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Cyber-Physical Urban Mobility Systems:
Opportunities and Challenges in Developing Countries

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ABSTRACT

Rapid population growth and the number of vehicles in cities have complicated urban mobility management. Digitalization supported by the internet of things and wireless communication has allowed some cities to mitigate the problem by taking advantage of the multiple benefits offered. These are cyber-physical systems (CPS), which are systems where a number of devices collaborate for the control of physical entities. This recent technology finds its application in urban mobility. However, in the context of developing countries, there are many local specificities one needs to consider. How could the integration of cyber-physical systems help urban decision makers to design sustainable urban mobility systems that meet the needs of the population? The paper proposed not only a recent review of the literature, but also a framework of CPS of urban mobility to guide decision makers. The challenges, opportunities, and barriers to innovation of CPS in urban environments in developing countries have also been identified.

KEYWORDS

Architectural framework, Complex System, Cyber-Physical Systems (CPS), Decision support systems, Urban Mobility system

INTRODUCTION

According to United Nations projections, by 2050 almost 70% of the population will live in cities (Cohen, 2006; Van & Marston, 2021). Moreover, these cities suffer from congestion, road accidents, high travel times, and air pollution (Monios & Bergqvist, 2020). These urban mobility problems are common in both developed and developing countries. But in developing countries, the situation is

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alarming, simply because of the lack of quality transport infrastructure, the lack of application of new technologies to the transport system, and the impact of the mix of transport modes (Mfenjou et al., 2018; Abdel et al., 2020). City managers sometimes develop strategies such as building new roads, especially inexpensive paved roads, which do not have a positive impact on improving road safety. The use of new technologies for decision support is almost non-existent. The actions undertaken do not provide sustainable solutions and the requirements of users in urban areas are not met.

The authors (Ngossaha et al., 2020) contributed significantly to sustainable urban mobility to preserve the environment for future generations in the context of developing countries. For the authors, the new mobility should enable the reduction of air pollution, collaboration between actors and integration of mobility services. Thus, the new paradigms consider mobility as a service (MaaS) and envisage the application of artificial intelligence algorithms, connected objects and Big Data (Mishra, 2021). However, developing countries need a decision-making framework to manage the interactions in the mobility system which is now seen as a system of systems. Coupling the urban mobility system with the cyber-physical system (CPS) paradigm can help to reduce collisions, avoid traffic jams, control traffic lights intelligently, ensure a more efficient multimodality, and find a last mile solution and a sustainable solution. To this end, CPS technology combines communication, control and data processing due to the advent of the Internet of Things and advanced technologies, such as 5G, cloud computing, machine learning, Big data and data processing. Nowadays, CPS technology has strongly integrated the field of transport, in which research works present new solutions for intelligent and safe mobility, such as the Cyber-Physical bike, Vehicular Cyber-Physical and even Traffic control based Cyber- physical system. This same CPS technology has also interested many researchers in various other fields, from healthcare, manufacturing, sports, human-machine interface, agriculture and more (Gupta et al., 2022). CPS is a suitable solution for integrated and sustainable urban mobility system (Pundir et al., 2022).

Integrated urban mobility is an important factor in the socio-economic development of cities and also an effective solution to reduce road safety problems (Al-Thani et al., 2022). The integrated urban mobility system refers to the integration of components like information systems urbanization, optimization of existing road network, decision making coordination, motorized transport (vehicle technology), non-motorized transport (bicycle paths and walking abilities), transport demand management (parking, car sharing) and cloud computing for interoperability. For this purpose, mobility data is collected by sensors and roadside unit installed on the road network and stored in urban Big Data (Dogan & Gurcan, 2022). The permanent analysis of Big data will make it possible to anticipate the consequences of interactions on the road (Nandhini & Ramanathan, 2022), and to challenge stakeholders in real time such as pedestrians, drivers, firefighters, the road police, hospital, and public services in charge of road transport.

Despite the interest of this area of research, the integration of services or systems is almost non-existent in developing countries, particularly in urban transport with the use of 5G. So, the integration of services in poor countries is a big challenge, especially with the lack of digitalization and the poor quality of infrastructure. A serious architectural design problem arises, involving multidisciplinary fields, mathematics, computer science, transport engineering, civil engineering, economics, sociology, and more (Lee & Lim, 2021). The challenges in the context of developing countries are enormous and marked by the presence of disruptions, privatization of the transport sector, very low subsidies for urban roads, and above all the prevailing poverty (Nnamani et al., 2022). For example, various disruptions, such as livestock crossing the road and disrupting traffic, degraded road conditions, houses next to the road, forks caused by yellow taxis, non-compliance of two or three-wheelers with traffic regulations and driver behavior. Therefore, developing countries need: (1) transformation of the urban mobility system into a sustainable urban mobility system to meet the well-being of the population, (2) application of new technologies to improve urban mobility services, (3) improved decision making through complex interaction situations, (4) interoperability of systems for efficient control and improved mobility. To this end, this paper not only presented a recent synthesis of the literature on cyber-physical system technologies and its application in the field of urban mobility, but also aimed to propose an architectural framework of cyber-physical urban mobility system in the context of developing countries to respond into integration systems challenge in the domain of transportation. Finally, the paper highlights some of the challenges and open research problems in the field of cyber-physical urban mobility systems in the perspective of designing an intelligent and sustainable mobility system that best meets the needs of users.

The rest of this paper is organized as follows. In section 2, the background of CPS technologies is presented, followed by its application in the field of urban mobility and related work on the design of urban mobility systems in section 3. Section 4 presents the methodology used to select articles from different databases. Section 5 presents the design of the architectural framework of the urban mobility system in developing countries and finally section 6 presents the challenges and opportunities identified for the design of the system as well as the perspectives. Finally, the conclusion and research perspectives are presented.

BACKGROUND

CPS Technologies

CPS technologies aim at integrating computation, communication and control capabilities with an engineering system (Cheng et al., 2018; Zhu, 2022). For this reason, IoT devices are considered the basis of CPS technologies (Jeschke et al., 2017). It is important not to confuse IoTs with CPS technologies. IoTs put more emphasis on objects connected through, which for CPS emphasizes the integration of computing, communication, and control capabilities to (un)connected physical objects. But at the same, IoT enables interconnection of devices through the network to share data, computing, and control objects (Gupta & Godavarti, 2020).

The concept of CPS has appeared in the first time in the United States in 2006 with the aim of making the network of systems interact with the physical world (Lee, 2006). This new paradigm is differently defined by scholars in recent works. According to (Gupta et al., 2019), CPS are distributed systems in constant interaction with their physical environment through detection. For (Kantarci et al., 2015), a CPS paradigm is a product resulting from the fusion of physical process and computer programs at multi-scale multilevel. For these authors, CPS aimed to extend the controllability, efficiency and reliability of a physical process. Emerging CPS applications are numerous, and are driven by the expansion of information communication technologies (ICTs) tools, mobile internet, Open Data, Big Data, artificial intelligence (AI), Machine Learning (ML), Cloud Computing (Ramasamy et al., 2022). Among so many CPS applications, there is the urban transportation domain high interests us in this paper.

CPS Applications in Transportation System

In the near future, CPS technology will be used for integrated urban mobility (Moller & Vakilzadian, 2016). Therefore, solutions to urban mobility problems require CPS to improve performance of a transportation system. Today, the development of mobility as a service (MaaS) based CPS technology has enabled the convergence of different transportation means, ticketing systems, and a web-client application to users to satisfy them (Deka & Khan, 2018; Bellini et al., 2022). This technology is able to control road traffic to reduce road accidents, congestion, and air pollution. Human errors on the road are multiple (Khattak et al., 2019). So it is very difficult to meet the expectations of pedestrians and drivers in terms of road safety. CPS technology may help humans to manage road traffic with the support of sensors or drones and actuators (Ari et al., 2016; Nouacer et al., 2020). In addition, the CPS-based transport system can be used to solve the last-mile problem, whose access in landlocked areas does not allow vehicles, but rather motorcycles and bicycles. To master the variety of disturbances on the road in developing countries and the very high number of interactions in the integrated transport system, a CPS-based urban mobility can improve the traditional mobility system with the integration of transportation infrastructure and connected objects with computer programs for their control. The main application areas of CPS in transportation system are presented below.

Cyber-Physical bike

According to the United Nations report, cases of bikes and motorcycles accidents are very fatal for drivers and passengers (Sirajudeen et al., 2022). The use of CPS technology coupled to the bike has made it possible to embedded video cameras and actuators to continuously monitor the cyclist's surroundings, and receive alerts in the event of danger (Smaldone et al., 2011). These alerts may improve road cycling safety and real-time detection of disturbances. Thus, a Cyber-Physical bike has video processing capabilities to perform automated rear-approaching vehicles detection. Other researchers have also proposed an intelligent control system to be integrated into smart bicycle in order to manage the interactions between the physiological behavior of the cyclist and the urban environment (Mannion et al., 2019). Mannion et al. relied on the pitchfork bifurcation system to design their on-board bike control system.

