Digital and programmable economy applications: A smart cities congestion case by fuzzy sets

Ferran Herraiz-Faixó

Francisco-Javier Arroyo-Cañada,

María-Pilar López-Jurado

Ana M. Lauroba-Pérez

***Abstract*.**

Currently, cities are facing great challenges such as the population growing, citizen wellbeing, externalities man-agement or environmental deterioration. The search for solutions are making significant inroads into the incorporation of ICT in them and subsequent large-scale digitalization such as programmable economy (PE) applications, offering the possibility to develop new approaches over these issues, in particular which related to sustainability management. Operating under a fuzzy numbers methodology and FIS (Fuzzy Inference System), the present exploratory work shows a new approach to city urban congestion management by deploying PE applications, which include some disruptive inputs such as the Internet of value, blockchain/DLT (distributed ledger technology), smarts contracts, digital assets and the monetization, all of this combined with the human motivation.

Keywords:
Programmable economy, blockchain, smart cities, urban congestion, fuzzy sets

1. Introduction

Smart Cities (SC) are moving forward from phase 1.0, or ecosystem connectivity, to phase 2.0, intensifying the decision-making process by involving all the actors that comprise the SC (government, busi-ness and residents) with the aim of improving quality of life, increasing competitiveness, promoting sus-tainability and creating open and inclusive platforms

[9, 23, 29]. However, what does smart truly mean?The adjective "smart" was born from the ideas of the "Smart Growth Movement" in the 1990s, which was intended to promote new forms of urban plan-ning. Technology companies appropriated this term for the deployment of ICT in cities [18]. Although there is no definitive consensus on the idea of SC, there seems to be approval on the connection of this term and the use of technology in cities. This deploy-ment is observed because there is growing pressure to improve the efficiency of cities while promoting aspects related to human capital [15, 30]. It seems clear that the impact of ICT on better city manage-ment is having a transversal impact on all agents [2], though there is a set of "soft" factors, such as citizen participation, collaboration or reward, that are associ-ated with the objectives of managing resources better, improving services offered or encouraging innova-tion, and all of them result in an improvement of wellbeing [7, 16, 45].

These new technologies seek to alleviate or resolve the different facets that occur in a SC, with one of them being the mobility of the subjects and things that happen in a SC. This mobility generates powerful negative externalities, all of which will increase, given that 55% of the world's population currently lives in urban areas and that forecasts for 2050 suggest that this percentage will reach 68% [37]. Possible future consequences can be considered worrisome. In the case of mobility, possible consequences include pollution, climate change, urban congestion or energy consumption. Cities currently account for 2/3 of the world's energy consumption and are responsible for 70% of greenhouse gas emissions [39]. The charges of massive mobility in SC have a considerable effect on inefficiency. It is estimated that congestion's impact on GDP (Gross Domestic Product) in most cities is 2 to 4% in terms of waste of time or energy and increase in the cost of doing business [4]. In the United States alone, congestion costs in cities will increase by 20%, from \$160 billion in 2014 to \$192 billion in 2020 [3]. Regarding this point, many institutions are setting detailed objectives on the efficiency of transport in terms of resources used and the environment, urban congestion, and the formulation of behavioural and social policies on the issue [11].

The objectives of this paper are, first, to highlight the importance of the digital and programmable economy (PE) as a tool to manage externalities. These concepts open up new SC management possibilities and are becoming key elements in formulating future urban strategies, more so if one takes into account the vertiginous acceleration of the negative externalities that occur in them, particularly those created by urban congestion.

Second, to emphasize the need to focus on the treatment of the current and new threats of SC from a more holistic and inclusive point of view, considering the vital importance that citizens will play in the search for new solutions. The great challenges that the SC of the future will face need to reinforce and promote the active participation of the citizen using the aforementioned opportunity offered by ICT in its different aspects. These technologies should be approached from a vehicular and social integrating point of view to facilitate the better management of the SC and not as ends in themselves.

To elucidate this subject, an exploratory approach to urban congestion phenomena is proposed using the paradigm structure-conduct-results (SCP) and fuzzy logic to present a new congestion model that uses an inference algorithm that makes it possible to simulate the level of expected congestion in a city based on the combination of the aggregate factors that will be developed in this study, such as the infrastructure and the programmable economy with the use of human reinforcement through the application of citizen' incentives. What is sought is to find the balance between these inputs in such a way that urban congestion can be reduced by deploying the programmable economy (PE) as a facilitator tool.

This paper is organized as follows: in section 2, the theoretical background is described. In section 3, the methodology is presented, followed by the results. Finally, section 4 summarizes the most important conclusions of this paper.

2. Theoretical background

2.1. Structure: Urban congestion

The situation of urban congestion worldwide is truly worrying. Taking the Tomtom index (incremental time necessary to make the same journey in traffic jam conditions compared with normal conditions) as a reference, it shows us that in such cities as Mexico City, the Tomtom index exceeds 66% [38]. A similar situation occurs in such countries as Thailand, Indonesia, and Brazil that occupy the first positions in the traffic jam ranking provided by INRIX [20], and the same happens in more developed cities. As already mentioned, the impact of this congestion on their productivity is alarming. The projections for the future are not very promising. With the incorporation of the misunderstood electric vehicle (EV), the idea of "zero emissions" being confused with "zero carbon emissions", the increase in the shared economy, the appearance of autonomous vehicle (AV) and even the increase of commercial vehicles (CV) making home deliveries caused by the increase of e-commerce all added together, it seems that traffic in cities will increase significantly, not decrease [3, 17].

Some solutions are offered in the literature, such as citizens' journey customization on a connected transport network via multimodal solutions (users can choose the best travel option at any time through the incorporation of ICTs and intelligent driving) or the accessibility increasing proximity concept and eliminating the need to move by increasing technology penetration (tele services) [46]. Some cities are deploying driving prohibitions or limitations for certain types of vehicles (Hamburg prohibits the circulation of the oldest and most polluting diesel vehicles in certain areas and streets) [10]. On the other hand, restrictive measures are implementing via quantities (driving prohibitions on odd or even numbers of alternate days have been adopted in Madrid, Mexico City, Beijing, Bogota, Caracas, and Santiago de Chile). Finally, there are toll initiatives (congestion pricing) where the vehicles that want to access the city's downtown during rush hour must pay, as in Singapore, London, Stockholm, Milan and Gothenburg. This last measure is supported by a recent study about using a congestion pricing viability tax to avoid traffic jams and pollution in large cities [12].

Whatever the solution that cities adopt, what seems obvious is that the enormous pressure toward SC efficient urban management is accelerating the use of ICT for finding proper solutions. Among many other technologies behind the ICT concept, today there is one major phenomena, the programmable economy (PE) and the concepts underlying it (IoT, blockchain/DLT, monetization, smart contract, and token economy) are revolutionizing the way that people understand and manage cities. These technologies could form new and diverse scenarios of value exchange, both monetary and non-monetary [13], and allow us to take a further step toward PE monetization. Regarding this point, it will be possible to convert urban physical or intangible assets (like urban space or traffic congestion) to digital assets, opening the possibility to create new business management models and revolutionise citizen and city interactions in a transparent and decentralized way.

These technologies will help to improve how cities and citizens coordinate, connect and organize. If cities want to change mobility and congestion, the PE offers new opportunities.

2.2. Conduct: Citizen's reinforcement

ICT measures, in some way, are contributing greatly to better mobility and a reduction of urban congestion; however, considering citizen habits as a basis, these measures are not sufficient. In this way, looking for a better resource combination and mobility and congestion solution could be accelerated through a better combination of digital technology and PE, which are then all together joined with citizen reinforcement, encouraging a change of habits. Tomorrow's cities (SC 2.0) are looking to provide a positive citizen and visitor experience, and they need to contemplate how to motivate them in their equation.

