Enabling Citizen-Centric ITS Services Through Blockchain and Human Incentives

Sofia Martins(✉), António Costa, Zafeiris Kokkinogenis, and Rosaldo J. F. Rossetti

Laboratório de Inteligência Artificial e Ciência de Computadores (LIACC), Departamento de Engenharia Informática (DEI), Faculdade de Engenharia da Universidade do Porto (FEUP), Rua Dr. Roberto Frias, 4200-465 Porto, Portugal
{up201606033,up201609065,zafeiris.kokkinogenis,rossetti}@fe.up.pt

Abstract. Given the increasing migration of populations from rural to metropolitan areas, it is imperative to make urban mobility more efficient in order to mitigate traffic, pollution and degradation of the quality of life. In this paper, we propose a system that attempts to influence drivers to follow a certain route by means of an incentive. The proposals are put forward based on predefined urban traffic network indicators in need of optimization, such as the carbon dioxide emissions in a specific route or another equally compatible with our model. Our hypothesis is that influencing drivers' behaviours can lead to the optimization of such indicators. The accumulated incentives are registered in a Blockchain network in order to ensure the unchanging and reliable registration of route proposals accepted by drivers. Additionally, we describe an application developed as a proof of concept and as a basis for future work.

Keywords: UVAR · Urban vehicle access regulations · Blockchain · ITS · Intelligent transport systems

1 Introduction

In 2018, 55% of the world's population lived in urban areas, as opposed to only 30% in 1950, and it is estimated that by 2050 more than two thirds will be living in urban centres [19]. This growth has been accompanied by an increasing need for mobility in urban centres, resulting in traffic congestion, emergencies and unforeseen accidents, and requiring significant changes in transport infrastructure. Inefficiencies result in lost time, reduced safety for both vehicles and pedestrians, high pollution, degradation of the quality of life, and waste of non-renewable fossil fuels [5].

Therefore, many cities and towns struggle to balance traffic congestion, noise levels, air pollution, accessibility, habitability and other pressures of urban life. One way to solve these issues is to regulate the vehicles or journeys access to urban infrastructure, balancing the need for vehicles accessing an area with a

A. L. Martins et al. (Eds.): INTSYS 2021, LNICST 426, pp. 85–94, 2022.
https://doi.org/10.1007/978-3-030-97603-3_7

reduction in the total number of vehicles. Three motivations stand out in the adoption of these measures: environmental aims, raising revenues, and reduce congestion [16].

This paper re-examines these issues and proposes an architecture based on Blockchain technology, in an attempt to mitigate them. The Blockchain is one type of Distributed Ledger Technology (DLT) which has become disruptive in recent years. More specifically, it serves as a digitized, decentralized public ledger of data, assets and all pertinent transactions that have been executed and shared among participants in the network [15]. Blockchain networks are categorized into public and private Blockchains; the difference between the two resides in the fact that public Blockchains allow anyone to join the network and execute transactions (as is the case of the Bitcoin application), whereas the latter enforces a controlled environment through participants' authentication that enables different access permissions. Today, there are various Blockchain frameworks available, offering functionalities that fit either (or both) private and public networks. Hyperledger Fabric[1] and Openchain[2] are just two examples of these frameworks, which promote the design and implementation of private Blockchain networks.

Key to the Blockchain technology is the concept of Smart Contracts, which are designed by the Blockchain developer and encapsulate the logic behind a value transaction within the network. These are automatically executed upon the fulfilment of certain conditions, therefore automating business processes by eliminating the need of a third-party intermediary for overseeing the transaction in real-time [15]. Moreover, ongoing studies have attempted to expand on their features, namely to embed them with pro-active behaviour [2], as well as agreement technologies in Multiagent Systems in the context of autonomous negotiations [3,17].