Vehicular Cyber-Physical

The problems of vehicle collisions and risk turns are numerous on the roads (Halim et al., 2022). Researchers have taken advantage of advances in real-time computing, software defined networking (SDN), blockchain, and machine learning to improve vehicles in driving experience with CPS-based models, which are able to manage interactions and disturbances through feedback-driven regulation (Bradley & Atkins, 2015). Other researchers have turned vehicles into mobile cloud computing, which allow interactive travel, pedestrian protection, and efficient driving (Jeong & Lee, 2014). However, vehicular cyber-physical systems (VCPS) applications include assisted driving, safety applications, self-driving, emergency communications, and infotainment (Rawat & Bajracharya, 2017). Thus for driving assistance for example, (Chen et al., 2020) proposed a fuzzy Markov model for road guidance to predict traffic problems.

Traffic control based Cyber-physical system

Control is a very important characteristic of CPS technology (Verma, 2022). Researchers have proposed CPS-oriented systems to traffic control. The studies carried out try to solve the major challenge based CPS when controlling traffic, the coupling of transportation behavior theory, information theory, and computer programs with computing, communications, and control capabilities (Jianjun et al., 2013). Jianjun et al. suggested that a proposal traffic control must manage three major components: traffic system control, traffic signal control, and traffic behavior control. (Farradyne, 2000) proposed traffic management application to manage the traffic flow for safety of motorists, pedestrians, crash victims on roads traffic. For Farradyne, coordination in Public transport is able to increase traffic efficiency and management of traffic flow, monitoring vehicles, and road conditions. In the same way, (Li et al., 2020) suggest that traffic management-based video cameras responds to traffic incidents prediction for example interference control in Inter-Vehicle Communications.

(Rebeiro et al., 2020) proposed spatial distributed IoT-based monitoring of urban air quality to protect the health issues resulting from urban environment pollution. Road monitoring systems refer to the systems in charge of supervising vehicles, road traffic conditions and air quality. Table 1 below summarizes some works based on CPS that have effectively contributed to improving urban transport.

Table 1 presented some works related to the management of transport systems based on CPS. The authors are interested in specific aspects (intelligent vehicle, security measure on wireless technology, privacy preservation, recommender system) of the transport system to improve the quality of mobility. The following section presents the CPS architecture models used in different study areas.

Table 1. Summary of studies works on CPS application in transportation management

Authors	Studies	Issues	Results
Smart Vehicle prototype			
Zhao et al., 2013	iCPS-Car: An Intelligent Cyber-physical System for Smart Automobiles	providing user-friendly and human-centered services to users through a vehicle	Car integrates remote surveillance, gesture-based control and media migration
Khan et al., 2019	Connected and Automated Vehicles in Urban Transportation Cyber-Physical Systems	Develop an adaptive traffic signal control algorithm with CVs and non-CVS	real-time adaptive traffic signal control algorithm
Privacy-Preserving on roads circulation			
Zhou et al., 2019	Privacy-Preserving Transportation Traffic Measurement in Intelligent Cyber-physical Road Systems	allow the collection of aggregate point-to-point data while preserving the privacy of individual vehicles	Novel measurement scheme practical and scalable
Wang et al., 2019	Towards an Efficient Cyber-Physical System for First-mile Taxi Transit in Urban Complex	Solving the first kilometer public transportation problem in China	a mini-bus system that carries passengers from an overcrowded urban complex to some nearby locations that are convenient for taking taxis
Security measurement on wireless technology			
Chen et al., 2017	Cyber-physical system enabled nearby traffic flow modelling for autonomous vehicles	Improve autonomous vehicle decision-making during times of bad quality of internet connection	Proposal for a nearby traffic model based on the theory of fluids using CPS sensors of autonomous vehicles
Evers et al., 2017	Security measurement on a cloud-based cyber-physical system used for ITS	Security and vulnerability of the bus data collection, transmission and storage systems	Mitigation techniques and cyber hygiene best practices
Chen et al., 2019	Deep Learning for Secure Mobile Edge Computing in Cyber-Physical Transportation Systems	Secure the MEC's Communication security against eavesdropping, jamming attacks	TCPS architecture model based on unsupervised learning techniques to detect attacks
Recommendation system			
Zhang et al., 2013	CallCab: A unified recommendation system for carpooling and regular taxicab services	Saving passenger's initial wait time and fare	A proposed recommendation system in a large scale network of taxis exploiting the GPS of taxis by MapReduce
Kantarci et al., 2015	Cyber-physical alternate route recommendation system for paramedics in an urban area	Select a low-cost route by paramedics with low latency and very high resilience	A route recommendation solution for paramedics using a cyber-physical system in an urban space
Rehman & Gruhn, 2017	Recommended Architecture for Car Parking Management System based on Cyber-Physical System	Reduce the wastage of time for looking for parking space by a user	A mobile web solution based on CPS technology to real-time find a parkings location

CPS Architecture Models

The cybernization of complex engineering systems requires the design of reliable and efficient architectures (Parri et al., 2021; Hunke et al., 2021). Convergence system aims at the large-scale integration of physical objects with computer programs, it called cyber-physical systems (CPS). The specific paradigms CPS applied to various domains are shown in Table 2. In the recent works, CPS architecture models have been used in the fourth industrial revolution, Education digitalization, Cyber security, healthcare, agriculture, military and more (Yaacoub et al., 2020).

The fourth industrial revolution aimed to improve human life and health where manufacturing, big data analytics together with augmented reality diagnoses patients with health irregularities and ascertain prognosis (Nayyar & Kumar, 2020). Industry 4.0 incorporates technologies like 3D printing, advanced robotics, cyber security, big data analytics, augmented reality, industrial internet of things, cloud computing, cyber-physical systems, horizontal & vertical integration to the production process of the industry (Kumar & Nayyar, 2020). All these technologies will allow industry 4.0 to offer ease understandable, increase reliability and efficiency, better accessibility, ease use, safe for everyone, customized products, and agility.

With the fourth industrial revolution, education must be transformed into Education digitalization to allow pupils or students to learn in various places and respective places, to personalize the training modules according to their abilities, to use tools for distance education, collaborating in the learning process with other learners, and more (Nafea & Toplu, 2021). So, the engineer from digital education will acquire interdisciplinary skills to easily address the problems of complex production systems. CPS technologies will bring quickness in the acquisition and competence of the learner for a very competitive know-how in enterprise. For example, (Mäkiö-Marusik et al., 2019) shown a novel learning and teaching concept "T-CHAT" that allows future engineer to acquire interdisciplinary knowledge and skills as well as a multidisciplinary view for being able to run industrial digitalization projects successfully.

Systems integration raises data protection concerns around the world (Wlazlo et al., 2021). IT protection covers the life cycle of data in the system. The democratization of the Internet has increased threats and attacks, for example the man-in-the-middle. Man-in-the-Middle Attack is a type of cyber-attack in which an unauthorized person enters the online network between the two users, avoiding the sight of both users (Narula et al., 2022). Wlazlo et al. shown how man-in-the-middle attacks can cause misguided operation and false measurements in an emulation-based cyber-physical power system against a smart grid model. Wlazlo et al. presented method to detect man-in-the-middle attack traffic by correlating Snort intrusion detection systems alerts with address resolution protocol and distributed network protocol-3 packet data, using network metrics such as retransmission rate and average round trip time. Countries have used cyber security to protect their computer systems with the five basic principles of computer security: confidentiality, integrity, authentication, non-repudiation and availability of information.

To essentially improve human well-being, scholars have studied the social factor. For example, (Wu et al., 2014) studied an emergency system to improve human factor. Wu et al. proposed Cyber-physical human system architecture to predict and control human. The same authors have also proposed in medicine a Cyber-Physical Human Medical System architecture for zero safety-critical human problems in the medical system interactions. (Gong et al., 2022) proposed CPS based human to satisfy the well-being of a human. Authors called it Cyber-physical-social system. (Sanchez et al., 2017) proposed CPS to ubiquitous sensing and gathered physical information about the environment or human social activities, called Cyber-Physical Social Sensing.

(Cardin et al., 2019) proposed a high-tech enterprise production architecture based on CPS technology. Authors proposed Cyber-Physical Production Systems to provide intelligence, connectivity and responsiveness for production enterprise.

STATE OF ART OF CPS IN URBAN MOBILITY SYSTEM

In this work, a total of 1470 published papers were studied. Following techniques for filtering duplicates and papers poor in content, 77 papers were selected following the procedure described in Table 4.