The move of cities' visions from "car-centric", anchored in the 1920s-30s, to "people-centric" (walking, riding, cycling or using public transportation) needs to be reinforced [39]. Therefore, there could be used some factors beyond the technological and economic ones, such as human reinforcement and motivation, in order to stimulate and involve citizens in congestion resolution.

Learning theory [32] or reinforcement theory refers to the stimuli used to produce desired behaviours. B.F. Skinner argues that the administrator only needs to understand the relationship between behaviours and their consequences in order to create conditions that encourage desirable behaviours and discourage undesirable ones. This appreciation could be used in urban city management to motivate citizens and support or dissuade their mobility conduct through negative incentives (congestion pricing, CP) applied to (private and commercial) unfriendly vehicles, and positive ones (uncongestion pricing, UP) applied to friendly vehicles in a particular area, all of which can contribute to better mobility in cities.

It is important to mention that the friendly or unfriendly vehicles classifications have been defined regarding urban transport environments' impact in developed countries according to their efficiency in terms of respecting the environment while minimizing the impact on the climate of greenhouse gases (CHG), [42], 1-Unfriendly: 61–170 max Co2-eq emissions/passenger by travel (-gasoline, diesel, electric- cars, motorbike, vans, trucks, coach). 2-Friendly: 25–60 max Co2-eq emissions/passenger by travel (bicycles, scooters, public transport-train, metro, bus).

2.3. External conditions: Programmable economy

In what way can SC combine technological advances with citizen reinforcement deployment such that they are encouraged to use minor polluting vehicles at the same time that city hall is allowed more efficient, rapid and transparent management over all this?

PE will be the answer. The PE concept was introduced by Gartner in 2014 to refer to an intelligent economic system that supports and, at the same time, manages the production and consumption of goods and services, making possible new exchanges of value (monetary and nonmonetary) [14]. PE is supported through blockchain or DLT, IoT, monetization, token economy, smart contracts, artificial intelligence and cryptography, thereby supporting new forms of value exchange, new types of markets and new forms of the economy. In this programmable economy, it will be the individuals and the smart machines that will define the value and determine how the exchanges will be determined through peer-to-peer transactions involving organizations and even smart machines and agents. The PE permits the creation of new business models by combining the physical world with the digital one, allowing predictions regarding behaviour to be made while changing the ways in which value is exchanged. The PE's implications include removing the middleman, imagining new ways of exchanging the value of the tangible and intangible between people and institutions, rethinking new forms of governance relationships, allowing greater automation by minimizing external oversight and decentralizing the economy and managing information better. However, perhaps one of the greatest characteristics of the PE is the possibility of monetizing things and services by redefining the economy and the way in which value is exchanged between intelligent physical or intangible things and citizens [33], enabled by the second generation of the internet; that is, through Web 2.0 going from an "internet of information" to an "internet of value", radically changing the operation of the economy and of institutions [36].

PE technology drastically reduces the cost of trust and allows us to imagine new business models and opens the possibility of deploying new forms of collaboration at the same time. As a source of trust, PE can expand organizations' and institutions' degree of digital transformation whereby they can share processes among all actors. All of this is possible due to the fact that this technology makes the information contained within it immutable, safe, shared and consensual [19].

On the other side, PE by smart contracts or intelligent contracts, a concept attributed to Nick Szabo [34] in 1996, facilitates the agreement of individuals, organizations and institutions in such contracts over how they want their business or public services to be carried out in a consistent and automated manner, keeping participant interactions recorded in a transparent manner at all times. This technology allows better decision-making between people or between machines without human intervention.

In addition, one of the most important characteristics of PE technology is that it allows the reduction, in a very consistent manner, of the so-called "transaction costs" defined in Coase's work, "The Nature of the Firm" [6]. These costs include the cost of organization, negotiation, information monitoring and coordination [31], and digital technologies can clearly reduce many of these costs. PE technology tends to reduce decisions and many coordination functions could be replaced by software, opening new institutional possibilities in order to reduce transaction, control, and monitoring costs and give them the possibility to achieve more efficient data coordination.

Thus, PE allows a strong impulse toward connected mobility by using IoT, DLT, smart contracts, tokens and digital wallets in all kinds of vehicles. In this way, if it is wanted to decongest a specific area of the city, the city's administrators could define a space (downtown area) in which there would be an exchange of externalities between friendly and unfriendly vehicles through the use of incentives and PE. Thus, the unfriendly vehicles that are mentioned before, can make certain token transfers automatically to city hall and friendly vehicles in order to pay congestion charges (congestion pricing) to accessing a specific city area, and friendly vehicles can receive them as shown in Fig. 1.

In other words, if city resources, such as space, are limited, then friendly and unfriendly vehicles (vehicles that cause urban congestion and its negative externalities, such as contamination, noise, and accidents) have a new way to compete for the city's scarce resources using the reinforcements' monetization. In this sense, friendly vehicles (and their owners) can obtain the positive incentives (uncongestion pricing) delivered by the PE if they have access to the same area by a more sustainable mode, such as receiving part of the congestion pricing paid by unfriendly vehicles in the same area. The form of this transaction from unfriendly to friendly vehicles is possible through PE and tokens and can be related to stable coins [22]. After that, friendly income can be exchanged for public transport discounts, payment of local taxes, commerce coupons in the congested area or users can exchange it for fiat money too, all with minimal human interaction.

Also, a part of this charge received by city hall can be reinvested directly in maintaining and constructing new city infrastructure.

Therefore, PE by externality monetization activates the possibility to deploy the digital asset concept (a digital asset market representing the physical assets, such as vehicle space in cities). In other words, through PE technologies it is possible to create a new city congestion scenario to manage and negotiate access for any vehicle to a specific area, motivating

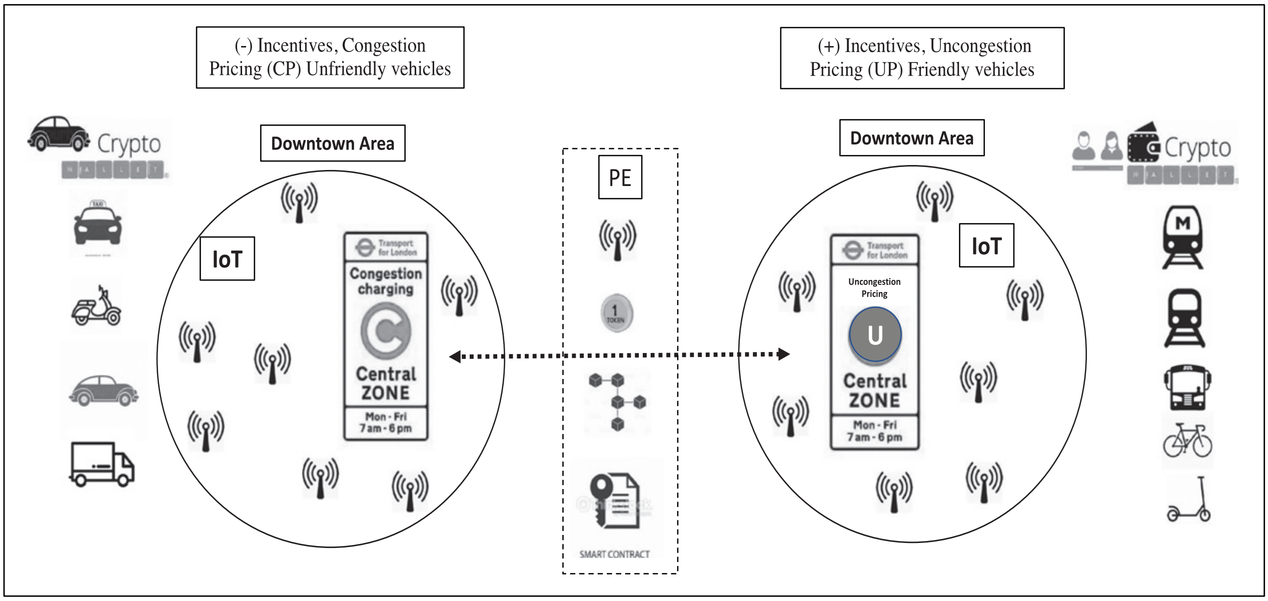

Fig. 1. Downtown congestion framework.

citizens through positive or negative incentives and dissuading the use of unfriendly vehicles and encouraging the use of friendly ones, such as public transportation or bicycles. On the other hand, PE applied to the institutional administration becomes an excellent technology for governance, decentralization and information systems. All of the above can have an impact on productivity and organizations' efficiency and will be extremely beneficial for them [8].