In this paper, we propose the adoption of a Blockchain architecture that manages rewards issued to drivers. The architecture encompasses two main components: a Server and a Client Application. We envision the latter to be deployed at mobile devices running on vehicles during commutes. Within those periods, drivers accept or reject route proposals issued by the Server and subsequently presented on the mobile device. The route proposals may incur some degree of inconvenience for the driver, such as added commute time, so a proper incentive mechanism needs to be employed. We adopt a reward-based incentive, which could include, for example, free tickets to access the cities' public transportation system. As a consequence, we expect these rewards to be determined by each municipality. We hypothesize that these incentives can lead to improvements in various indicators, including those related to carbon emissions and traffic congestion, as the Server establishes the proposals considering a specific objective: the optimization of those indicators. In addition, we rely on Blockchain technology for the distribution of rewards with added transaction transparency and reliability of drivers' compliance with accepted proposals, using Smart Contracts.

The remaining sections of this paper are organized as follows: Sect. 2 briefly describes the state of the art concerning Urban Vehicle Access Regulation

[1] Hyperledger Fabric, https://www.hyperledger.org/use/fabric.
[2] Openchain, https://www.openchain.org.

(UVAR); Sect. 3 elaborates on the technical aspects of the proposed architecture; Sect. 4 presents a proof of concept (PoC) that we have designed and implemented, and highlights preliminary findings collected from our experiments on the PoC; finally, Sect. 5 gathers conclusions and outlines relevant future approaches.

2 State of the Art

The main objective of the Urban Vehicle Access Regulation (UVAR) is to regulate the access of certain vehicles to specific areas, based on their class or purpose, mainly for air quality reasons, but also for long-term policies and objectives such as reducing congestion, noise and carbon emissions, improving the quality of life, and the attractiveness of urban and tourist centres [7].

Several techniques and typologies have been adopted to implement UVARs, either by physical restriction of access, such as physical barriers or traffic signs, or through application of circulation charges in reserved areas, toll rings or area license-based fees; such charges may vary according to the time of day, distance or duration of the journey, or type of vehicle [16].

The concept of Tradable Credits Scheme (TCS) was proposed as a way to manage daily traffic congestion by pre-scheduling the departure time in a competition among commuters to reduce travel costs [10], but also as a way to control emissions by encouraging users to switch from internal combustion to zero-emission vehicles in an approach where a central authority determines TCS parameters, such as credit and charging models by vehicle type [14]. Emissions Trading has been implemented by many governments to comply with international agreements and protocols. The transport sector has a large share in emissions. By implementing a *cap and trade* scheme at road user level, with distribution of future emissions among individuals, Blockchain technology can play a key role by increasing security, end-user control and transparency [6].

Over the past few years, the concept of gamification has been approached as a mean of promoting engagement and behaviour change, with positive and playful experiences, in non-game contexts [4]. Using information technologies embedded into everyday tasks and services [1], users are given support in creating global value [9]. Within the field of transport it is suggested to implement this concept to encourage more energy-efficient behaviour, based on the accumulation of rewards and creating competition between "players" [18], or for motivating driver cooperation in lane-changing scenarios [13]. Studies indicate that, at least in the first phase, a reward strategy should be used to encourage pro-social behaviour, rather than punishment, which plays a more appropriate role in maintaining it [8].

3 Proposed Approach

The main motivation for the development of the proposed system is to render cities more efficient and sustainable, leading vehicles to follow alternative routes rather than others that include roads with special characteristics that may be momentary, such as rush-hour congestion, or persistent, such as those where efforts are made to reduce carbon dioxide emissions. We define the latter route roads as *exclusion* roads.

Different vehicles may coexist within this system. We consider, for example, the distinct roles of a typical passenger vehicle and an emergency vehicle; undoubtedly, the latter should have indiscriminate access to any road, regardless of it being an *exclusion* road or not. In this setting, drivers of regular vehicles are motivated to follow one of the routes proposed by the system. We designate this set of routes with common *origin* and *destination* addresses as the *Special proposal set*.