Table 2. Recent works on CPS models applied to various domains

Authors	CPS applied	Target	Open problems identified
Gong et al., 2022	Cyber-Physical Social Systems	Social System	security and privacy, design efficiency, energy management, understanding of user's design intention and dynamic social relations learning
Sanchez et al., 2017	Cyber-Physical Social sensing	cyber-social sensing data	inclusion of automatic tools to build valid simulation models
Li et al., 2018	Cyber-Physical Social Computing	convergence of the physical, cyber, social spaces, and social computing	Novel measurement scheme practical and scalable
Lim et al., 2022	Cyber-Physical Human Systems	Convergence of the computers, cyber physical devices, and people	probability modelling of Emergency management systems; choose the right person for a given task
Wu et al., 2014	Cyber-Physical-Human Medical Systems	supervisory medical systems and medical staff	Reduction of the medical errors
Zeng et al., 2020	Cyber-Physical Cloud Systems	Cloud computing infrastructure	vulnerabilities of system, language for scalable cyber-physical cloud computing programming
Cardin et al., 2019	Cyber-Physical Production Systems Transportation Systems	human operators, the distribution of intelligence and the network technologies	Integration between practitioners and academics for real applicability results
Deka et al., 2018	Transportation Cyber-physical System	Traditional transportation systems	complexity and dimensionality protection, verification architectures of large-scale TCPS privacy data
Guo et al., 2018	Agriculture Cyber-physical Systems	Traditional Agriculture	proper hardware and software design, cost-effectiveness, compressive sensing, efficiency energy
This paper	Cyber-physical urban mobility Systems	urban mobility system	engineering design, architectural framework design, modeling and simulation, formal verification and validation, multi objective optimization

Sustainable Urban Mobility Systems Design

Studies on the design of sustainable mobility systems have not interested scholars too much over the ten last years. And yet, the design of such a system is a very complex problem in transport engineering, civil engineering, and computer science.

A sustainable mobility system stands for a mobility that contributes positively to the economy of the region, without compromising human health, environment, or the ability of future generations to meet their needs (Da et al., 2008; Yetim et al., 2020). Urban mobility must consider alternatives to private vehicle in order to reduce the pressure of motorized traffic on roads and the environment. However, (Ngossaha et al., 2020; Moskolaï et al., 2019) classified the approaches to the urban mobility systems design into two categories, (1) approach by sectoral analysis, and (2) global system-oriented approach. For authors, approach (1) does not bring visibility into the entire system, but rather creates conflict between the subsystems that can affect the efficiency of the mobility system. Approach (2) facilitates the control of the resilience of the system. Other studies have been conducted to propose new approaches to improve the urban mobility system.

(Wegener et al., 1994) proposed an analysis of the dynamics on the change of state of the mobility system based on the non-formal specification of the system. This approach considered the complexity of the system, even if it remains very limited, the management of interactions between several areas of mobility and the evaluation of the mobility coverage rate.

(Goldman et al., 2006) used a global approach to analyze the socioeconomic impact of urban mobility which remains frozen in the management of complexity with socio-economic impact. It presented efficiency, management gains and efficient monitoring of mobility actions.

(Jifeng et al., 2008) proposed an analysis of the dynamics of the mobility system based on the non-formal specification of the system. The limits of this approach are based on the management of the complexity only limited to the field studied. Interactions are not very representative of the whole system, and its representation is ill-suited to understanding it.

(Ngossaha et al., 2020) proposed a holistic approach considering the entire lifecycle of sustainable urban mobility system. Ngossaha et al. have subdivided the system into four subsystems: (i) the topology of the urban mobility system; (ii) the timetables of the urban mobility system; (iii) the urban mobility services; and (iv) the management of the urban occupation of mobility. Ngossaha et al. have developed a meta-model for a sustainable mobility system and propose a method for deploying the distributed architecture of the system. The proposed solution is a decision support tool for the city in the implementation of the urban mobility system for the future. Authors integrated the management of the system complexity by considering the interdisciplinary expertise and multidisciplinary domain. Unfortunately, the authors did not prove the validity of their proposed system architecture by modeling and simulation.

Finally, the mobility paradigm has evolved over time (Van et al., 2018). The twenty first century marks the fourth-generation mobility era. This new mobility relies on the sustainability, integration, intelligence, and autonomy of urban mobility system. For this reason, the urban mobility 4.0 design requires to reconcile the interests of the approaches proposed in the literature and to consider partially/fully the gaps cited in the proposed solutions: (1) the coupling of control, communication and data processing systems in the transportation system; (2) improving the analysis of the complex interactions between the different components of the system by taking into account the quality of the exchanged flows (energy, material, information and even geographical location) and the specific local requirements. This situation leads us to share the point of view of (Kumar et al., 2020), who defines urban mobility system as a complex system of systems that encompass physical and non-physical components that can work together to enable dynamic, real-time complex interactions between urban subsystems such as transportation, energy, healthcare, housing, food, entertainment, work, social interactions, and governance. So, the sustainable urban mobility system design must take account variables as the spatial pattern of human settlements, activities at a particular point of time, socio-economic and socio-cultural variables, non-connected (or connected) vehicles, bike-sharing system, mass transit, pedestrians, transportation infrastructures, transportation services providers, transactional environment and others (El-Sherif, 2021). This convergence and integration of systems reveals a new concept called Cyber-Physical System. The following figure (Fig. 1) shows an example of a CPS.

Main goal and Position

Considering the literature review, the implementation of an urban mobility system is a complex engineering task. However, important aspects should be considered when designing such a system, for example the economy, the socio-cultural context, local technological innovations, the environment, and more. Many approaches have been studied and presented in the Table 3.

Recent work has developed much more specific aspects of the transportation system. However, the urban mobility system is characterized by complex interactions between sub-systems. A holistic consideration of the system will allow to anticipate emerging phenomena in mobility systems that are sources of road insecurity and time loss. Thus, none of the approaches considered in the works studied considers the management of complex interactions and social collaborations in an urban environment. To this end, a methodology based on CPS coupled to the urban mobility system is needed in order to better consider the physical, informational and decision-making aspects in the

Figure 1. Cyber-Physical Social Sensing Scheme (Sánchez et al., 2017)

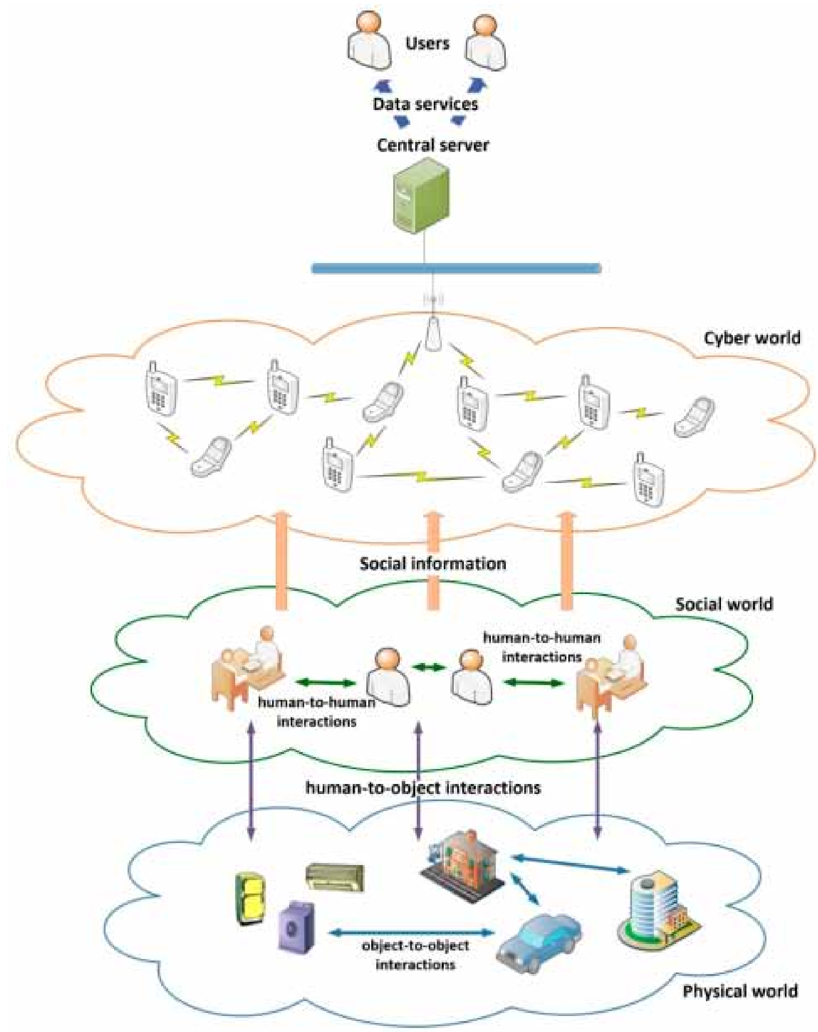


Table 3. Summary of works on the transportation CPS architecture modeling approach