In view of the above explanation, and to put all of these concepts in order, a new approach to urban congestion phenomena is presented using the Structure-Conduct-Performance (SCP) paradigm formulated by Mason and Bain.

This model states that the structural characteristics of the market determine the behaviour of agents and, in turn, their behaviours determine their outcomes. The SCP paradigm assumes that the structure of the market determines the conduct of the firms and these determine the results [1]. The concept of market structure is the set of characteristics that influence the behaviour and results of the agents that operate in it, and public policies would have a high impact on this structure [28, 41]. On the other hand, the conduct refers to the behaviour patterns followed by the firms that operate in the market [1]. These patterns include the behaviours or actions of the agents (citizens), and these conducts are determined by the characteristics of each industry (city mobility). Finally, the results of the market (city congestion level) are the product of the combination of its structure and its conduct. Also, if it is wanted to have a big SCP picture it is needed to add external conditions, such as socioeconomic factors, governmental policies and, in particular, the digital aspects of ICT. ICT plays a transcendental role in this model by conditioning the market, because any variation in ICT can cause changes in the model [5]. The measurement of these results can be determined in the form of benefits, profitability or efficiency related to the resources used [28].

Taking the SCP model as reference, it is proposed that the solutions to the congestion problem become more holistic and include, in addition to the different functions of Batty's Smart City [2], the combination of the external factors generated by digitization and the programmable economy, along with aspects related to behaviour, such as human reinforcement and the use of incentives (positive or negative congestion pricing depending on whether a friendly or unfriendly vehicle is owned), can change the game. All of this is contemplated in the SCPUC (Structure-Conduct-Performance Urban Congestion) model, as presented in Fig. 2.

Following the SCPUC model, a city's performance (arrow 3) is produced as a consequence of the city's structure and conduct (arrow 1). At the same time, the results can also be affected by variations in external city conditions if conducts' factors are managed by PE (arrow 2).

In this sense, placing the focus on urban congestion is difficult, and it is proposed to exclusively

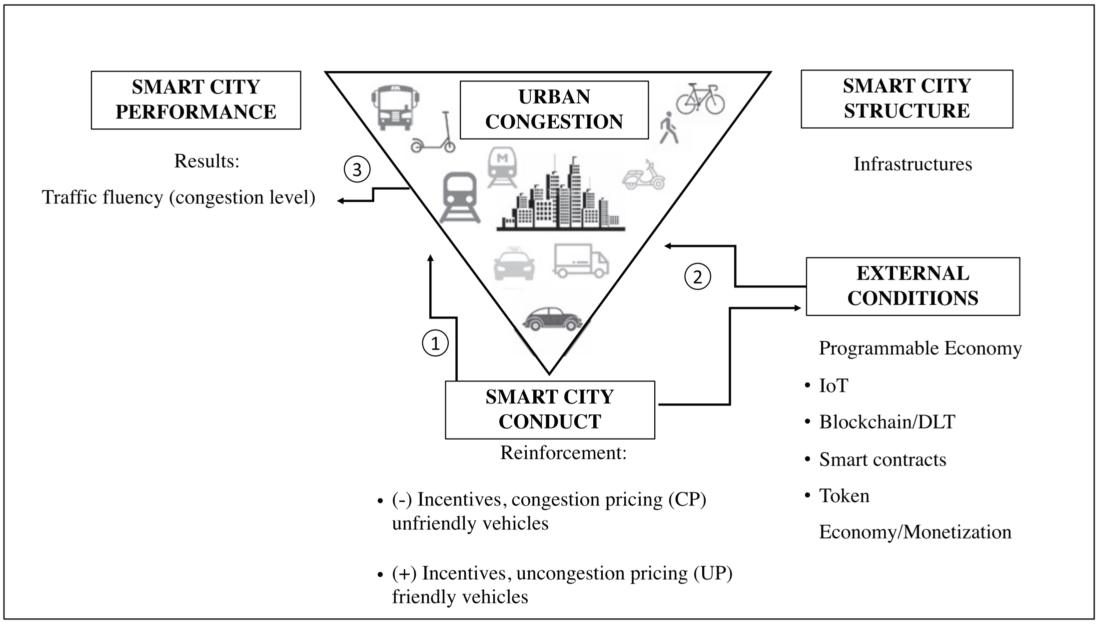

Fig. 2. SCPUC model.

address the principal externality that it generates. The main objective will be to increase traffic fluency in downtown areas, although the list of results, not treated here, would be expandable to others – improve city productivity (reduce waste of time due to traffic), improve the environment (more green areas and less noise/Co2 pollution), improve health (reduce personal stress, related diseases, and accidents) increase public transportation and friendly vehicle use (bicycles, electric skates), improve local financial resources, increase institutional governance efficiency (reduce transaction and monitoring costs), increase connectivity and networking (digitization), increase citizen participation (P2P, Apps) and build the backbone to deploy others digital assets (reward citizen behaviour) – not developed in this article.

The problem that is required to solve revolves around knowing to what extent the modification of the conduct factor by congestion incentives combined through PE technology reduce urban congestion and what kind of importance has the city structure in order to apply these initiatives. Specifically, and as a first phase, it is necessary to know whether the deployment of the programmable economy, together with the implementation of positive and negative incentives on the use of friendly and unfriendly vehicles in a defined area of the SC, as described in Fig. 1 (arrow 2), can alter traffic levels (arrow 3) more than if there are used only positive and negative incentives without PE (arrow 1) to maintain city structural fixes.

In the search for such results, there are no simple solutions, since inaccuracy and uncertainty act within cities. In addition, certain parts of the proposed urban mobility system are unknown, and cannot be measured reliably without clear limits on the concepts of structure, conduct and the external factors that occur in cities. For this reason, what is proposed is to make use of fuzzy systems methodology to reproduce reality more faithfully and to relax the restrictions because there are concepts that have no clear limits. Therefore, it is used fuzzy science in order to find an algorithm to understand if citizen reinforcement measures, such as congestion and uncongestion pricing deployed in particular areas, reduce a city's traffic and what would be the better way to deploy it, with PE or without it.

