Developing transport management system for integrating drones with smart cities

A dissertation submitted by:

Nguyen Dinh Dung

In Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy

Supervisors:

Dr. Rohács Daniel

Budapest, 2021
Statement of Original Authorship

I, Nguyen Dinh Dung, declare that this dissertation, “Developing transport management system for integrating drones with smart cities”, and the works presented in it are my work. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is made.

In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been previously submitted to meet requirements for an award at this or any other higher education institution.

Signature:  ____________________________

Date:
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<td>ACC</td>
<td>Adaptive Cruise Control</td>
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<tr>
<td>ACV</td>
<td>Autonomous and Connected Vehicle</td>
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<td>ATM</td>
<td>Air Transport Management</td>
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<tr>
<td>ATMS</td>
<td>Autonomic Transport Management System</td>
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<tr>
<td>BRT</td>
<td>Bus Rapid Transit</td>
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<tr>
<td>BVLOS</td>
<td>Beyond Visual Line-Of-Sight</td>
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<td>CbDMS</td>
<td>Cloud-based Drone Managing System</td>
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<tr>
<td>CNS</td>
<td>Communication, Navigation and Surveillance</td>
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<tr>
<td>CTM</td>
<td>Contract-based Traffic Management</td>
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<tr>
<td>CV</td>
<td>Cooperative Vehicle</td>
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<tr>
<td>D2D</td>
<td>Drone-to-Drone</td>
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<tr>
<td>D2T</td>
<td>Drone-to-Target</td>
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<tr>
<td>EASA</td>
<td>European Aviation Safety Agency</td>
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<td>ESC</td>
<td>Electronic Speed Controller</td>
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<td>EU</td>
<td>European Union</td>
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<tr>
<td>EV</td>
<td>Electric Vehicle</td>
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<tr>
<td>FAA</td>
<td>Federal Aviation Administration</td>
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<tr>
<td>FC</td>
<td>Flight Controller</td>
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<tr>
<td>FCU</td>
<td>Flight Controller Unit</td>
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<tr>
<td>FPV</td>
<td>First Person View</td>
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<tr>
<td>GCS</td>
<td>Ground Control Station</td>
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<tr>
<td>GHG</td>
<td>Global greenHouse Gas</td>
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<tr>
<td>GPS</td>
<td>Global Positioning System</td>
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<tr>
<td>ICAO</td>
<td>International Civil Aviation Organization</td>
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<tr>
<td>ICN</td>
<td>Information-Centric Networking</td>
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<tr>
<td>ICT</td>
<td>Information and Communication Technology</td>
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<tr>
<td>IoT</td>
<td>Internet of drone</td>
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<tr>
<td>IoD</td>
<td>Internet of drone</td>
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<tr>
<td>IoE</td>
<td>Internet of Everything</td>
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<tr>
<td>IT</td>
<td>Information Technology</td>
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<tr>
<td>ITTM</td>
<td>Intelligent Total Transport Management</td>
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<td>ITTMS</td>
<td>Intelligent Total Transport Management System</td>
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<tr>
<td>Acronym</td>
<td>Description</td>
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<tr>
<td>ITS</td>
<td>intelligent transportation system</td>
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<tr>
<td>JAS</td>
<td>Joint Aviation Authorities</td>
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<tr>
<td>KP</td>
<td>Knowledge Processor</td>
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<tr>
<td>LoRaWAN</td>
<td>Long-Range Wide Area Network</td>
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<tr>
<td>LPWAN</td>
<td>Low-Power Wide-Area Network</td>
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<tr>
<td>LTE</td>
<td>Long-Term Evolution</td>
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<tr>
<td>MaaS</td>
<td>Mobility-as-a-Service</td>
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<td>MEMS</td>
<td>Micro-Electric-Mechanical-System</td>
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<tr>
<td>NCV</td>
<td>Non-Cooperative Vehicle</td>
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<tr>
<td>PID</td>
<td>Proportional-Integral-Derivative</td>
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<td>PTM</td>
<td>Priority Transport Management</td>
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<td>SD</td>
<td>Safe Distance</td>
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<td>SIB</td>
<td>Semantic Information Broker</td>
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<tr>
<td>SP</td>
<td>Service Provider</td>
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<tr>
<td>SQL</td>
<td>Structured Query Language</td>
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<td>SSAP</td>
<td>Smart Space Access Protocol</td>
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<td>SUM</td>
<td>Shared Use Mobility</td>
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<td>TMS</td>
<td>Transportation Management Systems</td>
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<td>UAV</td>
<td>Unmanned Aerial Vehicle</td>
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<tr>
<td>UAS</td>
<td>Unmanned Aircraft System</td>
</tr>
<tr>
<td>U.S.</td>
<td>United States</td>
</tr>
<tr>
<td>UTM</td>
<td>UAV traffic management systems</td>
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<tr>
<td>VLOS</td>
<td>Visual Line-Of-Sight</td>
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<td>WLAN</td>
<td>Wireless Local Area Network</td>
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<tr>
<td>WPAN</td>
<td>Wireless Personal Area Network</td>
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List of Publications