Authors	Approach	Features	1	2	3	4	5
Feng et al., 2017	Context-aware	sensing of situations in road traffic	x	p	x	x	p
Carlos et al., 2019	Multi-Agent systems oriented to events	Observe the vehicular conditions	x	p	x	x	p
Jeong et al., 2020	Component-based	Human factors, V2V communication, driver's behavior	x	x	p	p	x
Ngossaha et al., 2020	Engineering	Sustainability parameters	p	p	p	x	x
Mladenovic et al., 2019	Mobility Credits	human cooperation and systemic self-organization	x	x	x	x	p
Rathore et al., 2021	Graph-based	transport-control model	p	p	x	x	x
Guzman & Nunez, 2021	CPS	collaborative urban traffic control	x	p	x	x	p
Tchappi et al., 2022	Holonic multilevel	Dynamics transportation system	p	p	x	x	x

Note: [1] Holistic, [2] Integration, [3] Interactions, [4] Social, [5] Optimization design of mobility systems. A synthesis of the literature on the design of urban mobility systems, the proposal of a new architectural framework and the identification of challenges and opportunities related to new technologies for mobility are the major objectives of this paper. These contributions will help mobility decision-makers in the design of systems that federate all physical components with computer programs to enable real-time control of mobility and consequently meet the needs of users in the context of developing countries.

METHODS

The study was developed based on scientific work published between 1969 and 2022. The compilation of a collection of keywords are used to form queries combining logical operators such as, OR and AND. For example, CPS OR ITS, Smart mobility OR ITS, and more. The queries formulated are entered into Google scholar search engine to download references papers from respective IEEExplorer, Springer, MDPI, ACM, and Web of Science databases. The results from the method are described in Table 4 bellow. Clearly, the method is based on six processes.

The process one identifies the different possible keywords related to the subject to be treated. For example, CPS, Intelligent transportation system (ITS), Mobility as a Service (MaaS), and more. The process two performs information research based on the keywords selected via the search engine Google scholar. The process three consists in breaking down the documents gathered by journal IEEExplore, SpringerLink, ACM, ScienceDirect, MDPI and Web of Science. The process four consists in applying a reading filter to remove unnecessary files among the various downloaded documents. For a document to be retained, it had to develop aspects on the ITS, the opportunities and challenges on the scope of application of CPS to transport, transport in developing countries, the paradigm of sustainable urban mobility, and the architecture of CPS. The process five merges the selected documents. And in the last process, it is a question of simply eliminating the duplicates by the documents.

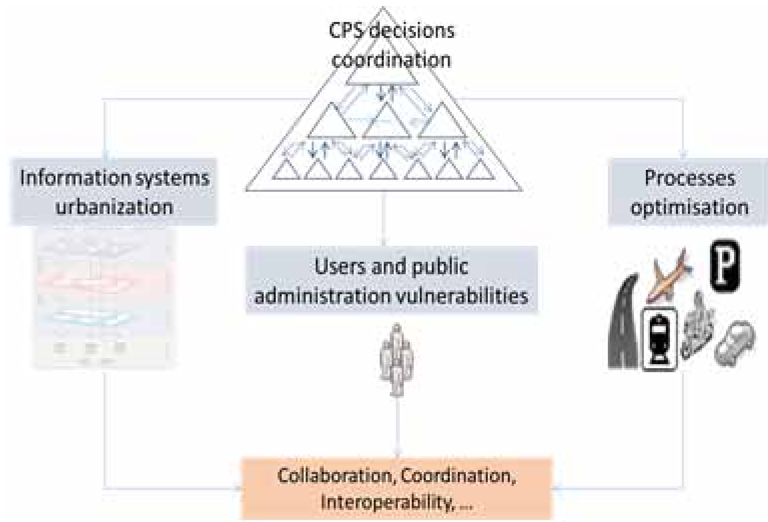
ARCHITECTURAL FRAMEWORK OF CYBER-PHYSICAL SYSTEM IN URBAN MOBILITY: CASE OF DEVELOPING COUNTRIES

The context of developing countries is a huge challenge to take up, especially since all the aspects have to be redone (Mfenjou et al., 2018; Holzinger et al., 2021). An architectural framework for CPUMS is shown in Fig. 2. The architecture brings out three main important dimensions for efficient numerical convergence and control system: (1) decisional dimension responsible for coordinating between public and private partners, (2) infrastructural dimension to meet users' expectations, and (3) informational dimension responsible for providing a digital platform for MaaS. So proposed architecture is composed in details with coordination of CPS decisions, urbanization information systems, vulnerabilities of users and public administration, collaboration, coordination and interoperability, and process optimization.

Table 4. A detailed Procedure of literature search of scientific papers

No	PROCESS	SEARCH
1	Search terms	Set of queries
2	Search engine	Google Scholar
3	Findings by journals	IEEE (673), Springer (129), ACM (67), Elsevier (551), Web of Science (50)
4	Filtering by reading	IEEE (61), Springer (13), ACM (9), Elsevier (18), Web of Science (20)
5	Merge results	121
6	Duplication removal	**77**

Figure 2. Architectural framework of Cyber-Physical Urban Mobility System



Coordination of CPS decisions makes it possible to coordinate the management of interactions between connected objects (vehicles, communication infrastructure, surveillance cameras, and traffic lights). Drivers need real-time information about the traffic situation to make decisions, and passengers desire transportation services to which the system should recommend solutions to satisfy passengers' needs. The stakes for this module are enormous for the robustness and reliability of the intelligent and flexible system.

Urbanization Information Systems is based on urbanization of cities and land use. It provides flexibility on the transportation system to ensure: 1) its evolution, 2) its modularity, and 3) its renovation, while preserving the functioning of the system. It enables communication control, costs reduction. Therefore, this module aims to creating an agile, flexible and scalable information system for proposed architecture CPUMS. The impact of the construction of additional roads and their tarring has proven to be less important, because road accidents are still current events. This module brings here the possibility to digitize the urban systems, for much more intelligent in the management of the mobility and the decision-making.

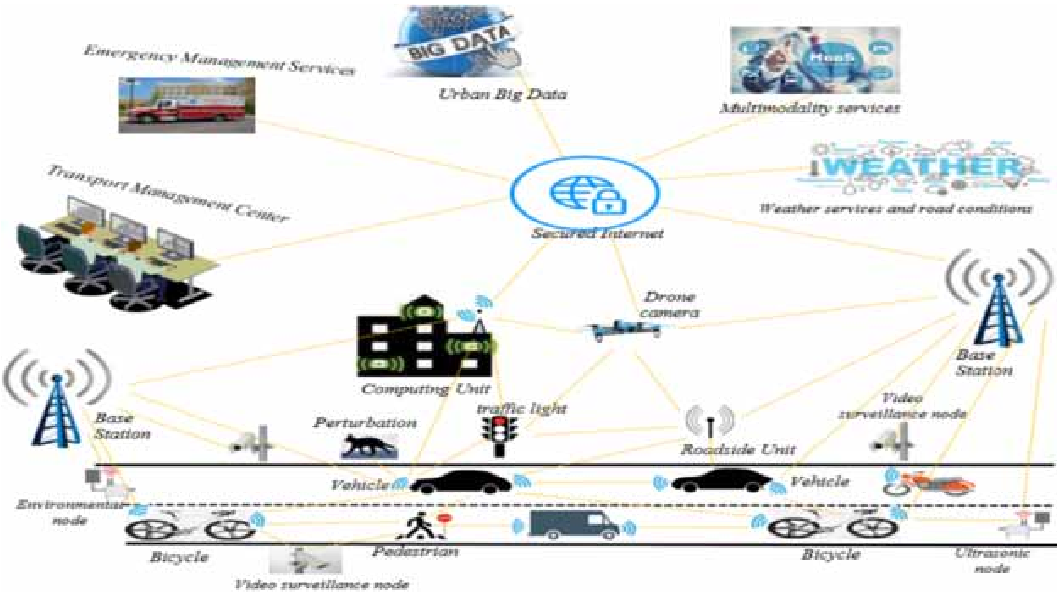
Vulnerabilities of users and public administration is responsible for integrity checking, consideration of socioeconomic requirements for human urban mobility. The most venerable social stratum is the poor, the elderly, and the handicapped. They suffer from the impacts of air pollution on the roads, and the high cost of transportation. The intelligence and hyper connectivity advocated by CPS technologies are able to problem solving.

