





# The Role of Artificial Intelligence in Smart Cities: Systematic Literature Review

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**Abstract.** The increase in urban population has brought climate, technological and economic changes that may negatively affect the quality of life in cities. In response, the concept of a smart city has emerged referring to use of novel ICTs to reduce the adverse effects on cities and its inhabitants. Among other technologies, Artificial Intelligence (AI) is used in that context, evolving rapidly and playing an essential role in supporting intelligent city-wide systems in different domains. It is thus beneficial to identify current research advances and get a better understanding of the role the AI plays in this particular context. Consequently, there is a need to systematically study the connection between AI and smart cities, by focusing on the findings that uncover its role, possible applications, but also challenges to using the concepts and technologies branded as AI in smart cities. Therefore, the paper presents a systematic literature review and provides insights into the achievements and advances of AI in smart cities pertaining to the mentioned aspects.

**Keywords:** Smart city · Artificial intelligence · Systematic literature review

## 1 Introduction

Growing urban populations, environmental pollution, climate change, infrastructure breakdown, and lack of resources are some of the challenges cities face. Such challenges require novel solutions, giving rise to an encouraging concept of a “Smart City” (SC). By employing smart solutions, existing day-to-day scenarios in the cities can be significantly improved, and new ones could be created whereby the aim is to increase the quality of life of its residents.

With the rapid development of Artificial Intelligence (AI), opportunities emerge to improve public services, some of which are presented in the paper. As AI develops faster, new and smart solutions for cities and its citizens are developing at the same rate, but also leading to the development of associated tools used for malicious purposes. Cyber-attacks can compromise the privacy of data collected through the Internet of Things (IoT) devices containing not only public but also personal data of individuals. In addition to privacy concerns, if the safety of citizens and systems that use smart solutions is compromised, it can lead to potentially disastrous situations such as attacks on traffic, health, surveillance and security systems etc.

Ethical issues remain another significant challenge. A well-known example is a dilemma involving autonomous vehicles in SCs, where, in an accident scenario, the vehicle decides whether to sacrifice the passenger, a pedestrian or hit another vehicle (Dennis and Slavkovik 2018). Such issues require human participation in decision-making and novel standards and ethical norms. Further to this, there are ethical issues concerning facial recognition, behavioural traits identification, voice recognition, and other trends. The accelerated development of AI in the future is likely to increase the number of ethical challenges.

The rise in interest in AI and SCs, its potentials and issues, has led many researchers to contribute to the field, resulting in a sharp increase in the number of published studies. Although this increase provides more insights and greater body-of-knowledge in a specific area, we as users need more time to identify relevant studies in a particular case. Thus, this paper presents an attempt to systematically review the relevant literature on the topic of AI in SCs, and can consequently serve as a starting point for further research in the field.

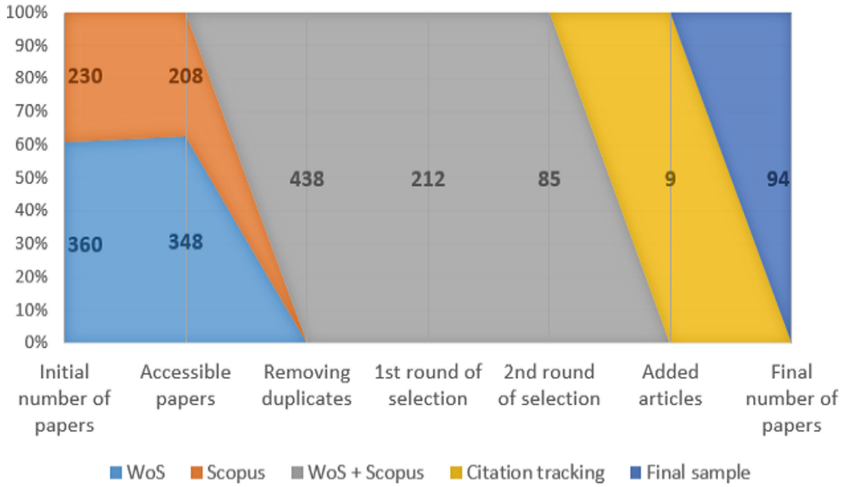
The methodology for the review is presented in Sect. 2, categorisation of papers in Sect. 3, followed by the review in Sect. 4, and concluding remarks in Sect. 5.