Influencing driver's behaviour change, that is, leading the driver to select one of the *special proposal* routes instead of the fastest route is not sufficient without a proper incentive since, most often, the former will not overlap with the latter specially considering the sustainable driving factors. The choice of a proper incentive should be managed by a municipality and could vary from monetary incentives to free tickets to access the cities' public transportation system; in the latter case, the incentive alone would also foster the city's environmental sustainability.

3.1 The Android App, The MSP and The CA

The proposed architecture, as depicted in Fig. 1, includes an Android App component; the assumption being made is that each vehicle has associated a mobile device, where the Android App is installed. Drivers may register their vehicles through a Membership Service Provider (MSP), which is responsible for requesting to a Certification Authority (CA) the public and private keys that uniquely identify the vehicle and prove its identity. Each vehicle is registered with the MSP through its License Plate. Having a mapping of the cryptographic hashes generated from these License Plates to the vehicle category, the MSP is able to recognise to which category each vehicle belongs.

3.2 The Server

Upon registration within the Android application, the driver may access its navigation mode and select an origin-destination pair for its upcoming trip, as in all navigation applications that are available in the market. The Server's REST API provides the list of available locations along with this first request from the Client Application. It then submits the list of alternative routes, some of which may include *exclusion* roads according to their momentary or persistent characteristics, which are properly monitored by the Server. The set of routes that do not traverse any *exclusion* road comprise the *special proposal* set and provide the means to influence the driver's route selection strategy.

The incentive mechanism, in turn, motivates the need for a system that is capable of properly managing the set of incentive transactions that occur whenever the drivers opt for one of the *special proposal* routes. Among the possible candidate solutions to address this need, one stands out today: the Blockchain.

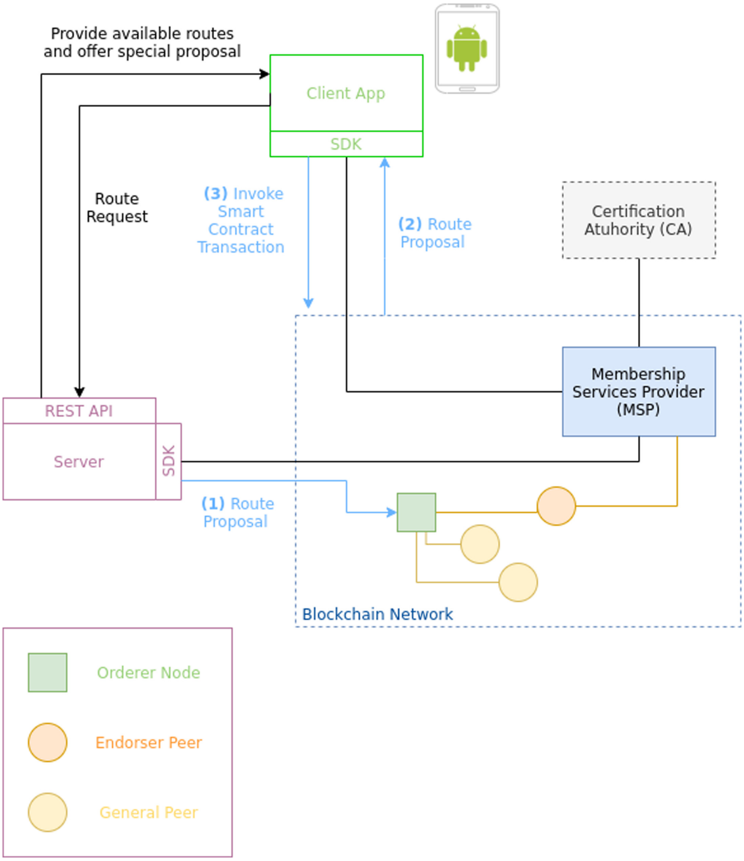

Fig. 1. Proposed architecture.

3.3 Blockchain System

Any DLT system – such as Blockchain – enables the proper transfer of value, namely through immutability, consensus and security. Within the scope of the proposed system, the Blockchain provides the means to record drivers' compliance with accepted proposed routes, which have inherent value in the form of incentives.