Collaboration, Coordination and Interoperability simplify the process of evolving complex engineering subsystems, communication languages specification, interactions control and management between subsystems or components to ensure system interoperability.

In developing countries, the road is a social good. Priority and the rules of the road during crossings are neglected in favor of precipitation and bifurcations, major causes of mobility problems. Optimization processes can develop optimal transport theories for reducing travel time, promoting multimodality, carpooling, smart parking, traffic jams and errors for these countries. The system suggested in this paper is composed of subsystems that may have the ability to communicate, process data and control objects through computer programs. Fig. 3 shows an implementation of the proposed architecture.

The system proposed has three essential elements: the cyber world, the physical world and the multiform interconnection links (microwave links, optic fiber distribution networks, local area networks

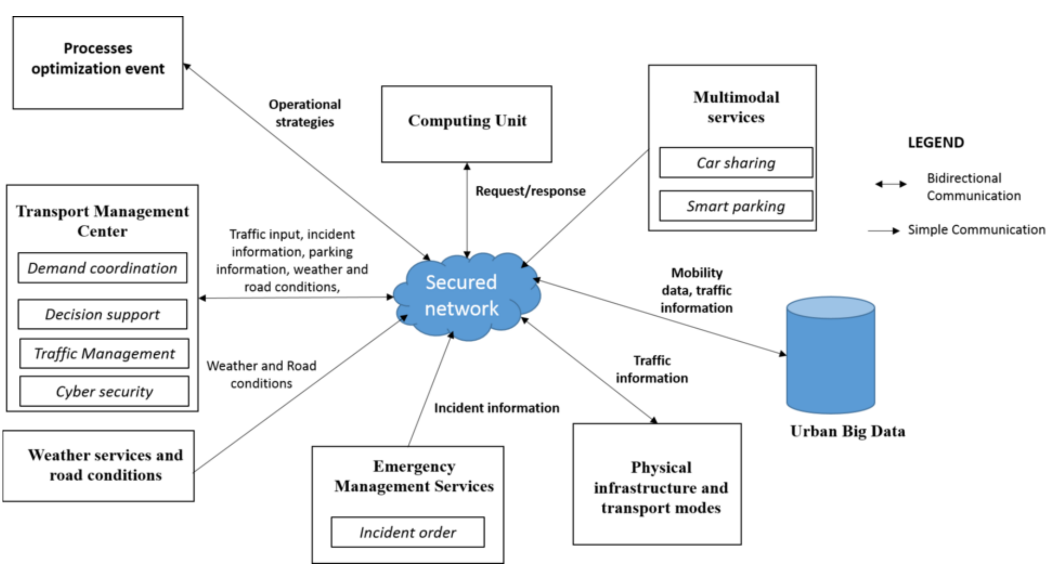
Figure 3. Deployment of Cyber-Physical Urban Mobility System



or 4G/5G/LTE network). The decision-making system includes the transport management center, emergency management services, weather and street condition services, multimodal management services, the data processing center and urban big data. The physical world includes transport infrastructure, pedestrians, vehicles, bicycles, animals and ICT tools (drones, sensors, RSUs, routers).

Figure 2 and figure 3 can be mapped by the physical representation below (Fig. 4) to show how the interfaces are implemented among the constituent components.

Figure 4. Complex interactions between interfaces of components in CPUMS



Transport Management Center (TMC) is responsible for monitoring road network conditions and traffic control. TMC exchange with the global system with secured transportation network. Emergency Management Services (EMS) represents systems that launch alert or incident order to the transport management center. EMS manages sensors, drones, RSU and video cameras to enhance safety transportation. Weather services and road conditions presents road conditions and meteorology. Computing unit is responsible for real-time computing operations in the system. Multimodal Services integrates intelligent vehicle parking services and the carpooling management system. Processes optimization event is responsible for providing demand responses for shortest path, intelligent traffic light optimization, optimized driving assistance.

CHALLENGES AND OPEN RESEARCH ISSUES OF CPUMS

Urban mobility system design is one of the complex tasks for government or engineer transportation. Urban mobility has undergone many changes, ranging from era of horse-drawn carriages to the era of digital mobility. CPS is the bedrock of the fourth-generation industry today. The CPS coupled the physical infrastructures of the transport to the computer algorithms for their efficient and effective controls. However, the use of solutions based on CPS pose enormous challenges, especially in the context of developing countries. These challenges relate to the deployment and optimal connectivity of connected objects, location mobile objects, management of quality of services, development of optimization processes for optimal transport, collaboration between connected (non-connected) objects, interactions and disturbances management, computing, implementation and validation of the architecture.

Particularly for developing countries, the urban mobility system design based on CPS technology needs to consider some aspects, high number of non-employees, poverty of the populations, local digital innovations (drone cameras), and environmental protection.

Thus, Table 5 presents an overview of the work that highlights the distinctive elements between the urban environments of developed countries and developing countries. Table 5 clearly shows developing countries under a delay in the use of new technologies, and a complex socioeconomic context.

Table 5. A comparative studies of transportation system in developing/developed countries

No	Authors	Factors	Developed Countries	Developing Countries
1	Cheshire et al., 2020	Multicultural society	**x**	**p**
2	Bernardo et al., 2019	Transport means	Walk, bicycles, motorized 2-wheelers or more than, metro, railway	walk, motorized 2 wheelers and more, vehicles, domestic animals
3	Doge et al., 2020	Multimodality	p	x
4	Afshar et al., 2020	ICT development	p	x
5	Bernardo et al., 2019	Smart/Integrated Mobility	p	x
6	Van et al., 2021	Rapid population growth	x	p
7	Cervero et al., 2013	Non-employees	x	p
8	Moghim et al., 2019	Pollution and energy consumption	high	acceptable
9	Vsurdonja et al., 2020	Smart city	p	x
10	Alinda et al., 2020	Landlocked district	x	p
11	Meilua et al., 2018	Transport management	private/public	private
12	Fan et al., 2005	Road Quality	p	x
13	Zhang et al., 2020	Route optimization techniques	p	x
14	Ferrara et al., 2019	e-vehicles	p	x
15	Dey et al., 2018	Connected (Autonomous) Vehicles	p	x

Therefore, developed countries have already been anchored in new technologies for a decade. Their urban environment is almost completely digital. Today, these types of countries are rather in the optimal choice of the best innovative technology. Unfortunately, in developing countries, CPUMS development will encounter challenges, as

- Position location. The location of households and connected devices in urban environment is an NP-hard problem in developing countries (Rossit et al., 2022). Georeferencing is almost non-existent, apart from internet users who are rarely used Google Map solution. Localization is important for the emergence and recommendation services by human mobility.
- Management of interactions to avoid emerging situations.
- Optimal deployment of computational devices with better coverage in an unreferenced space.
- The management of exchanges between connected mobile agents and the protection of its exchanges against cybernetic attacks knowing that developing countries are poorly equipped.
- Managing the collection and processing of the urban Big Data.
- The multi-objective process model's formulation for decision support for decision makers.

And also, the solutions proposed must be light and less costly in order to respond to the economic, financial and technological barriers faced by these countries.

CONCLUSION AND PERSPECTIVES

In this paper, a review of the state of the art in the design of sustainable urban mobility systems was conducted. A literature search method integrating database search and related journal search was proposed to select all relevant articles. Based on the selected main articles, the cyber-physical urban mobility system was reviewed, and some related works focusing on sector analysis approaches were presented as well as the design of intelligent transport architecture in the literature. In addition, a comparative study of the concepts applied in developed and developing countries was performed. Based on the local context of developing countries, we have proposed an architectural framework of cyber-physical urban mobility system. A synoptic table of the CPS conceptualization presented helped us to formalize the meaning of each concept in terms of its acronym, constituents, objectives, and identified open problems. Finally, the challenges and open issues of the contribution of cyber-physical systems in urban mobility in the context of developing countries were presented. In view of the upcoming development of an integrated and flexible urban mobility system in developing countries, limitations and perspectives were presented. Future work will cover three main aspects, (1) verification of validation proposal cyber-physical architecture of urban mobility system, (2) developing optimization performance processes to real-time intersections management, and (3) verifying correctness of our model with real mobility data in the context developing countries.