3. Methodology

3.1. Fuzzy logic

The theory of fuzzy sets was introduced in 1965 by Lofti A. Zadeh. The idea resides in the fact that the elements that make up human thought are not numbers but linguistic labels. According to the principle of incompatibility as the complexity of a system increases, the ability to be precise decreases to the point that precision and meaning are exclusive characteristics [44]. From this idea, fuzzy logic allows us to represent common thought in a mathematical language based on the theory of fuzzy sets and their characteristic functions. Fuzzy logic's applications have increased to the point of being considered a real revolution, developing a large number of extensions, such as soft computing that covers the fuzzy sets and fuzzy logic for approximate reasoning and the theory of possibility [27]. According to this theory, it is been considering a referential set or universe of discourse, U, and an ordinary subset, A ⊂ U, of those elements that fulfil a specific characteristic. For ordinary subsets there are only 2 possibilities, ∀ x ∈ U: "x" satisfies the characteristic (x∈A) or "x" does not comply (xÏA). Therefore, the membership function of A is defined:

$$\forall x \in U \mu_A(x) = \begin{cases} 1 \, if \; x \in A \\ 0 \, if \; x \notin A \end{cases}$$

An ordinary subset of A ⊂ U is symbolized by the pair (U, $\mu_A(x)$).

Now, if the elements of A can take any value in a range [0, 1], it could be said that there are elements of U that fulfil the characteristics defined in subset A, but only to a certain degree. In this sense, the membership function of A will be defined as,

∀ x ∈ U:

$\mu_A(x)$: U⟶ [0,1]

X⟶ $\mu_A(x) = 0, 1$

In this way it is possible to construct a fuzzy subset (U, $\mu_A(x)$) symbolized by $A \subset U$.

$$A = \{(x, \mu_A(x)) / x \in U\}$$

On the other hand, fuzzy logic allows the assignment of linguistic values to the variables of a problem, similar to the evaluation of a parameter usually conducted by people, whether they are experts or not [21, 47].

In this sense, the universe of discourse is the range of possible values for an input to a fuzzy system. A fuzzy set is any set that allows its members to have different grades of membership (membership function) in the interval [0, 1]. Linguistic variables are the input or output variables of the system whose values are words or sentences from a natural language, instead of numerical values. A linguistic variable is generally decomposed into a set of linguistic terms.

3.2. Mandami fuzzy inference systems

There are two well-known rule-based fuzzy inference systems (FIS), the Mandami fuzzy method [24] and the Tagaki Sugeno (T-S) fuzzy method [35]. The main idea of the Mandami method is to describe process states by means of linguistic variables and to use these variables as inputs to control rules. The Mandami fuzzy model involves developing membership functions and defining the subsequent rules. The rules connect the input variables with the output variables and are based on the fuzzy state description that is obtained by the definition of the linguistic variables.

The basic components of a Mandami Fuzzy System [25] are the following: fuzzification, a knowledge base with an inference system and defuzzification. Meanwhile, the general structure of a fuzzy model includes the input variables, the development of rules and the output variables.

i. Fuzzification, understood as the introduction of input values and their interpretation as linguistic values, determines the membership functions of the system variables in the fuzzy sets. The universe of discourse of each variable was determined by the linguistic components for input and for output. A fuzzy set is defined by the expression below:

$$A = \{(x, \mu_A(x)) / x \varepsilon U, \mu_A(x) \, \varepsilon \, [0, 1]\}$$

where U represents the universal set, x is an element of U, A is a fuzzy subset in U and $\mu_A(x)$ is the membership function of fuzzy set A.

ii. The knowledge base consists of fuzzy rules defined with the help of experts. A single fuzzy if-then rule assumes the form:

If x is A Then y is B

where A and B are linguistic values defined by fuzzy sets in the range (universe of discourse) x and y, respectively. The "x is A" part of the if-then rule is called the antecedent or premise, while the "y is B" part of the rule is called the consequent or conclusion [43]. During data processing, a fuzzy system fuzzifies the crisp data and applies the Mandami inference system using the fuzzy rules (by experts). In this study, the fuzzy control rules are of the form

$$R_i : If \; X_1 is A_i^1 and \ldots and X_r is A_i^r \; Then \; Yis C_i$$

where the variables X_j, $j \in \{1, 2, \ldots, r\}$, and Y have the domains U_j and V, respectively. The firing levels of the rules, denoted by $\{\propto_i\}$ are computed by

$$\propto_i = T\left(\propto_i^1, \ldots, \propto_i^r\right)$$

where T is a t-norm and $\propto_i^j$ is the firing level for A_i^j, $j\varepsilon\{1, 2, \ldots, r\}$. The causal link from $X_1, \ldots, X_r$ to Y is represented using an implication operator, *I*.

This results in the conclusion C_i inferred from the rule R_i being

$$\mu_{C_i}(x) = I\left(\alpha_i, \mu_{C_i}(x)\right), \forall x\varepsilon U$$

and using Mandami implication *I* the formula is

$$\mu_{C_i}(x) = I_M(\alpha_i, \mu_C(x)) = \min\{\alpha, \mu_C(x)\}.$$

The final output of the model is the aggregation of outputs from all rules using the max operator:

$$\mu_C(x) = \vee_{i=1}^n\left[\alpha_i \wedge \mu_{c_i}(x)\right] = \vee_{i=1}^n \mu_{c_i}(x)$$

iii. Defuzzification is used to obtain an output from the previous fuzzy set. A centroid method is usually used. Subsequent defuzzification produces a crisp value output. Defuzzification uses some methods, such as centre of gravity or centroid (COG), mean of maximum (MOM), and first of maximum (FOM). Centre of gravity is the most popular and the most precise method used for defuzzification. The centre of gravity method is a grade weighted by the areas under the aggregated output functions. The formula for the centroid is given as

$$\text{COG} = \frac{\int \mu_c(x)\, x dx}{\int \mu_c(x)\, dx}$$

where $\int \mu_c(x)\, dx \neq 0\, forall \mu_i$

3.3. *Fuzzy inference system to estimate the congestion*

This section introduces a fuzzy inference system to estimate urban congestion (FISUC) by algorithm. The objective of the proposed algorithm is to provide the urban congestion function of a city based on the input given as structure (infrastructure), conduct (negative incentives in the form of congestion pricing for unfriendly vehicles and positive incentives in the form of uncongestion pricing for friendly vehicles) and an external factor (programmable economy). The linguistics variables, fuzzy set and universe of discourse are given in Table 1 and Table 2.

Fig. 3 shows a block diagram of the proposed FISUC algorithm (urban congestion), which includes a fuzzification block, a knowledgebase, a fuzzy inference engine and a defuzzification block.

Table 1
Linguistic variables

Structure (S)	Conduct (C)	External (E)	Congestion (CO)
-City Infrastruct.	-(–) Incentives, Congestion Pricing (CP) Unfriendly vehicles. -(+) Incentives, Uncongestion Pricing (UP) Friendly vehicles.	-Programmable Economy (IoT, Blockchain, DLT, smart contracts, monetization and token economy)	-City traffic level

Table 2
Fuzzy set and universe of discourse

Linguistic Variable	Fuzzy Set	Discourse of Universe
Structure (S)	$A_s = \{x, \mu_s(x)/x\varepsilon[0, 100]\}$	$U = [0, 100]$
Conduct (C)	$A_C = \{x, \mu_C(x)/x\varepsilon[0, 100]\}$	$U = [0, 100]$
External (E)	$A_E = \{x, \mu_E(x)/x\varepsilon[0, 100]\}$	$U = [0, 100]$
Congestion (CO)	$A_{CO} = \{x, \mu_T(x)/x\varepsilon[-100, 0]\}$	$U = [-100, 0]$

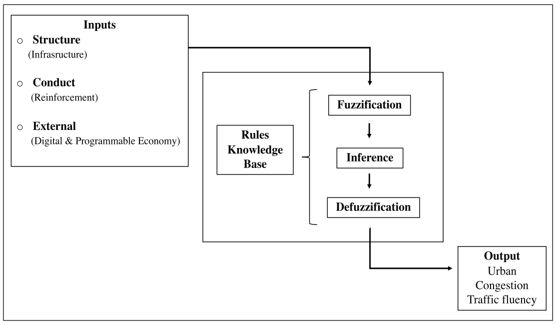

Fig. 3. FISUC Algorithm.