## 2 Methodology for Literature Review

A systematic literature review was done to formally synthesise primary studies relevant to the already described area of interest (Kofod-Peterson 2015). It differs from non-systematic studies as it is methodologically framed, with a series of well-defined steps. A predetermined protocol includes identification, selection, evaluation and analysis of relevant studies that are eligible for review, going beyond limitations of traditional reviews (Palka et al. 2018). During the process, relevant recommendations (Wolfswinkel et al. 2013) were followed, and standard databases (Web of Science – WoS and Scopus) were selected as sources. Although other databases may be suitable for this purpose, they contain a large number of papers that are already indexed in the two databases so this would significantly increase the number of duplicates. The keywords used to search for the papers are “artificial intelligence” AND (“smart city” OR “smart cities”), but limited to scientific papers written in English. Another limitation is that alternative and related keywords such as “computational intelligence” were not considered at this stage.

Visualisation of the terms from the papers from the WoS database search is presented in Fig. 1 to get a general overview of the results. It was created using the VOSviewer tool based on a set of general data of the papers and abstracts. Four clusters are revealed, each marked with a different colour. The size of a circle indicates the frequency of occurrence of a particular term in a dataset, and the length of the line between two terms their relationship. Understandably so, the term AI appears in the dataset most frequently. The shorter length of the line between the two terms, for example, between the terms AI and big data, indicates a stronger connection confirming the relevance of big data technologies in AI.





**Fig. 2.** Literature sampling procedure (Source: Authors)

The final number of papers after the sampling procedure is 94. The span of these papers is only five years, starting from 2015 to 2020. Although both terms (AI and SC) are represented in the database earlier than 2015, and the initial list of papers contained papers published earlier (though not before 2012), many papers did not meet the presented criteria for the 1<sup>st</sup> and 2<sup>nd</sup> selection rounds. Looking at the final list of selected papers, in 2019 a total of 39 were published, i.e. 3.25 per month, while in 2020 a total of 25 papers were published during the first six months, i.e. 4.17 per month. The growth in the number of papers is not surprising, given that AI is a rapidly evolving discipline. Out of the selection, the largest number of papers (17) was published in the journal IEEE Access. This is followed by the IEEE Internet of Things Journal (with 9 papers), Applied Sciences (6 papers), Sensors (5 papers) and Sustainability (3 papers). The remaining 54 papers were published in other journals (45 different outlets), one or two papers per journal. In the five journals listed here, 40 out of 94 papers were published, accounting for 43%.

### 3 Categorising the Papers for the Literature Review

Due to the diversity in the content of the final list of papers focusing on different aspects of the connection between AI and SCs, several categories were created based on relevant literature reviews (Rjab and Mellouli 2018, 2019). The three main categories are General role, Application areas and Challenges. Each of these categories refers to AI in SCs, i.e. the role of AI in SCs, the application of AI in SCs and the challenges that may arise from the use of AI in SCs. These categories are further divided into subcategories, as presented in Table 1. In particular, a large number of papers explores the use of AI in mobility (e.g. traffic safety, smart parking) so these were grouped under the subcategory Mobility of category Application areas. Other subcategories were defined similarly. Consequently, and in line with good review practices (Webster and Watson 2002), a

cluster of references was created in the form of a concept matrix. This way, it is easy to see the most represented concepts/subcategories (in terms of content), as well as the ones containing fewer studies so it can serve as a good starting point for future reviews. Several papers fall into two different categories, for example (Liang et al. 2019) discussing both the role and challenges of AI for the security in SCs (thus bringing the total number of papers across categories to  $N = 109$ ).