In Fig. 1 we can observe the interplay of the Server, the Client App and the Blockchain Network; the previous component follows a similar architecture as the one implemented by the Hyperledger Fabric framework. Whilst the Server replies to the Client App with a set of *special proposal* routes it also issues one transaction proposal for each of those routes, through the SDK. The proposal is signed by the Server using its private key (since it is also registered with the MSP). Upon this stage, the proposal enters the Blockchain network and is passed to the Orderer Node, which asks the Endorser Peer to validate the Server's key by

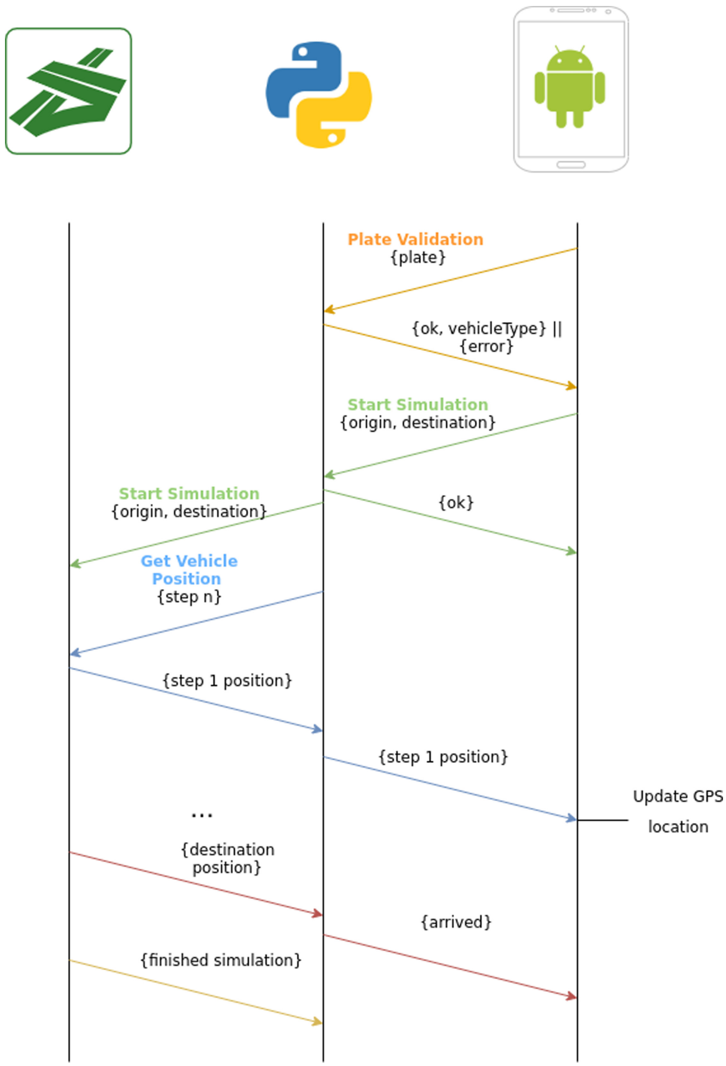

Fig. 2. Experimental setup.

consulting the MSP. If the proposal is successfully validated (the key is accepted, that is, it is recognized by the MSP and belongs to the one possible proposal initiator – the Server) then it is delivered to the Client App through the SDK. Finally, if the driver accepts one of these proposals, its private key is used to sign the proposal and invoke the proper Smart Contract execution (that encapsulates the transaction conditions) to the Blockchain Network. Again, the Orderer Node initiates the validation of the last signature and, upon receiving the confirmation of the validity of the proposal, it generates a transaction block and delivers it to the General Peers, which record it, thereby maintaining the integrity of the network and ensuring the immutable recording of the transaction.