The content of this thesis has been published in the following papers:

Journal papers


Book chapters


Conference papers


Abstract

Drones, commonly term for unmanned aerial vehicles (UAVs), are remotely piloted aircraft with vital roles in protection and commercial sectors. Drones can direct themselves automatically without any human control. A drone can equip various Internet of Things (IoT) devices, including sensors and payloads, to perform several specific tasks such as delivering packages, patrol areas, monitoring infrastructure, searching, and securing. In these platforms, drones were used as teleoperated vehicles through the Internet or radio-link, based on low-level co-operations straight associated with the primary drone flights. However, controlling and managing drones through the Internet or radio-link poses new challenges, which means that many drone applications, particularly airspace, raise the need for drone traffic management or, in general, unmanned aircraft vehicle traffic management (UTM). The investigations into UTM development for the drones’ urban operation and analysis of the possible solutions have identified several significant problems, such as difficulties in using passive surveillance systems and the complexity of conflict/obstacle detection and resolution. Therefore, this research proposes integrating drones into the urban total transport management systems and developing unique methods for managing many drones in formation flight. Such approaches include working dynamically variable groups of drones, swarm optimization, and drone-following models for individual vehicles are moving with similar trajectories.

Firstly, an intelligent total transport management system (ITTMS) has been developed for transport management in smart cities. The ITTMS aims to manage the whole transport system in an optimized form and to improve mobility. Due to the fast development of Information Technology (IT), ITTMS could be a solution for urban transport management. The ITTMS has provided more effective and efficient services in urban transportation, improve safety and security, and enables the general quality of the environment in cities for working and living. The ITTMS can operate as a single system that could increase user comfort, security, reduce traffic jams, save energy by providing users real-time data regarding traffic reports, rerouting traffic, and adjusting speed limits based on this information.

Secondly, this dissertation presents unique methods for managing many drones in smart cities, including drone-following models and cloud-based drone managing system. The drone-following models are based on the drones' initial idea of a leading drone in the traffic flow. There are two types of drone-following models. The first model is a safe distance model (SD model), in which a safe distance between a drone and it's ahead is maintained. By applying the stochastic diffusion process, an improved model, called the Markov model, is deduced. Based on the simulation results, it could be noted that there is no accident and no unrealistic deceleration, and the velocity of the followed drone is changed
according to the speed of the drone ahead. Besides, the cloud-based drone managing system (CbDMS) motivated by the IoT and the Internet of Drones (IoD) technologies have shown exemplary performance in dealing with complicated and active traffic flows. This platform has three main layers, including the physical layer, cloud layer, and control layer. The CbDMS is an advanced approach for managing drones to meet critical features, which associates real-time streaming, cloud computing, regularly refreshed information, and intelligent acknowledgment of dynamically varying situations. With CbDMS, complicated missions can be taken with efficiency, improving safety and applicability. Also, drones can detect obstacles and plan their paths using onboard sensors that receive information in real-time. It means that drones can survey and gather environmental information. Keeping this information up to date enables online managing and controlling drones, one of the most advantages of drone applications.

Last but not least, this dissertation provides an investigation of the landing process of UAVs. The landing approach is one of the critical stages of the entire flight to bring the UAV to land safely at the desired location. UAVs' landing stages consist of three stages: the directive stage, the lower altitude stage, and the deceleration stage. The landing areas are determined by solving the system of differential motion of aircraft, on which the desired landing orbit is calculated. The simulation results show the shapes of the trajectories in different initial conditions.