**Table 1.** The categorisation of selected papers

Cat.	Subcategories	No. of papers	Authors
General role	Ethical aspects	3	Shen et al. (2019), Sholla et al. (2020), Zhou et al. (2020)
	Security	7	Chen et al. (2019a), Diro et al. (2017), Falco et al. (2018), Kim et al. (2020), Liang et al. (2019), Roldan et al. (2020), Xu et al. (2020)
	Data management	9	Al Zamil et al. (2019), Aydin et al. (2015), Chen et al. (2019b), Dilawar et al. (2018), Ferrara et al. (2019), Gong et al. (2019), Iqbal et al. (2020), Shu et al. (2019), Yao et al. (2019)
	Other	3	Anthony (2020), Austin et al. (2020), Gomez et al. (2018)
Application areas	Mobility	20	Chen et al. (2019b), Iqbal et al. (2020), Asad et al. (2020), Aymen et al. (2019), Cai et al. (2019), Choudhury et al. (2018), El-Wakeel et al. (2018), Hossen et al. (2019), Huang et al. (2016), Huang et al. (2019), Hwang et al. (2019), Ke et al. (2020), Ke et al. (2020), Li et al. (2018), Mannion et al. (2015), Martinez Garcia et al. (2018), Niu et al. (2015), Qiu et al. (2020), Wan et al. (2018), Wang et al. (2020)
	Environment	11	Chen et al. (2019b), Ahmed et al. (2019), Cao et al. (2019), Jung et al. (2020), Khan et al. (2019), Mo et al. (2019), Park et al. (2019), Ping et al. (2020), Rojek et al. (2019), Wu et al. (2020), Zhang et al. (2019)
	Surveillance	12	Chen et al. (2019b), Jung et al. (2020), Iqbal et al. (2020), Almeida et al. (2018), Castelli et al. (2017), Eldrandaly et al. (2019), Medapati et al. (2019), Liu et al. (2019a), Miraftebzadeh et al. (2018), Qin et al. (2018), Xiong et al. (2017), Zhao et al. (2019b)

(continued)

**Table 1.** (continued)

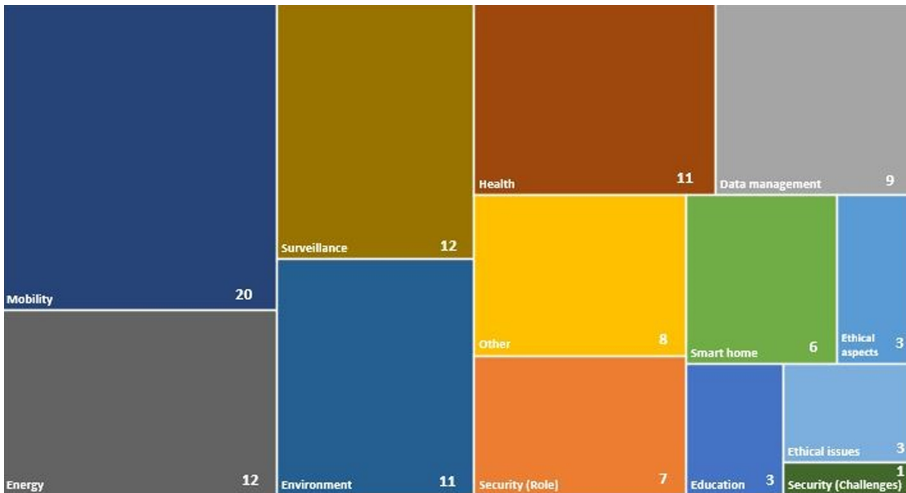
Cat.	Subcategories	No. of papers	Authors
	Energy	12	Aymen et al. (2019), Austin et al. (2020), Abbas et al. (2020), Almashaie et al. (2019), Hurst et al. (2020), Idowu et al. (2016), Liu et al. (2019c), Park et al. (2019), Serban et al. (2020), Le et al. (2019a), Le et al. (2019b), Vazquez-Canteli et al. (2018)
	Smart home	6	Hurst et al. (2020), Xu et al. (2020), Lin et al. (2017), Ponce et al. (2018), Sanam et al. (2020), Yassine et al. (2017)
	Health	11	Chen et al. (2019b), Iqbal et al. (2020), Zhou et al. (2020), Ajerla et al. (2019), Alhussein et al. (2019), Alhussein et al. (2019), Amin et al. (2019), Mohanta et al. (2019), Obinikpo et al. (2017), Venkatesh et al. (2018), Zhang et al. (2017)
	Education	3	Gomede et al. (2020), Gomede et al. (2018), Wang S. (2019)
	Other	8	Iqbal et al. (2020), Dilawar et al. (2018), Liu et al. (2020), Liu et al. (2019b), Manzanilla-Salazar et al. (2020), Shousong et al. (2019), Talamo et al. (2020), Zhao et al. (2019a)
Challenges	Security	1	Liang et al. (2019)
	Ethical issues	3	Calvo (2020), Dennis et al. (2018), Etzioni et al. (2016)