The proposed algorithm consists of three steps: fuzzification, fuzzy rules, and defuzzification.

Step1 – Fuzzification: in order to keep the number of fuzzy rules at a reasonable level, input can be defined as fuzzy set levels with three membership functions known as "Low", "Medium" and "High". For the output, the congestion (city traffic level) fuzzy set has three membership functions, such as "Jam", "Dense", and "Fluid".

To define the structure, conduct and external membership functions, it is used the Global Competitive Index Report 2017-2018 [40] sub index

Table 3
Structure membership function

Linguistic V.	Functions
Low (L)	L Function: $1-\mu_x = \begin{cases} 0 & if\ x \leq 38 \\ \frac{x-38}{57-38} & if\ x \in (38,57) \\ 1 & if\ x \geq 57 \end{cases}$
Medium (M)	Triangular Function: $\mu_x = \begin{cases} 0 & if\ x \leq 45 \\ \frac{x-45}{62-45} & if\ x \in (45,62) \\ \frac{78-x}{78-62} & if\ x \in (62,78) \\ 0 & if\ x \geq 78 \end{cases}$
High (H)	L Function: $1-\mu_x = \begin{cases} 0 & if\ x \leq 64 \\ \frac{x-80}{80-64} & if\ x \in (64,80) \\ 1 & if\ x \geq 80 \end{cases}$

Table 4
Conduct membership function

Linguistic V.	Functions
Low (L)	L Function: $1-\mu_x = \begin{cases} 0 & if\ x \leq 35 \\ \frac{x-35}{45-35} & if\ x \in (35,45) \\ 1 & if\ x \geq 45 \end{cases}$
Medium (M)	Triangular Function: $\mu_x = \begin{cases} 0 & if\ x \leq 35 \\ \frac{x-35}{60-35} & if\ x \in (35,60) \\ \frac{85-x}{85-60} & if\ x \in (60,85) \\ 0 & if\ x \geq 85 \end{cases}$
High (H)	L Function: $1-\mu_x = \begin{cases} 0 & if\ x \leq 75 \\ \frac{x-75}{85-75} & if\ x \in (75,85) \\ 1 & if\ x \geq 85 \end{cases}$

Table 5
External membership function

Linguistic V.	Functions
Low (L)	L Function: $1-\mu_x = \begin{cases} 0 & if\ x \leq 30 \\ \frac{x-30}{46-30} & if\ x \in (30,46) \\ 1 & if\ x \geq 46 \end{cases}$
Medium (M)	Triangular Function: $\mu_x = \begin{cases} 0 & if\ x \leq 40 \\ \frac{x-40}{60-40} & if\ x \in (40,60) \\ \frac{60-x}{85-60} & if\ x \in (60,85) \\ 0 & if\ x \geq 85 \end{cases}$
High (H)	L Function: $1-\mu_x = \begin{cases} 0 & if\ x \leq 75 \\ \frac{x-75}{90-75} & if\ x \in (75,90) \\ 1 & if\ x \geq 90 \end{cases}$

Table 6
Congestion membership function

Linguistic V.	Functions
Jam (J)	L Function: $1-\mu_x = \begin{cases} 0 & if\ x \leq -50 \\ \frac{x-(-50)}{-30-(-50)} & if\ x \in (-50,-30) \\ 1 & if\ x \geq -30 \end{cases}$
Dense (D)	Triangular Function: $\mu_x = \begin{cases} 0 & if\ x \leq -35 \\ \frac{x-(-35)}{-22-(-35)} & if\ x \in (-35,-22) \\ \frac{-10-x}{-10-(-22)} & if\ x \in (-22,-10) \\ 0 & if\ x \geq -10 \end{cases}$
Fluid (F)	L Function: $1-\mu_x = \begin{cases} 0 & if\ x \leq -15 \\ \frac{x-(-15)}{-5-(-15)} & if\ x \in (-15,-5) \\ 1 & if\ x \geq -5 \end{cases}$

approach, including their "basic requirement" sub index (institutions, infrastructure, macroeconomics, and environment), "efficiency enhancer" sub index (higher education, high efficiency, labour market efficiency, financial market, and technological readiness), and "innovation and sophistication" sub index (business sophistication and innovation), respectively behind a universe of discourse valued between 0 and 100. To obtain the congestion membership function, it is used the TomTom Congestion Index (increase in overall travel time when compared to a free float situation or uncongested situation) [38] approach as a close reference in a universe of discourse valued between -100 and 0.

It is divided the initial linguistic variables where each has their own appropriated linguistic values defining the fuzzy set membership function, as explained in Tables 3, 4, 5 and 6.

Step2 – Fuzzy Rules: in this step, it is used linguistic quantification to specify a set of rules that captures the experts' knowledge about how to control the output.

To be able to determine which are the rules to apply to the model, two SC experts (Public Administration and Private Enterprise) were asked through personal interviews to carry out the rules.

It is important to mention that this project has been divided into two phases: In a first phase, it is tested the model with two SC experts to later introduce their acquired learning, then go to phase two and extend the number of experts to 10 in the fields of: institutional, technology, blockchain, urban planning, public transportation, private sector, automotive industry, commerce and academics.

The interview methodology started by explaining the model, then experts completed some matrix in order to establish the importance of structure, conduct and external issues in urban traffic congestion, thereby establishing the rules given in Table 7.

Table 7
Rules (Knowledge base)

Rule	If Structure	And Conduct	And External	Then Congestion
1	H	H	L	D
2	H	M	L	D
3	H	L	L	D
4	H	H	M	F
5	H	M	M	F
6	H	L	M	D
7	H	H	H	F
8	H	M	H	F
9	H	L	H	D
10	M	H	L	D
11	M	M	L	J
12	M	L	L	J
13	M	H	M	F
14	M	M	M	D
15	M	L	M	J
16	M	H	H	F
17	M	M	H	F
18	M	L	H	D
19	L	H	L	J
20	L	M	L	J
21	L	L	L	J
22	L	H	M	D
23	L	M	M	F
24	L	L	M	J
25	L	H	H	D
26	L	M	H	D
27	L	L	H	J

Step3 – Defuzzification: the inputs for the fuzzy system introduced in this study were structure, conduct and externalities, all of which are crisp. Initially, the fuzzy system fuzzifies the crisp data and then, with the Mandami inference system, applies the fuzzy rules. Finally, using COG, it is determined the congestion output (city traffic level).

3.4. Results

Figs. 4 and 5 show the output of the fuzzy inference system in the Matlab (Toolbox Fuzzy Logic Matlab) [26], software for the prediction of urban congestion. For example, if the values of input variables for a particular city (i.e., structure (infrastructure), conduct (incentives) and externalities (PE)) are 85.2, 45 and 45 respectively, then the membership functions profile is shown in Fig. 4. The values of output variables (i.e., congestion) would be –11.3, belonging to the dense language variable.