REFERENCES

Abdel Wahed Ahmed, M. M., & Abd El Monem, N. (2020). Sustainable and green transportation for better quality of life case study greater Cairo–Egypt. *HBRC Journal*, *16*(1), 17–37. doi:10.1080/16874048.2020.1719340

Afshar Ali, M., Alam, K., & Taylor, B. (2020). Incorporating affordability, efficiency, and quality in the ICT development index: Implications for index building and ICT policymaking. *The Information Society*, *36*(2), 71–96. doi:10.1080/01972243.2019.1702601

Al-Thani, H., Koç, M., Isaifan, R. J., & Bicer, Y. (2022). A Review of the Integrated Renewable Energy Systems for Sustainable Urban Mobility. *Sustainability*, *14*(17), 10517. doi:10.3390/su141710517

Alinda, F., Ssekamatte, D., Kisambira, E., & Kagoro, A. (2020). Advancing climate change adaptation in Ugandas agricultural programming for sustainable development: Key milestones and constraints. *African Journal of Environmental Science and Technology*, *14*(10), 301–310.

Ari, A. A. A., Yenke, B. O., Labraoui, N., Damakoa, I., & Gueroui, A. (2016). A power efficient cluster-based routing algorithm for wireless sensor networks: Honeybees swarm intelligence based approach. *Journal of Network and Computer Applications*, *69*, 77–97. doi:10.1016/j.jnca.2016.04.020

Bellini, P., Nesi, P., & Pantaleo, G. (2022). IoT-Enabled Smart Cities: A Review of Concepts, Frameworks and Key Technologies. *Applied Sciences (Basel, Switzerland)*, *12*(3), 1607. doi:10.3390/app12031607

Bernardo, M. R. (2019). Smart cities–smart mobility: the impact of multimodal mobility services in the metropolitan area of Lisbon [Doctoral dissertation, NOVA University, Portugal].

Bradley, J. M., & Atkins, E. M. (2015). Optimization and control of cyber-physical vehicle systems. *Sensors (Basel)*, *15*(9), 23020–23049. doi:10.3390/s150923020 PMID:26378541

Cardin, O. (2019). Classification of cyber-physical production systems applications: Proposition of an analysis framework. *Computers in Industry*, *104*, 11–21. doi:10.1016/j.compind.2018.10.002

Carlos-Mancilla, M., López Neri, E., & Hermenegildo-Dominguez, L. A. (2019). A Cyber-Physical System Modelling Framework for an Intelligent Urban Traffic System. *Computación y Sistemas*, *23*(2), 299–311.

Cervero, R. (2013). Linking urban transport and land use in developing countries. *Journal of Transport and Land Use*, *6*(1), 7–24. doi:10.5198/jtlu.v6i1.425

Chen, B., Yang, Z., Huang, S., Du, X., Cui, Z., Bhimani, J., & Mi, N. (2017, December). *Cyber-physical system enabled nearby traffic flow modelling for autonomous vehicles*. In 36th international performance computing and communications conference (IPCCC) (pp. 1-6). IEEE. doi:10.1109/PCCC.2017.8280498

Chen, C., Liu, X., Qiu, T., & Sangaiah, A. K. (2020). A short-term traffic prediction model in the vehicular cyber–physical systems. *Future Generation Computer Systems*, *105*, 894–903. doi:10.1016/j.future.2017.06.006

Chen, Y., Zhang, Y., Maharjan, S., Alam, M., & Wu, T. (2019). Deep learning for secure mobile edge computing in cyber-physical transportation systems. *IEEE Network*, *33*(4), 36–41. doi:10.1109/MNET.2019.1800458

Cheng, Y., Zhang, Y., Ji, P., Xu, W., Zhou, Z., & Tao, F. (2018). Cyber-physical integration for moving digital factories forward towards smart manufacturing: A survey. *International Journal of Advanced Manufacturing Technology*, *97*(1), 1209–1221. doi:10.1007/s00170-018-2001-2

Cheshire, J. (2020). Taking the longer view: Explaining Multicultural London English and Multicultural Paris French. *Journal of Sociolinguistics*, *24*(3), 308–327. doi:10.1111/josl.12385

Cohen, B. (2006). Urbanization in developing countries: Current trends, future projections, and key challenges for sustainability. *Technology in Society*, *28*(1-2), 63–80. doi:10.1016/j.techsoc.2005.10.005

Da Silva, A. N. R., da Silva Costa, M., & Macedo, M. H. (2008). Multiple views of sustainable urban mobility: The case of Brazil. *Transport Policy*, *15*(6), 350–360. doi:10.1016/j.tranpol.2008.12.003

Deka, L., Khan, S. M., Chowdhury, M., & Ayres, N. (2018). Transportation cyber-physical system and its importance for future mobility. In *Transportation Cyber-Physical Systems* (pp. 1–20). Elsevier. doi:10.1016/B978-0-12-814295-0.00001-0

Dey, K., Fries, R., & Ahmed, S. (2018). *Future of transportation cyber-physical systems–Smart cities/regions*. Transportation cyber-physical systems, 267-307.

Dogan, O., & Gurcan, O. F. (2022). Applications of big data and green IoT-enabling technologies for smart cities. In Research Anthology on Big Data Analytics, Architectures, and Applications (pp. 1090-1109). IGI Global. doi:10.4018/978-1-6684-3662-2.ch052

Döge, N., & Abraham, M. (2020). Towards Seamless Travelling in Europe–Demand and Approaches to Promote Multimodal Traveling Within Europe. In *Towards User-Centric Transport in Europe 2* (pp. 240–253). Springer. doi:10.1007/978-3-030-38028-1_17

El-Sherif, D. M. (2021). Urban mobility systems components. In *Solving Urban Infrastructure Problems Using Smart City Technologies* (pp. 89–106). Elsevier. doi:10.1016/B978-0-12-816816-5.00004-8

Evers, K., Oram, R., El-Tawab, S., Heydari, M. H., & Park, B. B. (2017, June). *Security measurement on a cloud-based cyber-physical system used for intelligent transportation*. In *2017 IEEE International Conference on Vehicular Electronics and Safety (ICVES)* (pp. 97-102). IEEE. doi:10.1109/ICVES.2017.7991908

Fan, S., & Chan-Kang, C. (2005). *Road development, economic growth, and poverty reduction in China* (Vol. 12). Intl Food Policy Res Inst.

Farradyne, P. B. (2000). *Traffic incident management handbook*. Prepared for Federal Highway Administration, Office of Travel Management.

Feng, Y., An, X., & Li, S. (2017, July). *Application of context-aware in intelligent transportation CPS*. In 36th Chinese Control Conference (CCC) (pp. 7577-7581). IEEE. doi:10.23919/ChiCC.2017.8028553

Ferrara, M., Liberto, C., Nigro, M., Trojani, M., & Valenti, G. (2019). Multimodal choice model for e-mobility scenarios. *Transportation Research Procedia*, *37*, 409–416. doi:10.1016/j.trpro.2018.12.210

Goldman, T., & Gorham, R. (2006). Sustainable urban transport: Four innovative directions. *Technology in Society*, *28*(1-2), 261–273. doi:10.1016/j.techsoc.2005.10.007

Gong, K., Yang, J., Wang, X., Jiang, C., Xiong, Z., Zhang, M., Guo, M., Lv, R., Wang, S., & Zhang, S. (2022). Comprehensive review of modeling, structure, and integration techniques of smart buildings in the cyber-physical-social system. *Frontiers in Energy*, *16*(1), 1–21. doi:10.1007/s11708-021-0792-6

Guffin, M. B. (2015). *Cyberabad Moves: Mobilizing Futures in a South Indian City*. University of California.

Guo, J., Liu, R., Cheng, D., Shanthini, A., & Vadivel, T. (2022). Urbanization Based on IoT Using Big Data Analytics the Impact of Internet of Things and Big Data in Urbanization. *Arabian Journal for Science and Engineering*, 1–15. doi:10.1007/s13369-021-06124-2

Guo, P., Dusadeerungsikul, P. O., & Nof, S. Y. (2018). Agricultural cyber physical system collaboration for greenhouse stress management. *Computers and Electronics in Agriculture*, *150*, 439–454. doi:10.1016/j.compag.2018.05.022

Gupta, N., Gottapu, S. K., Nayak, R., Gupta, A. K., Derawi, M., & Khakurel, J. (Eds.). (2022). *Human-Machine Interaction and IoT Applications for a Smarter World*. CRC Press. doi:10.1201/9781003268796

Gupta, R. K., Koh, J., & Hong, D. (2019, June). New models and methods for programming cyber-physical systems (keynote). In *Proceedings of the 20th ACM SIGPLAN/SIGBED International Conference on Languages, Compilers, and Tools for Embedded Systems* (pp. 1-3). ACM. doi:10.1145/3316482.3338093

Gupta, S., & Godavarti, R. (2020). IoT data management using cloud computing and big data technologies. [IJSI]. *International Journal of Software Innovation*, *8*(4), 50–58. doi:10.4018/IJSI.2020100104

Guzmán, J. A., & Núñez, F. (2021). A Cyber-Physical Systems Approach to Collaborative Intersection Management and Control. *IEEE Access: Practical Innovations, Open Solutions*, *9*, 99617–99632. doi:10.1109/ACCESS.2021.3096330

Halim, Z., Sulaiman, M., Waqas, M., & Aydın, D. (2022). Deep neural network-based identification of driving risk utilizing driver dependent vehicle driving features: A scheme for critical infrastructure protection. *Journal of Ambient Intelligence and Humanized Computing*, 1–19. doi:10.1007/s12652-022-03734-y

Holzinger, A., Weippl, E., Tjoa, A. M., & Kieseberg, P. (2021, August). Digital transformation for sustainable development goals (sdgs)-a security, safety and privacy perspective on AI. In *International Cross-Domain Conference for Machine Learning and Knowledge Extraction* (pp. 1-20). Springer. doi:10.1007/978-3-030-84060-0_1

Hunke, F., Thomsen, H., & Satzger, G. (2021, January). *Investigating Modular Reuse as an Underlying Mechanism of Conceptualization during Service Design–the Case of Key Activity Orchestration*. In *Proceedings of the 54th Hawaii International Conference on System Sciences* (p. 1191). doi:10.24251/HICSS.2021.145

Jeong, J. P., & Lee, E. (2014). Vehicular cyber-physical systems for smart road networks. *Information and Communications Magazine*, *31*(3), 103–116.