Providing a better view of representation per subcategories, Fig. 3 emphasises the popularity of AI use in mobility systems with as many as 20 papers. The gap between the prevalent subcategory in terms of the Application area – Mobility, and the two succeeding – Surveillance and Energy (equally represented by 12 papers per subcategory) demonstrates the interest in AI in the context of smart mobility well. This is followed by Health and Environment application areas with the same number of papers (11), Smart home (6), Education (3), and 8 papers on various topics in the subcategory Other.

## 4 Overview of Research Studies Focusing on Artificial Intelligence in Smart Cities

### 4.1 Studies on the General Role of AI in Smart Cities

Many (ethical) considerations have to be taken into account in the implementation of SC solutions. Collecting large amounts of data, public and personal, using a variety of



**Fig. 3.** Visual representation of subcategories with number of papers (source: authors)

IoT devices brings attention to issues related to the privacy of collected data. Papers presenting IoT-collected data protection solutions are based on blockchain and machine learning (ML) (Shen et al. 2019), and the human-in-the-loop model (Zhou et al. 2019). Furthermore, it is given that smart devices are deprived of moral, religious and legal responsibilities which can lead to situations where human rights may be compromised; here Sholla et al. (2020) propose a system for checking the ethical compliance of smart things.

*Security* solutions based on AI algorithms are devised to ensure safe and reliable use of smart solutions, so, e.g., Chen et al. (2019a) propose an algorithm that provides smart control of wireless communications and intelligent applications. Also, the use of deep learning (DL) algorithms has been proposed to detect cyber-attacks more effectively (Diro and Chilamkurti 2017), similar as recommending other AI techniques for tackling data that cannot be processed in time and can thus pose a potential threat, to detect anomalies (Xu et al. 2020). Falco et al. (2018) present the development of a tool for assessing the risk of critical infrastructure that could potentially encounter a cyber-attack. Similarly, there are examples of good practices for using AI in the context of cybersecurity in SCs, e.g., a solution that uses ML and proposes an intelligent architecture that can detect different types of IoT security attacks in real-time (Roldan et al. 2020), and an integrated security system presented by Kim and Ben-Othman (2020). Numerous benefits of using ML to increase the security of IoT devices are identified by Liang et al. (2019).

On a related note, issues associated with *data management* stem from the fact that IoT devices collect audio, video, images or text data that is difficult to manage with traditional algorithms. The role of ML is inspected (Aydin et al. 2015) to facilitate data management with applications in image classification (Shu and Cai 2019) and by employing DL algorithms (Chen 2019b) to classify, among other, audio data (Al Zamil et al. 2019). Ferrara et al. (2019) present models that use AI to analyse data collected

through sensors in real-time. It is also deemed necessary to improve management of data traffic in IoT-networks, by, e.g., classifying data traffic using DL techniques to improve network security and service quality (Yao et al. 2019). Other examples of using ML algorithms are focusing on social networks data to get a better understanding of citizens' preferences (Dilawar et al. 2018). On the note of participation, it is essential to involve nonprofits in SC projects, and the factors that drive them to engage are analysed through the use of ML successfully (Gong et al. 2019). The concept of big data plays a vital role in building functional SCs since traditional data analysis cannot cope with the sheer volume of data, which is why AI methods are used (Iqbal et al. 2020).