Controlling levels between input structure variables with IF-THEN are presented in Fig. 5 (dark, grey and white areas represents jammed, dense and fluent traffic, respectively). As shown, congested traffic decreases as the structure – horizontal axis – and PE – vertical axis – increase for any given level of

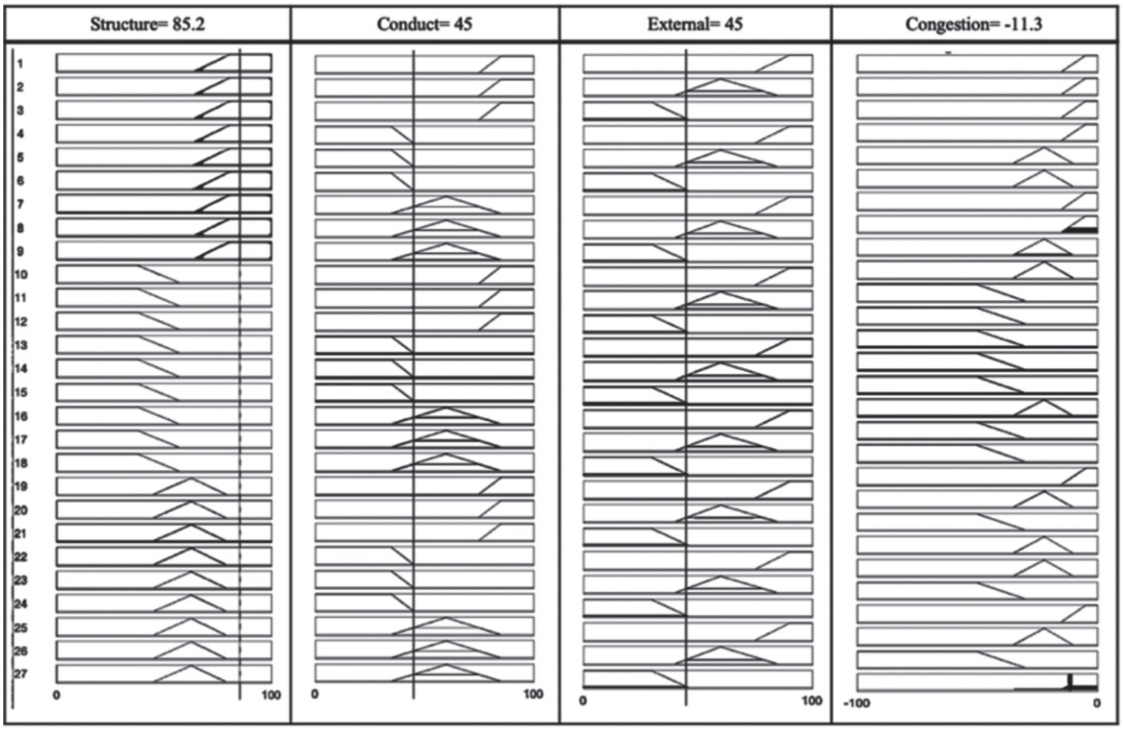

Fig. 4. Membership functions example from Matlab.

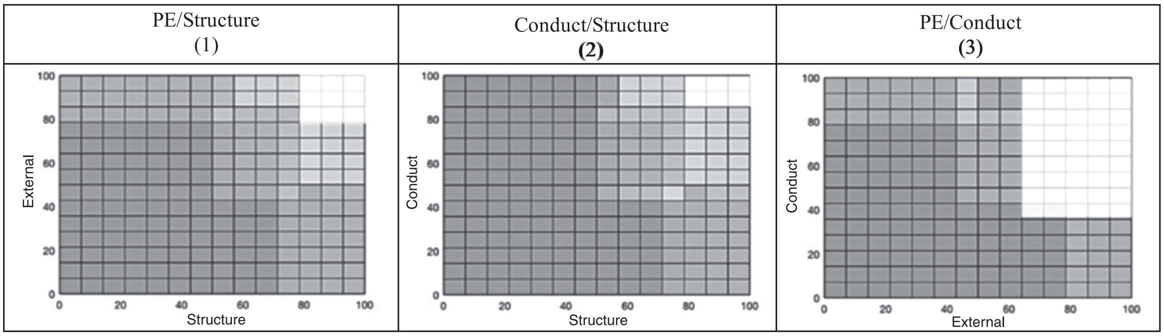

Fig. 5. Control levels between inputs and outputs (Matlab).

Table 8
Fuzzy inference system urban congestion (FISUC)

City	TomTom Real Traffic Congestion Index 2018	FISUC (1) (Absolute) S = City level C = 0, PE = 0	FISUC (2) (Absolute) S = City level C = 45, *P* = 45	FISUC (3) (Absolute) S = City level C = 80, PE = 0
Mexico	66	67	37	46
Bangkok	45	49	33	42
London	45	42	35	39
Beijing	45	48	33	42
L.Angeles	45	45	34	41
Brussels	38	40	35	36
Munich	30	22	11	12

structure, with its effects being more noticeable if the structure is larger (1). In this way, the intensive use of PE from a certain level of structure has a greater impact on the reduction of congestion levels. On the other side, actions carried out through initiatives on conduct – vertical axis – (positive and negative incentives) alone to reduce the level of congestion are more limited to certain levels of city structure – horizontal axis– (2). In other words, at the same level of structure, the expected results are greater if the two inputs (conduct plus PE) are combined at the same time. In this way it is clear that the joint effect of conduct through the deployment of PE on the reduction of congestion is greater (3).

The analysis diagram of the sensitivity of empirical data from the TomTom Traffic Index vs the values predicted by the fuzzy inference system urban congestion (FISUC) simulation data in several cities (Mexico City, Bangkok, London, Beijing, Los Angeles, Brussels and Munich) with different levels of inputs are revealed in absolute values in Table 8 and in graphic version in Fig. 6.

As can be seen in Fig. 6, there is a good correlation between the TomTom traffic index (real) and the congestion simulation –FISUC (1) – with $R^2 = 0.924$, which is notably high. On the other hand, Fig. 6 also shows us the greatest potential savings of time is obtained if the deployment of the variable conduct and PE were carried out at the same time –FISUC (2)– and not conducted in isolation –FISUC (3)–, keeping the structure variable (infrastructure) constant.

4. Conclusions

The results presented by this exploratory study would allow institutions and organizations to take more effective measures to progress aspects related to SC mobility and, in particular, to improve urban congestion problems from a broader point of view that includes the programmable economy and human capital elements. To achieve objectives a knowledge base has been acquired through a group of SC experts and representative organization indicators have been used to calibrate the membership functions of the input and output variables. Through this knowledge, it was possible to extract the linguistic variables and their rules, making it possible to build a diffuse inference system. Also, this system has been tested using the Fuzzy Logic Toolbox from Matlab.

In this research, the objective of which is to reduce the negative externalities generated by urban mobility (congestion), used fuzzy systems (Mandami inference) for the diagnosis of urban congestion considering some inputs (infrastructure, conduct and programmable economy) and regarding SCP paradigm and the reinforcement theory. These inputs are not exhaustive of the complex urban mobility system, but they have a large impact on it. It is been observed that by using the FISUC algorithm and keeping the urban infrastructure variable constant by each city, the impact of deploying an incentive