Jeong, S., Baek, Y., & Son, S. H. (2020). Component-Based Interactive Framework for Intelligent Transportation Cyber-Physical Systems. *Sensors (Basel)*, *20*(1), 264. doi:10.3390/s20010264 PMID:31906463

Jeschke, S., Brecher, C., Meisen, T., Özdemir, D., & Eschert, T. (2017). Industrial internet of things and cyber manufacturing systems. In *Industrial internet of things* (pp. 3–19). Springer. doi:10.1007/978-3-319-42559-7_1

Jianjun, S., Xu, W., Jizhen, G., & Yangzhou, C. (2013). The analysis of traffic control cyber-physical systems. *Procedia: Social and Behavioral Sciences*, *96*, 2487–2496. doi:10.1016/j.sbspro.2013.08.278

Jifeng, W.., Huapu, L.., & Hu, P. (2008). System dynamics model of urban transportation system and its application. *Journal of Transportation Systems Engineering and Information Technology*, *8*(3), 83–89. doi:10.1016/S1570-6672(08)60027-6

Kantarci, B. (2015, March). *Cyber-physical alternate route recommendation system for paramedics in an urban area*. In *2015 IEEE Wireless Communications and Networking Conference (WCNC)* (pp. 2155-2160). IEEE. doi:10.1109/WCNC.2015.7127801

Khan, S. M. (2019). *Connected and automated vehicles in urban transportation cyber-physical systems* (Doctoral dissertation, Clemson University).

Khattak, A., Ahmad, N., Wali, B., & Dumbaugh, E. (2019). Developing a Taxonomy of Human Errors and Violations that Lead to Crashes (No. CSCRS-R19). Collaborative Sciences Center for Road Safety.

Kumar, A., & Nayyar, A. (2020). si3-Industry: A sustainable, intelligent, innovative, internet-of-things industry. In A roadmap to Industry 4.0: Smart production, sharp business and sustainable development (pp. 1-21). Springer, Cham.

Kumar, H., Singh, M. K., Gupta, M. P., & Madaan, J. (2020). Moving towards smart cities: Solutions that lead to the Smart City Transformation Framework. *Technological Forecasting and Social Change*, *153*, 119281. doi:10.1016/j.techfore.2018.04.024

Lee, C., & Lim, C. (2021). From technological development to social advance: A review of Industry 4.0 through machine learning. *Technological Forecasting and Social Change*, *167*, 120653. doi:10.1016/j.techfore.2021.120653

Lee, E. A. (2006, October). Cyber-physical systems-are computing foundations adequate. In Position paper for NSF workshop on cyber-physical systems: research motivation, techniques and roadmap (Vol. 2, pp. 1-9).

Li, C., Zhang, H., Zhang, T., Rao, J., & Yin, G. (2020). Cyber-physical scheduling for predictable reliability of inter-vehicle communications. *IEEE Transactions on Vehicular Technology*, *69*(4), 4192–4206. doi:10.1109/TVT.2020.2968591

Li, S., Bi, F., Chen, W., Miao, X., Liu, J., & Tang, C. (2018). An improved information security risk assessments method for cyber-physical-social computing and networking. *IEEE Access: Practical Innovations, Open Solutions*, *6*, 10311–10319. doi:10.1109/ACCESS.2018.2800664

Lim, Y., Zhou, C., Tan, Y., Fang, Y., & Singh, M. M. (2022, January). *Personal Thermal Comfort Model for Cyber-Physical Human Centric Systems using Incomplete Supervised Learning Method*. In *2022 International Conference on Information Networking (ICOIN)* (pp. 270-275). IEEE. doi:10.1109/ICOIN53446.2022.9687181

Mäkiö-Marusik, E., Colombo, A. W., Mäkiö, J., & Pechmann, A. (2019). Concept and case study for teaching and learning industrial digitalization. *Procedia Manufacturing*, *31*, 97–102. doi:10.1016/j.promfg.2019.03.016

Mannion, A., Lhachemi, H., Russo, G., Sweeney, S., & Shorten, R. (2019, December). On the design of cyber-physical control system for a smart pedelec (Ebike). In *58th Conference on Decision and Control (CDC)* (pp. 2108-2113). IEEE.

Meilă, A. D. (2018). Sustainable urban mobility in the sharing economy: Digital platforms, collaborative governance, and innovative transportation. *Contemporary Readings in Law and Social Justice*, *10*(1), 130–136. doi:10.22381/CRLSJ10120186

Mfenjou, M. L., Ari, A. A. A., Abdou, W., & Spies, F. (2018). Methodology and trends for an intelligent transport system in developing countries. *Sustainable Computing: Informatics and Systems*, *19*, 96–111. doi:10.1016/j.suscom.2018.08.002

Mishra, S. (2021). Network Traffic Analysis Using Machine Learning Techniques in IoT Networks. [IJSI]. *International Journal of Software Innovation*, *9*(4), 1–17. doi:10.4018/IJSI.289172

Mladenović, M. N., Abbas, M., Roncoli, C., & Chenani, S. B. (2019, October). A cooperative framework for Universal Basic Mobility System: Mobility credits approach. In *IEEE Intelligent Transportation Systems Conference (ITSC)* (pp. 694-701). IEEE. doi:10.1109/ITSC.2019.8916964

Moghim, S., & Garna, R. K. (2019). Countries' classification by environmental resilience. *Journal of Environmental Management*, *230*, 345–354. doi:10.1016/j.jenvman.2018.09.090 PMID:30293019

Möller, D. P., & Vakilzadian, H. (2016, May). Cyber-physical systems in smart transportation. In *international conference on electro information technology (EIT)* (pp. 0776-0781). IEEE.

Monios, J., & Bergqvist, R. (2020). Logistics and the networked society: A conceptual framework for smart network business models using electric autonomous vehicles (EAVs). *Technological Forecasting and Social Change*, *151*, 119824. doi:10.1016/j.techfore.2019.119824

Moskolaï, J. N., Houé, R. N., Karray, M. H., & Archimède, B. (2019, October). Ontology based approach for complexity management in the design of a sustainable urban mobility system. In *International Conference on Systems, Man and Cybernetics (SMC)* (pp. 3223-3228). IEEE. doi:10.1109/SMC.2019.8914648

Nafea, R. M. E. D., & Toplu, E. K. (2021). Future of Education in Industry 4.0: Educational Digitization–A Canadian Case Study. In Research Anthology on Digital Transformation, Organizational Change, and the Impact of Remote Work (pp. 1977-1997). IGI Global.

Nandhini, R. S., & Ramanathan, L. (2022). Integration of Big Data Analytics Into Cyber-Physical Systems. Cyber-Physical Systems: Foundations and Techniques, 19-41.

Narula, G., Nagrath, P., Hans, D., & Nayyar, A. (2022). Novel Defending and Prevention Technique for Man-in-the-Middle Attacks in Cyber-Physical Networks. *Cyber-Physical Systems: Foundations and Techniques*, (pp. 147-177).

Nayyar, A., & Kumar, A. (Eds.). (2020). *A roadmap to industry 4.0: smart production, sharp business and sustainable development* (pp. 1–21). Springer. doi:10.1007/978-3-030-14544-6

Ngossaha, J. M., Ngouna, R. H., Archimède, B., Patrascu, R. G., Petrisor, A. I., & Ndjodo, M. F. (2020). Methodological Framework for Defining the Sustainability Management Process for Urban Mobility Systems Based on System Engineering. [IJDIBE]. *International Journal of Digital Innovation in the Built Environment*, *9*(1), 1–21. doi:10.4018/IJDIBE.2020010101

Nnamani, K. E., Ngoka, R. O., Okoye, K. M., & Nwoke, H. U. (2022). The Nigerian state and the realities of managing COVID-19 pandemic: whither political restructuring and economic diversification?. *African Identities*, 1-22.