There are *other* problems where AI can bring relevant solutions to SCs. For example, to improve the capacity of network structures in SCs, Gomez et al. (2018) suggest optimal network load balancing techniques. For strategic decision-making in the implementation of SC initiatives, AI is used to develop a recommender system for SC planning (Anthony 2020). Another option is, with the help of AI and ML, to build city's digital twin that will play a role in data collection and processing, event identification and automated decision making (Austin et al. 2020).

## 4.2 Studies on the Application Areas of AI in Smart Cities

As presented already, (smart) mobility is where AI is used frequently as a part of SCs initiatives. Traffic data is analysed using DL algorithms to enable safer and smarter use of transport networks with applications to transport flow, personal mobility and parking in particular (Chen 2019b). With the help of sensors and ML techniques (Hossem 2019), such as neural networks (Cai et al. 2019), and a combination of AI algorithms and edge computing paradigms (Ke et al. 2020), drivers can get helpful assistance in finding a parking space. Radar images are also implemented and analysed as an excellent option for SCs as these minimise privacy issues (Martinez Garcia et al. 2018). An increasing number of electric vehicles in the streets necessitates research on new approaches to energy management, e.g. based on two-way communication between vehicles and buildings using neural networks (Aymen and Mahmoudi 2019). One of the most significant challenges in urban mobility management is stakeholder safety. In that context, an improved framework for detecting pedestrians using neural networks was presented (Choudhury et al. 2018). Poor roads cause vehicle damage and congestion and can affect traffic safety. In response to this problem, a road anomaly monitoring framework was introduced that uses ML techniques and collects data from motion sensors available in most vehicles, allowing the detection of road irregularities and their impact on vehicle movement (El-Wakeel et al. 2018). An intelligent system focused on forecasting taxi demand was also presented (Iqbal et al. 2020), and tested in the city of Shanghai (Huang et al. 2019). Another example from China is the use of DL in transportation systems (Li et al. 2018). Vehicle identification also plays a vital role in forensic research; DL techniques are used for improved model detection capability (Ke and Zhang 2020). Differences in the datasets used to identify vehicles can lead to inadequate solutions, and a specific learning method has been proposed to address it (Wang et al. 2020). With solutions for traffic management using DL queues and waiting times could be reduced effectively (Mannion et al. 2015; Wan and Hwang 2018). An innovative route search

mechanism based on traffic prediction and DL techniques can also improve driving conditions and reduce time-to-destination (Niu et al. 2015). Precise determination of paths using DL to optimise travel times is proposed (Qiu et al. 2020). Energy-wise optimisation of train routes, as a part of a train management framework using ML, was presented (Huang 2019). In this context, passenger data from sensors installed at railway stations have also been used to optimise passenger traffic (Asad et al. 2020; Hwang et al. 2019).

Effective environmental monitoring is one of the critical tasks in SCs. Using neural networks, scientists can identify the causes of problems, issue prior warnings, and organise resources for rescue (Chen et al. 2019b), e.g. for wildfires, extreme waves, cold, and heat, a faster decision-making framework based on AI has been presented (Jung et al. 2020). Air pollution is becoming a severe problem; and a system for early detection of changes in air quality is of great importance (Mo et al. 2019), as is the analysis of water quality trends and detection of anomalies (Ahmed et al. 2019). A system for detecting water leaks from pipes has been developed based on neural networks to minimise water losses (Rojek and Studzinski 2019). Noise detection is another essential aspect of SC management; a method based on neural networks improves the current performance of urban sound recognition (Cao et al. 2019). Early detection of smoke can prevent large disasters where neural network-based smoke detection systems can be effective (Khan et al. 2019). Also, a system with a mechanism to minimise data transmission delays in the described contexts was presented (Liu et al. 2019c), while other AI methods are proposed to detect and predict fire sources in inconspicuous places such as tunnels (Wu et al. 2020). Furthermore, street waste detection systems based on DL are also valuable (Ping et al. 2020; Zhang et al. 2017).