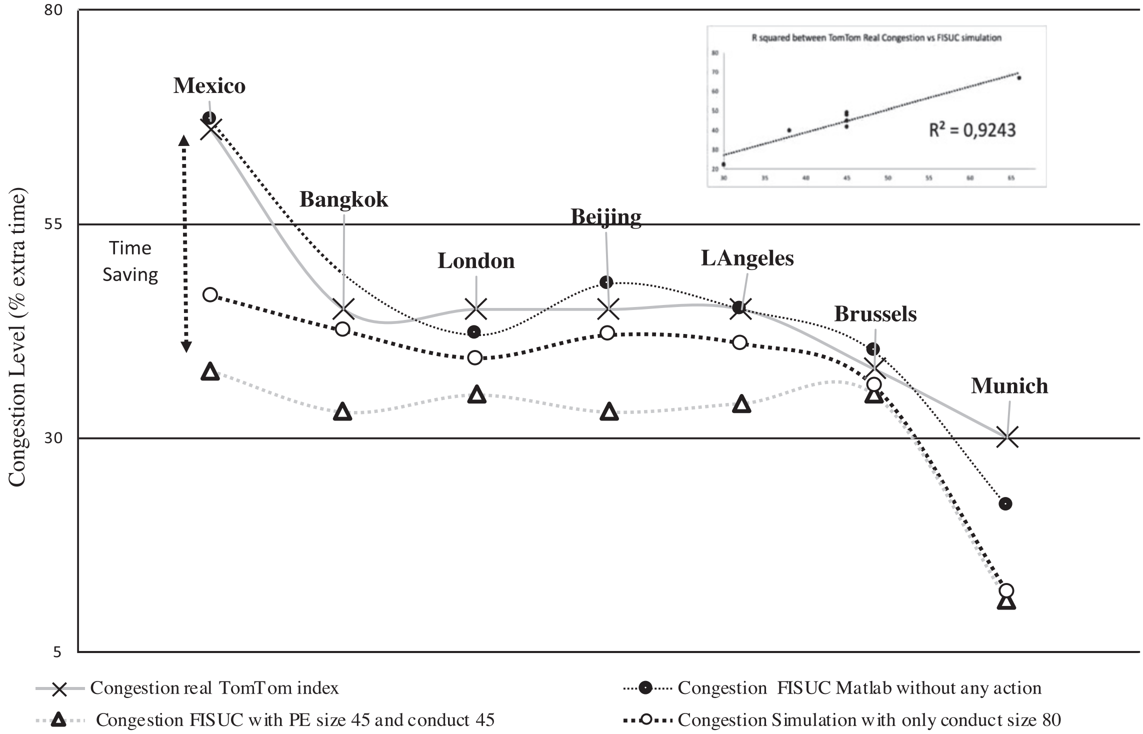

Fig. 6. Congestion examples (real vs FISUC) by cities.

base that rewards sustainable mobility and discourages the use of less sustainable vehicles through PE technology is greater than if it was done in isolation, presenting both options a high impact in terms of traffic reduction and drivers' time savings. The benefits of the application of the proposed fuzzy inference system may vary depending on the initial level of infrastructure. Regarding this point, it is been observed that there are limitations in the city "structure" affecting the ability to take advantage of the benefits of the other inputs. In this sense, the deployments of incentives require a medium level of structure to be effective. Therefore, cities without a minimum level of infrastructure should prioritize investing in it first to subsequently reach a certain level of infrastructure that allows them to capitalize other initiatives. Likewise, from a certain level of city structure (medium-high), the best initiatives to reduce congestion levels go through the application of incentives on behaviour and the PE at the same time, and do not focus so much on improving the infrastructure only. Initial city infrastructure level is a key aspect to assess the application of more advanced initiatives. So, developed smart cities can start and deploy PE's initiatives, meanwhile early cities developers need to invest and improve their infrastructures firstly in order to achieve structure tipping point that permit them to take off and, after that, combine with PE and take advantage of it. In this way, it cannot be affirmed that the same level of infrastructure corresponds with the same level of congestion because there are specific variables of each city that are very important, such as geographic density or economic centres and jobs locations.

In this article, it is also wanted to highlight the possibility of exploring the treatment of other externalities generated in cities through the programmable economy as the congestion issue was treated in this article. The set of concepts that this technology includes, all of them together, will be of vital importance in the future. Pushing citizens' participation in city decision-making at the same time in transparent, reliable, monetized, peer-to-peer and decentralized manner to open a new way for urban managers to explore externalities or other issues. In no case is this study intended to relegate the role of institutions, but to the contrary seeks to provide them with technological capabilities to find new modes of fairer management efficiency and dissuade citizens from generating negative footprints and encouraging them to contribute to generating a more sustainable city.

As limitations of this article go, it should be noted that this approach is in its first phase. At this moment, this research has only attempted to test the feasibility of the model in order to move on to the next phase. On the other hand, as for other limitations, this paper does not talk about the important technologies needed in order to implement the PE, such as 5G, artificial intelligence, big data, the machine to machine economy or cryptography. Also, this article does not include other variables of great relevance and very high impact included in the SCP paradigm for cities, such as legal aspects, taxes, user profiles, government policies and many more.

As part of future research, it is planned to add new variables to the proposed system such a monetary or non-monetary incentives, multimodal transport tickets and tele-services penetration in cities because, as it has been seen in theoretical background section, all of them are being testing in some cities and data could be available for it study. On the other hand, it could be analysed other results derived from this work, such as the impact of reduced congestion on SC productivity or its effects on citizens' health, or open up the possibility to apply PE and diffuse systems to the treatment of other urban externalities like waste recycling or unhealthy consumption.

References

[1] J. Bain, *Barriers to New Competition*. Harvard University Press. Hup.harvard.edu (1956) at http://www.hup.harvard.edu/catalog.php?isbn=9780674188037 (visited on 05/2017).

[2] M. Batty, K.W. Axhausen, F. Giannotti, A. Pozdnoukhov, A. Bazzanio, M. Wachowicz, G. Ouzounis and Y. Portugali, Smart Cities of the future. *The European Physical Journal: Special Topics* **214** (2012), 481–518.

[3] S. Bouton, E. Hannon, L. Haydamous, B. Heid, S. Knupfer, T. Naucler, F. Neuhaus, S. Nijssens and S. Ramanathan, An Integrated Perspective on the Future of Mobility, part 2: Transforming Urban Delivery. Mckinsey.com (2017) at https://www.mckinsey.com/ /media/mckinsey/business%20functions/sustainability%20and%20resource%20productivity/our%20insights/urban%20commercial%20transport%20and%20the%20future%20of%20mobility/an-integrated-perspective-on-the-future-of-mobility.ashx (visited on 02/2018).

[4] S. Bouton, S.M. Knupfer, I. Mihov and S. Swartz, Urban Mobility at a Tipping Point. *McKinsey&Company* (2015), 1–23.

[5] Canback, Structure, Conduct, Performance, SCP. (2018) Canback.com at https://www.canback.com/news3/scp/ (visited on 02/2018).

[6] R.H. Coase, The Nature of the Firm, *Economica* **4** (1937), 386–405.

[7] M. Cooray, R. Duus and L. Bundgaard, These Three Factors are Critical to the Success of Future Cities. World Economic Forum (2017) at http://amp.weforum.org/agenda/2017/09/these-three-factors-are-critical-to-the-success-of-future-cities (visited on 09/2017).

[8] S. Davidson, P. De Filippi and J. Potts, Disrupting Governance: The New Institutional Economics of Distributed Ledger Technology. SSRN (2016), doi:10.2139/ssrn.2811995

[9] W. Eggers and J. Skowron, Forces of Change: Smart Cities. Www2.deloitte.com (2018) at https://www2.deloitte.com/content/dam/insights/us/articles/4421_Forces-of-change-Smart-cities/DI_Forces-of-change-Smart-cities.pdf (visited on 08/2018).

[10] Europapress, "Hamburgo podría convertirse en la primera ciudad alemana que prohíbe circular a los vehículos" diésel. europapress.es (2018) at http://www.europapress.es/motor/coches-00640/noticia-hamburgo-podria-convertirse-primera-ciudad-alemana-prohibe-circular-vehiculos-diesel-20180521183834.htmlm (visited on 05/2018).

[11] European Commission, Horizon 2020 - Smart, Green and Integrated Transport. Important notice on the second Horizon 2020 Work Programme **129** (2017) 77–93.