4 Proof of Concept

The demonstration of the Proof of Concept was conducted using SUMO (Simulation of Urban MObility), an open source microscopic and continuous multi-modal traffic simulation package [11], enabling us to individually model each vehicle and its dynamics [12]. The city of Porto, together it is usual traffic flow, compose our experimental scenario. Figure 3 illustrates this scenario on our SUMO environment, which is based on OpenStreetMap. The TraCI (Traffic Control Interface) API enables access to the simulated vehicles and manipulation of their behaviour in real time. A route was considered between Campo dos Mártires da Pátria and Rua de Camões, with a reserved access area in Rua dos Clérigos.

A Python application is employed as a middleware between the traffic simulator and an emulated Android mobile device. It acts as a logical unit to control the driver's decisions. In addition, it exchanges the vehicle's geolocation with the respective Android device, that is, mocks the Android device's GPS location, as given in Fig. 2. In turn, the Android device executes an application through which drivers can accept or reject route proposals, as expected from a real-world deployment in which the driver would be assisted by the application running in its mobile phone during commute. Figure 4 depicts some *screens* of the application we have developed and emulated in our simulations. Also, for simplicity of the experiment, it takes on the role of the CA and the MSP depicted in Fig. 1, with information about the classes of vehicles and the restricted access zones. As a result, it carries out class authentication of the vehicle, distinguishing between a private passenger vehicle and a priority emergency vehicle.

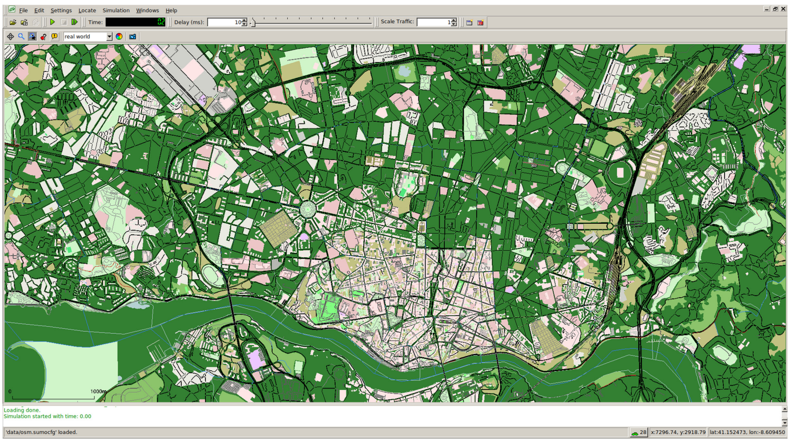

Fig. 3. Porto city map in SUMO.