Surveillance cameras can be used for various purposes in sustainable cities; new AI algorithms are introduced to adjust camera orientation and improve view coverage (Eldrandaly et al. 2019). It is becoming common to surveil and monitor whether a large number of people in one place represents traffic congestion or a traffic jam (Liu et al. 2019a). In that regard, for network congestion management, an algorithm for network load balance is designed (Zhao et al. 2019b). Video surveillance for fire detection using neural networks is also a welcomed solution (Jung et al. 2020) for increased safety, as well as systems that analyse data on crime from large datasets (Castelli et al. 2017). A model that describes user behaviour based on DL predicts subsequent actions and recognises behavioural anomalies (Almeida and Azkune 2018). Similarly, it is possible to identify abnormal behaviour in mass video surveillance data (Qin et al. 2018). Other examples include face recognition systems that use AI (Chen et al. 2019b) and compare face images with those from databases (Medapati et al. 2019), identifying people using their biometric and behavioural traits (Iqbal et al. 2020), and re-identifying individuals (Xiong et al. 2019), especially in crowds (Miraftabzadeh et al. 2018).

Energy management is one of the most demanding problems in SCs, this being a reason why the topic is getting a lot of attention. Here, an energy management design based on IoT devices and ML is proposed (Liu et al. 2019c) and a platform for the development of an energy-wise sustainable city based on AI (Park et al. 2019). Renewable energy is vital for the development of cities where significant progress is made, as confirmed by analyses on the use of AI in the renewable energy sector (Serban and Lytras 2020; Almeshaei et al. 2019; Abbas et al. 2020). A digital twin architecture and

a simplified analysis of energy consumption in buildings in the Chicago area using ML (Austin et al. 2020) and a similar purpose model (Idowu et al. 2016) and techniques (Le et al. 2019a) have been proposed, e.g. predicting heat load in buildings (Le et al. 2019b). Also, a simulation environment is presented, combining an energy simulator and a platform for the implementation of ML algorithms to plan and manage energy consumption in buildings (Vazquez-Canteli 2018). A study exploring the use of AI to optimise energy use in electric vehicles (Aymen and Mahmoudi 2019) has already been mentioned above.

In smart homes, ML can be used to analyse data from smart gas meters and predict fuel consumption (Hurst et al. 2020). Data on indoor air trends and quality can be used to detect correlations with peoples' behaviour (Lin et al. 2017), and predict indoor climate conditions (Ponce and Gutierrez 2018). Precise localisation of different subjects indoors using wireless signals based on ML techniques (Sanam and Godrich 2020) is also of relevance in this context. Collecting data from smart devices in home environments can reveal behavioural patterns of individuals who live there and use ML techniques to obtain information used in healthcare (Yassine et al. 2017). Smart devices, in combination with DL algorithms, can serve to detect other anomalies in households (Xu et al. 2020) as well.

With the development of AI technologies, many applications in healthcare have been presented, including a model that uses neural networks and enables biometric identification of a person based on electrocardiograms (Zhang et al. 2017). By collecting data from sensors, it is possible to (remotely) monitor the condition of patients (Chen et al. 2019b; Iqbal et al. 2020; Venkatesh et al. 2018; Ajerla et al. 2019) and with the implementation of new 5G networks, the benefits could be even more significant (Mohanta et al. 2019). Other notable examples include a DL platform that records voice using smartphones and sends information about voice changes to reduce visits to the doctor in particular cases (Alhussein and Muhammad 2019). A system has also been proposed that automatically detects possible diseases using DL to examine brain activities using electroencephalographic (EEG) data (Alhussein et al. 2019). EEG sensors and others can record patient data such as facial expressions, speech, movements, gestures to be processed by AI. In this way, the patient's condition is monitored in real-time, and emergency care is provided as needed (Amin et al. 2019). Patient data collected through sensors are considered sensitive data; therefore, DL techniques can be used for its protection (Obinikpo and Kantarci 2017) in addition to prediction and decision-making purposes. A study combining AI with the human-in-the-loop model to preserve privacy in smart healthcare (Zhou et al. 2020) has been mentioned already.