Nouacer, R., Hussein, M., Espinoza, H., Ouhammou, Y., Ladeira, M., & Castiñeira, R. (2020). Towards a framework of key technologies for drones. *Microprocessors and Microsystems*, *77*, 103142. doi:10.1016/j.micpro.2020.103142

Parri, J., Patara, F., Sampietro, S., & Vicario, E. (2021). A framework for model-driven engineering of resilient software-controlled systems. *Computing*, *103*(4), 589–612. doi:10.1007/s00607-020-00841-6

Pundir, A., Singh, S., Kumar, M., Bafila, A., & Saxena, G. J. (2022). Cyber-Physical Systems Enabled Transport Networks in Smart Cities: Challenges and Enabling Technologies of the New Mobility Era. *IEEE Access: Practical Innovations, Open Solutions*, *10*, 16350–16364. doi:10.1109/ACCESS.2022.3147323

Ramasamy, L. K., Khan, F., Shah, M., Prasad, B. V. V. S., Iwendi, C., & Biamba, C. (2022). Secure Smart Wearable Computing through Artificial Intelligence-Enabled Internet of Things and Cyber-Physical Systems for Health Monitoring. *Sensors (Basel)*, *22*(3), 1076. doi:10.3390/s22031076 PMID:35161820

Rathore, M. M., Attique Shah, S., Awad, A., Shukla, D., Vimal, S., & Paul, A. (2021). A cyber-physical system and graph-based approach for transportation management in smart cities. *Sustainability*, *13*(14), 7606. doi:10.3390/su13147606

Rawat, D. B., & Bajracharya, C. (2017). Vehicular cyber physical systems. Springer, 10, 978-3. doi:10.1007/978-3-319-44494-9

Rebeiro-Hargrave, A., Motlagh, N. H., Varjonen, S., Lagerspetz, E., Nurmi, P., & Tarkoma, S. (2020). MegaSense: Cyber-physical system for real-time urban air quality monitoring. In *2020 conference on industrial electronics and applications (ICIEA)* (pp. 1-6). IEEE.

Rossit, D. G., & Nesmachnow, S. (2022). Waste bins location problem: A review of recent advances in the storage stage of the Municipal Solid Waste reverse logistic chain. *Journal of Cleaner Production*, *342*, 130793. doi:10.1016/j.jclepro.2022.130793

Sánchez, B. B., Alcarria, R., Sánchez-Picot, Á., & Sánchez-de-Rivera, D. (2017). A methodology for the design of application-specific cyber-physical social sensing co-simulators. *Sensors (Basel)*, *17*(10), 2177. doi:10.3390/s17102177 PMID:28937610

Sirajudeen, A. O., Law, T. H., Wong, S. V., & Ng, C. P. (2022). The motorcycle deaths to passenger car deaths ratio and economic performance: A panel data analysis. *Accident; Analysis and Prevention*, *165*, 106533. doi:10.1016/j.aap.2021.106533 PMID:34902624

Smaldone, S., Tonde, C., Ananthanarayanan, V. K., Elgammal, A., & Iftode, L. (2011, March). The cyber-physical bike: A step towards safer green transportation. In *Proceedings of the 12th Workshop on Mobile Computing Systems and Applications* (pp. 56-61). doi:10.1145/2184489.2184502

Šurdonja, S., Giuffrè, T., & Deluka-Tibljaš, A. (2020). Smart mobility solutions–necessary precondition for a well-functioning smart city. *Transportation Research Procedia*, *45*, 604–611. doi:10.1016/j.trpro.2020.03.051

Tchappi, I., Mualla, Y., Galland, S., Bottaro, A., Kamla, V. C., & Kamgang, J. C. (2022). Multilevel and holonic model for dynamic holarchy management: Application to large-scale road traffic. *Engineering Applications of Artificial Intelligence*, *109*, 104622. doi:10.1016/j.engappai.2021.104622

Ur Rehman, S., & Gruhn, V. (2017, May). Recommended architecture for car parking management system based on cyber-physical system. In 2017 International Conference on Engineering & MIS (ICEMIS) (pp. 1-6). IEEE. doi:10.1109/ICEMIS.2017.8272987

Van Audenhove, F. J., Rominger, G., Korn, A., Bettati, A., Steylemans, N., Zintel, M., . . . Haon, S. (2018). The Future of Mobility 3.0—Reinventing Mobility in the Era of Disruption and Creativity. Arthur D. Little.

Van Hoof, J., & Marston, H. R. (2021). Age-friendly cities and communities: State of the art and future perspectives. *International Journal of Environmental Research and Public Health*, *18*(4), 1644. doi:10.3390/ijerph18041644 PMID:33572181

Verma, R. (2021). Smart City Healthcare Cyber Physical System: Characteristics, Technologies and Challenges. *Wireless Personal Communications*, 1–21. PMID:34462622

Wang, F. Y., Tang, Y., Liu, X., & Yuan, Y. (2019). Social education: Opportunities and challenges in cyber-physical-social space. *IEEE Transactions on Computational Social Systems*, *6*(2), 191–196. doi:10.1109/TCSS.2019.2905941

Wang, J., Xu, P., Li, J., Sun, X., Tian, W., Ling, J., & Liu, H. (2019, January). Towards an Efficient Cyber-Physical System for First-Mile Taxi Transit in Urban Complex. In *19th International Symposium on High Assurance Systems Engineering (HASE)* (pp. 9-16). IEEE. doi:10.1109/HASE.2019.00012

Wegener, M. (1994). Operational urban models state of the art. *Journal of the American Planning Association*, *60*(1), 17–29. doi:10.1080/01944369408975547

Wlazlo, P., Sahu, A., Mao, Z., Huang, H., Goulart, A., Davis, K., & Zonouz, S. (2021). Man-in-the-middle attacks and defence in a power system cyber-physical testbed. IET Cyber-Physical Systems. *Theory & Applications*, *6*(3), 164–177.

Wu, P. L., Raguraman, D., Sha, L., Berlin, R. B., & Goldman, J. M. (2014, August). A treatment validation protocol for cyber-physical-human medical systems. In *40th EUROMICRO Conference on Software Engineering and Advanced Applications* (pp. 183-190). IEEE. doi:10.1109/SEAA.2014.10

Yaacoub, J. P. A., Salman, O., Noura, H. N., Kaaniche, N., Chehab, A., & Malli, M. (2020). Cyber-physical systems security: Limitations, issues and future trends. *Microprocessors and Microsystems*, *77*, 103201. doi:10.1016/j.micpro.2020.103201 PMID:32834204

Yetim, B., İlgün, G., Çilhoroz, Y., Demirci, Ş., & Konca, M. (2021). The socioeconomic determinants of health expenditure in OECD: An examination on panel data. *International Journal of Healthcare Management*, *14*(4), 1265–1269. doi:10.1080/20479700.2020.1756112

Zeng, D., Gu, L., & Yao, H. (2020). Towards energy efficient service composition in green energy powered cyber–physical fog systems. *Future Generation Computer Systems*, *105*, 757–765. doi:10.1016/j.future.2018.01.060

Zhang, D., He, T., Liu, Y., & Stankovic, J. A. (2013, October). CallCab: A unified recommendation system for carpooling and regular taxicab services. In *International Conference on Big Data* (pp. 439-447). IEEE. doi:10.1109/BigData.2013.6691605

Zhang, D., & Zhu, H. (2020). Optimization of Urban Transportation Network Path. In *Data Processing Techniques and Applications for Cyber-Physical Systems (DPTA 2019)* (pp. 15–22). Springer. doi:10.1007/978-981-15-1468-5_3

Zhao, S., Li, S., Chen, L., Ding, Y., Zheng, Z., & Pan, G. (2013, August). iCPS-Car: An intelligent cyber-physical system for smart automobiles. In *International Conference on Green Computing and Communications and IEEE Internet of Things and IEEE Cyber, Physical and Social Computing* (pp. 818-825). IEEE. doi:10.1109/GreenCom-iThings-CPSCom.2013.145

Zhou, Y., Wang, J., & Yang, H. (2019). Resilience of transportation systems: Concepts and comprehensive review. *IEEE Transactions on Intelligent Transportation Systems*, *20*(12), 4262–4276. doi:10.1109/TITS.2018.2883766

Zhu, K. (2022). Introduction to the Smart Machining System. In *Smart Machining Systems* (pp. 1–18). Springer.

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