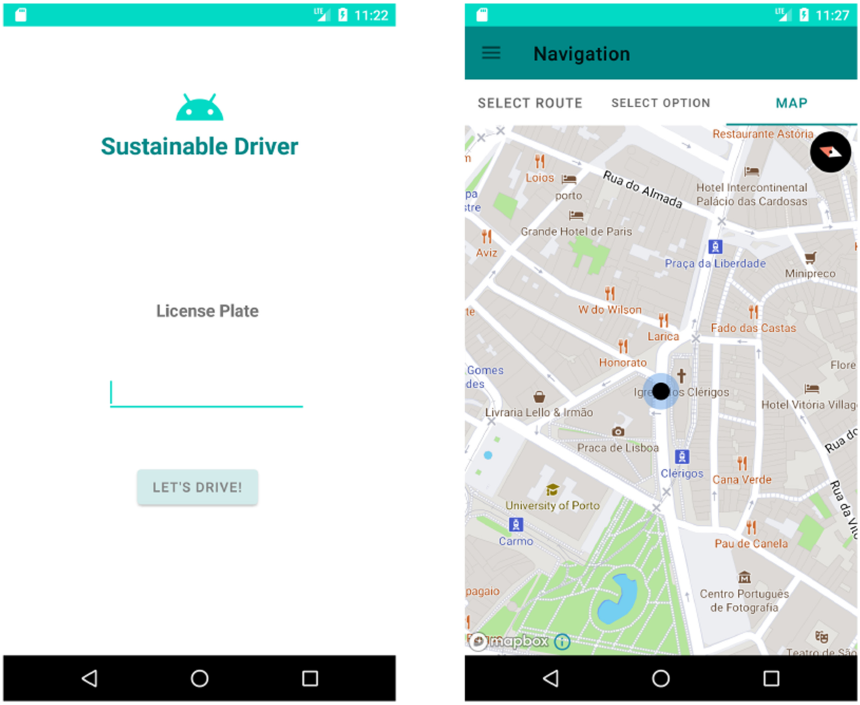

Fig. 4. Application screens: *login* and *navigation*.

The Android application issues the identification of the vehicle to the system for validation of the registration and vehicle type (*emergency* or *passenger*), by means of the MSP and the CA, mimicked by the middleware as in Fig. 2. This information is used to implement the logic behind the route proposals and verification of compliance with the proposals. The driver chooses an origin-destination pair and has the possibility to choose between two routes, one of which will avoid the exclusion zone, subject to an incentive, and will receive a bonus by accepting the proposed alternative route and following it until reaching the preset destination. However, when entering the exclusion zone, emergency vehicles will only receive a notification as navigational information, whereas passenger vehicles, encouraged to change their behaviour, will receive a warning of breach of the proposed agreement.

5 Conclusions and Future Work

The implementation of the UVARs has been essentially a task in the context of European policy and local administrations. In this work, we have focused on a strategy to promote behavioural change, in the context of UVARs, in order to encourage more sustainable practice in urban centres and to remove car traffic from the most sensitive areas. The prospect of being able to achieve this goal, serves as a continuous incentive for future research.

We have proposed an architecture for a system that addresses the interplay of gamification, the pervasiveness of mobile devices and the Blockchain technology. In addition, we have presented a proof of concept, by means of an urban mobility simulator, which aimed at illustrating the client-level implementation of this system.

Future work will focus on the Distributed Ledger-level of the system, through the deployment of an Hyperledger Fabric-based network, operating through programmable Smart Contracts to ensure compliance with the conditions regarding route acceptance, leading to incentive recognition and auditing. In addition, further development of the system will rely on the current experimental setup, using the *Mock GPS* functionality.

Acknowledgment. This work is a result of project DynamiCITY: Fostering Dynamic Adaptation of Smart Cities to Cope with Crises and Disruptions, with reference NORTE-01-0145-FEDER-000073, supported by Norte Portugal Regional Operational Programme (NORTE 2020), under the PORTUGAL 2020 Partnership Agreement, through the European Regional Development Fund (ERDF). This research has been developed within the Artificial Intelligence and Computer Science Laboratory, University of Porto (LIACC), FCT/UID/CEC/0027/2020, funded by national funds through the FCT/MCTES (PIDDAC).

References

1. Bui, A., Veit, D., Webster, J.: Gamification - a novel phenomenon or a new wrapping for existing concepts? In: Thirty Sixth International Conference on Information Systems, Fort Worth, December 2015
2. Ciatto, G., Maffi, A., Mariani, S., Omicini, A.: Smart contracts are more than objects: pro-activeness on the blockchain. In: Prieto, J., Das, A.K., Ferretti, S., Pinto, A., Corchado, J.M. (eds.) Blockchain and Applications, pp. 45–53. Advances in Intelligent Systems and Computing, Springer, Cham (2020). https://doi.org/10.1007/978-3-030-23813-1_6
3. Ciatto, G., Mariani, S., Omicini, A., Zambonelli, F.: From agents to blockchain: stairway to integration. Appl. Sci. **10**, 7460 (2020). https://doi.org/10.3390/app10217460
4. Deterding, S., Dixon, D., Khaled, R., Nacke, L.: From game design elements to gamefulness: defining gamification. In: Proceedings of the 15th International Academic MindTrek Conference: Envisioning Future Media Environments. MindTrek 2011, vol. 11, pp. 9–15. Association for Computing Machinery, September 2011
5. Dimitrakopoulos, G., Demestichas, P.: Intelligent transportation systems. IEEE Veh. Technol. Mag. **5**(1), 77–84 (2010). https://doi.org/10.1109/MVT.2009.935537
6. Eckert, J., López, D., Azevedo, C.L., Farooq, B.: A blockchain-based user-centric emission monitoring and trading system for multi-modal mobility. In: 2020 Forum on Integrated and Sustainable Transportation Systems (FISTS), pp. 328–334, November 2020. https://doi.org/10.1109/FISTS46898.2020.9264892