Optimising educational content that would match the abilities of learners is one of the main tasks of smart education. To that end, an AI model was presented (Wang et al. 2019). AI methods were used in another study to improve e-learning systems with regard to different learning styles (Gomede et al. 2018), later extended to include more effective ways to leverage AI for developing individual learner profiles in individualised approach and goal-setting (Gomede et al. 2020).

Other uses of AI that cannot be grouped straightforwardly in the categories above are listed here. For example, inadequate and small data samples and errors in quantifying the features needed to assess the value of residential land make it difficult to estimate

its value adequately. Here, a value estimation method using AI and transfer learning was studied (Shousong et al. 2019). Another example is selecting the optimal location of new stores based on DL (Liu et al. 2019b). Conservation and restoration of cultural assets is a complex process that requires the participation of individuals from different fields, including data scientists as the processes include the use of IoT and AI (Talamo et al. 2020). A framework based on ML can be used to successfully detect failures on wireless network base stations (Manzanilla-Salazar et al. 2020). Another area where AI is used is robot intelligence; to ensure the timely response of robots to stimuli from the external environment, DL and the Internet of Robotic Things (IoRT) have been proposed to monitor and control their behaviour (Liu et al. 2020).

### 4.3 Studies on the Challenges of AI in Smart Cities

Smart solutions require storing large datasets collected from IoT devices and often remain unprotected from cyber-attacks. Although ML is frequently used in supporting the security of cybernetic systems (as presented already with the studies that tackle the role of AI in security management), full protection cannot be guaranteed. Equally, AI is also used when performing cyber-attacks (Liang et al. 2019), and for that reason, it is worth analysing it from the perspective of lasting challenges.

Due to the ability of AI to analyse large datasets, in specific cases, some control and decision-making processes have been taken over by algorithms, some of which can contribute to unequal opportunities and treatment of individuals, contributing to social inequalities (Calvo 2020). Also, the number of smart systems such as autonomous vehicles that make independent decisions is growing, which is why there is a need to eliminate possible unethical behaviour through controlled models of AI (Etzioni and Etzioni 2016). In response to ethical questions related to the use of AI in SC solutions, a new discipline of artificial intelligence has emerged - machine ethics that develops intelligent systems with ethical concepts. Since this discipline is still in its infancy, it faces many challenges (Dennis and Slavkovik 2018).

## 5 Concluding Remarks

By selecting scientific papers from the interest area following a standard systematic process, a total of 94 papers was identified as relevant. All papers from the selected sample were published from 2015 to mid-2020, with the largest number in the last two years. Therefore, the review contains a novel overview of AI in SCs, complementing recent studies (Rjab and Mellouli 2018; Rjab and Mellouli 2019).

Categories and subcategories have been defined, and the papers categorised considering its primary focus. There is an observable disproportion between the number of papers in different categories, with the majority representing specific solutions for the application of AI in SCs, and a minimum number of those that cover the area of challenges and barriers to using AI in SCs. A popular topic is smart mobility, addressing improvement of parking, traffic management and safety. On the other hand, the lack of papers dealing with ethical and safety issues does not mean that such problems do not exist, but that either there is no interest from researchers, or that these problems

have not yet been sufficiently researched. Although AI provides many benefits for the development of smart solutions, it has been used for cyber-attacks and manipulation of personal data collected from various sensors, making this problem non-negligible.

The main shortcomings of the paper are the limited number of databases searched (WoS and Scopus) and possible bias of the authors in selecting the final list of papers for the review. Even though increasing the number of sources (beyond the two standard ones) would significantly increase the number of duplicates, it would improve the quality of the literature review by offering a more representative view of publications on the topic. The paper can thus serve as a starting point for further research.

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