe. Except respecting the same standard, not yet set, other solutions can be implemented on the HETC application level.

The solution suggested in the article can be implemented on top of existing systems without changing it using multi-agent technology. Existing software can be left intact. The agents are just additional modules offering interoperability function at different HETC levels and different HETC modules. For two same agents (at the same level and of the same HETC functionality) interoperability is defined with ontology and ontology matching. For example, one agent uses TIS VES ontology and other uses PISTA VES ontology. Ontology mapping enables one agent to map data and information to format and meaning other agent understands. HETC information has to be identified in detail and all functionalities on all HETC levels have to be fully understood, for such ontology mapping.

The ontology is organized hierarchically, like HETC, to provide interoperability on each HETC level and for each HETC module. Current results relate to VES module on HETC lane level but future research will comprise other HETC levels and modules.

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Više-agentski sustav za naplatu cestarine. Članak opisuje elektroničku naplatu cestarine (ENC), tehnologije koje se koriste pri ENC-u i pitanje interoperabilnosti te predlaže moguće rješenje problema interoperabilnosti utemeljeno na više-agentskoj tehnologiji i novo razvijenim ENC ontologijama. RFID (Radio Frequency IDentification) tehnologija je temelj ENC sustava za identifikaciju korisnika. Jedinstveni standard za ENC sustave još nije definiran pa interoperabilnost ENC sustava s obzirom na definiciju klasa vozila i identifikaciju korisnika još uvijek nije riješena. Problem interoperabilnosti proizlazi iz različitih modela naplaćivanja raznih operatora. Postoji potreba za definiranjem prilagodljivog sustava zasnovanog na novim definiranim ENC ontologijama koji se može koristiti za naplatu cestarine u raznim poslovnim rješenjima. Predložena metoda predstavlja jasnu specifikaciju i realizaciju interoperabilnog ENC-a.

Ključne riječi: Elektronička naplata cestarine, interoperabilnost, više-agentski sustav, ontologija

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