7. Enei, R.: Vehicle types, exemptions and (cross-border) enforcement of successful urban vehicle access regulations (UVARs) schemes across Europe. Technical Report, European Commission, Directorate-General for Mobility and Transport, April 2017
8. Góis, A.R., Santos, F.P., Pacheco, J.M., Santos, F.C.: Reward and punishment in climate change dilemmas. Sci. Rep. **9**(1), 16193 (2019). https://doi.org/10.1038/s41598-019-52524-8
9. Huotari, K., Hamari, J.: Defining gamification: a service marketing perspective. In: Proceedings of the 16th International Academic MindTrek Conference, pp. 17–22. MindTrek 2012, ACM, New York, NY, USA, October 2012
10. Liang, L., Xu, M.: Using tradable credit scheme for morning commuting congestion Management with an activity-based approach. In: 2019 IEEE Intelligent Transportation Systems Conference (ITSC), pp. 962–967, October 2019. https://doi.org/10.1109/ITSC.2019.8916997
11. Lopez, P.A., et al.: Microscopic traffic simulation using sumo. In: The 21st IEEE International Conference on Intelligent Transportation Systems. IEEE (2018). https://elib.dlr.de/124092/
12. Lopez, P.A., et al.: Microscopic traffic simulation using SUMO. In: The 21st IEEE International Conference on Intelligent Transportation Systems, pp. 2575–2582. 2019 IEEE Intelligent Transportation Systems Conference (ITSC), IEEE, Maui, HI, November 2018. https://doi.org/10.1109/ITSC.2018.8569938
13. Lütteken, N., Zimmermann, M., Bengler, K.J.: Using gamification to motivate human cooperation in a lane-change scenario. In: 2016 IEEE 19th International Conference on Intelligent Transportation Systems (ITSC), pp. 899–906, November 2016
14. Miralinaghi, M., Peeta, S.: Promoting zero-emissions vehicles using robust multi-period tradable credit scheme. Transp. Res. Part D: Transp. Environ. **75**, 265–285 (2019). https://doi.org/10.1016/j.trd.2019.08.012
15. Nawari, N.O., Ravindran, S.: Blockchain and the built environment: potentials and limitations. J. Build. Eng. **25**, 100832 (2019). https://doi.org/10.1016/j.jobe.2019.100832
16. Ricci, A., et al.: Study on urban vehicle access regulations. Final Report, European commission, directorate-general for mobility and transport, April 2017
17. Rúbio, T.R.P.M., Kokkinogenis, Z., Cardoso, H.L., Rossetti, R.J.F., Oliveira, E.: Regulating blockchain smart contracts with agent-based markets. In: Moura Oliveira, P., Novais, P., Reis, L.P. (eds.) Progress in Artificial Intelligence. pp. 399–411. Lecture Notes in Computer Science, Springer, Cham (2019). https://doi.org/10.1007/978-3-030-30241-2_34
18. Shreenath, V.M., Kornevs, M., Raghothama, J., Meijer, S.: A feasibility study for gamification in transport maintenance: requirements to implement gamification in heterogeneous organizations. In: 2015 7th International Conference on Games and Virtual Worlds for Serious Applications (VS-Games), pp. 1–7, September 2015
19. United Nations, Department of Economic and Social Affairs, Population Division: World urbanization prospects: the 2018 revision (2019)