[12] X. Fageda and R. Flores-Fillol, Atascos y Contaminación en las Grandes Ciudades: Análisis y Soluciones. *Fedea Policy Papers* (2018).

[13] Gartner, Programmable Economy Has the Potential to Disrupt Every Facet of the Global Economy. Gartner, (2015). Gartner.com at https://www.gartner.com/newsroom/id/3146018 (visited on 01/2018)

[14] Gartner, Analysts Explore Next Phases of Digital Business. Gartner Symposium/ITxpo, October, 2015, 4–8 in Orlando at https://www.gartner.com/newsroom/id/3146018 (visited on 01/2018)

[15] J.R. Gil-Garcia, T.A. Pardo and T. Nam, In Smarter as the New Urban Agenda. Springer, *Cham*, (2016), 1–19. doi:10.1007/978-3-319-17620-8

[16] M. Giudice and D. Straub, IT and Entrepreneurism: An On-Again, Off-Again Love Affair or a Marriage? *MIS Quarterly* **35** (2011), iii–vii.

[17] J. Hahn, Cities of Tomorrow- Challenges, Visions, Ways Forward. *European Union Regional Policy Journal* **112** (2011). doi:10.2776/41803

[18] C. Harrison and I.A. Donnelly, A Theory of Smart Cities. Proceedings of the 55th Annual Meeting of the ISSS - Hull, UK **1**(15) (2011), doi:10.1017/CBO9781107415324.004

[19] HBR, How Blockchain Will Accelerate Business Performance and Power the Smart Economy. *Harvard Business Review* (2017) at https://hbr.org/sponsored/2017/10/how-Blockchain-will-accelerate-business-performance-and-power-the-smart-economy (visited on 11/2018).

[20] INRIX, Los Angeles Tops INRIX Global Congestion Ranking | INRIX. INRIX - INRIX (2017) at http://inrix.com/press-releases/scorecard-2017/ (visited on 05/2018).

[21] J.H. Jones, Evaluation Project Risks with Linguistic Variables, Proceedings of the Fourth Annual International Symposium, National Council on Systems Engineering (NCOSE), San Jose, CA, (August, 1994).

[22] B. Luginbühl, An Explanation for the Rise Of 'Stable Coins' as a Low-Volatility Cryptocurrency. Forbes.com (2018) at https://www.forbes.com/sites/rachelwolfson/2018/03/29/an-explanation-for-the-rise-of-stable-coins-as-a-low-volatility-cryptocurrency/#336c56685700 (visited 07/2018).

[23] T.W. Malone, R. Laubacher and C. Dellarocas, Harnessing Crowds: Mapping the Genome of Collective Intelligence. *SSRN* (2009), doi:10.2139/ssrn.1381502

[24] E.H. Mandami and S. Assilian, An Experiment in Linguistic Synthesis with a Fuzzy Logic Controller, *International Journal of Man-Machine Studies* **7**(1) (1975), 1–13.

[25] E.H. Mandami, Application of Fuzzy Logic to Approximate Reasoning Using Linguistic Synthesis, *IEEE Trans. Computers* **26**(12) (1977), 1182–1191.
[26] Matlab, El Lenguaje del Cálculo Técnico. Es.mathworks.com (2018) at https://es.mathworks.com/products/MATLAB.html (visited on 10/2018)
[27] J. Merigó-Lindahl, *Nuevas Extensiones a los Operadores OWA y su Aplicación en los Métodos de Decisión*. Diposit.ub.edu (2009) at http://diposit.ub.edu/dspace/handle/2445/35378.
[28] D. Neuberger, Structure, Conduct and Performance in Banking Markets. Econpapers (1997). Econpapers.repec.org at https://econpapers.repec.org/paper/zbwroswps/12.htm (visited on 09/2018)
[29] Ottawa, Smart City 2.0. City of Ottawa. Planning, Infrastructure and Economic Development, (2017). Documents.ottawa.ca at https://documents.ottawa.ca/sites/documents.ottawa.ca/files/smart city strategy en.pdf.
[30] C. Perera, A. Zaslavsky, P. Christen and D. Georgakopoulos, Sensing as a service model for Smart Cities supported by Internet of Things, *Telecommunications Technologies* **25** (2014), 81–93.
[31] J. Potts, E. Rennie and J. Goldenfein, Blockchains and the Crypto city. Degruyter (2017). Degruyter.com at https://www.degruyter.com/view/j/itit.2017.59.issue-6/itit-2017-0006/itit-2017-0006.xml (visited 04/2018).
[32] B. Skinner, *Science and Human Behavior*. Macmillan, 59–90 (1953). doi:10.1901/jeab.2003.80-345
[33] H. Sloan, What is the Programmable Economy? IoT For All (2018) at https://www.iotforall.com/what-is-programmable-economy/ (visited on 09/2018).
[34] N. Szabo, Smart Contracts: Building Blocks for Digital Markets. (1996), Fon.hum.uva.nl at http://www.fon.hum.uva.nl/rob/Courses/InformationInSpeech/CDROM/Literature/LOTwinterschool2006/szabo.best.vwh.net/smart contracts 2.html (visited on 02/2018).
[35] T. Takagi and M. Sugeno, Fuzzy identification of systems and its applications to modeling and control, *IEEE Trans Syst, Man, Cybern* **15** (1985), 116–132.
[36] D. Tapscott, Getting Serious about Blockchain. McKinsey & Company (2017). at https://www.mckinsey.com/industries/high-tech/our-insights/getting-serious-about-Blockchain (visited on 06/2018).
[37] The World Bank, Urban Development. World Bank (2018) at https://www.worldbank.org/en/topic/urbandevelopment (visited 03/2018).
[38] TomTom, TomTom Traffic Index. Tomtom.com (2016) at https://www.tomtom.com/en gb/trafficindex/ (visited on 05/2018)
[39] WEF, Ten Urban Innovations. Www3.weforum.org (2015) at http://www3.weforum.org/docs/Top 10 Emerging Urban Innovations report 2010 20.10.pdf (visited on 10/2018)
[40] WEF, The Global Competitiveness Report 2018. World Economic Forum, (2018) at http://reports.weforum.org/global-competitiveness-report-2018/ (visited on 08/2018)
[41] L. Weiss, *Quantitative Studies of Industrial Organization. In Frontiers of Quantitative Economics*. ed. Michael Intrili-gator, Amsterdam: North Holland Publishing Co., (1971), 211–223.
[42] WHO, Urban Transport and Health. Sustainable Transport. A Sourcebook for Policy-Maker in Developing Cities. Who.int (2011) at http://www.who.int/hia/green economy/giz transport.pdf (visited on 07/2018)
[43] C. Yuanyuan, J. Limin and Z. Zundong, Mandami Model Based Adaptive Neural Fuzzy Inference System and its Application, *International Journal of Computational Intelligence* **5**(1) (2009), 22–29.
[44] L.A. Zadeh, The Concept of a Linguistic Variable and its application to Approximate Reasoning. Part 1, *Information Sciences* **8** (1975), 199–249, "Part 2", *Information Sciences* **8** (1975), 301–357, "Part 3", *Information Sciences* **9** (1975), 43–49.
[45] A. Zanella, N. Bui, A. Castellani, L. Vangelista and M. Zorzi, Internet of Things for Smart Cities, *IEEE Internet of Things Journal* **1** (2014), 22–32.
[46] S. Zielinski, New Mobility: The Next Generation of Sustainable Urban Transportation. Naefrontiers.org (2012) at https://www.naefrontiers.org/file.aspx?id=21915
[47] H.J. Zimmermann, Fuzzy Sets, Decision Making, and Expert Systems, *Kluwer Academic Publishers* **3** (1987), 97–103.