Throughout the dissertation, analytical work developed during the thesis is validated by extensive simulation, comparisons, and experiments to evaluate the proposed method and confirm its feasibility and effectiveness. Discussions on theoretical aspects and implementation details are included together with some recommendations.
Introduction

Drones or Unmanned Aerial Vehicles (UAV) are aircraft that can autonomously fly and complete their missions. Drones were initially used in military and civilian applications, such as surveillance, policing, firefighting, and search and rescue missions. More recently, retail companies such as Domino’s, UPS, and Amazon are developing drones to make fast deliveries to their customers. Theoretically, this makes the customers happy as they receive the purchased item within minutes. Also, in terms of cost, drones significantly reduce the delivery cost compared with other traditional logistic networks.

When the number of drones has been increasing, severe accidents can appear in the sky, even in simple situations. The investigation of drone traffic safety and the intelligent transportation system’s development needs managing drones in the traffic flows. Thus, the drone-following models describing the one-by-one following the process of drones are the essential solutions. These models are based on the idea that each drone can be flown under the leading drone stimuli, which can be expressed by the function of safety distance or relative velocity of two drones.

Furthermore, undertaking a literature review of existing urban transport management systems and urban air transport management systems determines their effectiveness and limitations in monitoring and controlling vehicles.

The primary purpose of this research is to introduce the drone-following models and developed these models for integrating drones with smart city transport management systems.

The importance of the research

- Rapid technological development changes;
- Appearing new types of drones: commercial drones and delivering drones.
- We need innovative ideas on controlling, managing, and monitoring the drones in traffic flows in the urban air transportation system.
- Developing the drone-following models for integrating drones with smart city transport management system regarding new product and reducing cost.

The innovation of the research

- With the dramatic increase of the drones, the role of the manager in the air transport system is critical. Therefore, it is needed innovative ideas on how to manage these drones.
- Management based on the drone-following models.
• Developing methodology for integrating drones with smart city transport management system.

Technological motivation

• Technology allows us to collect, measure, evaluate, and interpret data with innovative devices.

• Technical supporting decisions developed to be tailored to fit developed countries.

• The transport management system necessitating efficient decision making supporting models.

Methodology

• The drones will be managed as an object. This approach will be made using drone-following models based on determining the drone acceleration depending on the differences in velocities and distances between the given drone and its leading drone.

• Developing models based on the Markov chain process.

• Using advanced cloud computing, the Internet to monitor and control drones in a real-time environment.

Thesis objectives

Within the given time frame and provided facilities, the following specific objectives are expected to be achieved:

• Developing the urban transport management system for integrating with drones. The system can be operated as a single system that monitors and controls drones in a real-time environment.

• Improvement of the drone-following models for managing and controlling drones in smart city traffic flow.

• Developing methodologies for integrating drone motion into urban air traffic.

In order to complete the dissertation, those main objectives are split partially as the followings:

i) To develop an intelligent total transport management system in smart cities, which used a vast distributed network of sensors.

ii) To provide the control layer that is a hierarchically organized software set.

iii) To improve the differential system equations of specialized UAV motion to determine the more accurate the landing areas with reducing environmental impacts.

iv) To create the simulation in Matlab environment for calculating the shortest landing orbit.
v) To develop models based on the principle that keeps a safe distance according to relative velocity for managing drones in urban traffic flow.

vi) To create the numerical simulation environment for demonstrating the safe distance between drones.

vii) To model the obstacles in the collision avoidance process in the path planning of the drones.

viii) To introduce some new constraints for improving the impact of avoidance capacity and task capability.

ix) To create a framework based on cloud devices and services such as computation, storage, and web services to monitor and control drones.

x) To test the proposed framework practically in real drones and environmental scenarios for validation purposes.

**Thesis organization**

This dissertation consists of five main chapters and is organized as follows:

*Chapter 1: Smart city total transport management system overview of references*

The first chapter presents the relevant literature survey of the four main parts to construct the thesis: smart city, total transport management, drones in a smart city, and drone management. The first part describes a smart city's concept, dimensions, a similar term, and architecture. The second part presents the smart city total transport management system, including a short overview of the concepts for transport management system in the smart city and a new transport management approach called contract-based and priority transport management. The opportunities, challenges for drones and their applications in smart cities are presented in the third part. The chapter ends with short reviews of drone management in smart cities.

*Chapter 2: Intelligent total transportation management system for future smart cities*

This chapter introduces a vision and a concept of managing the total transportation system by defining the concept, the methodologies, and the required sub-model developments for the future intelligent transportation related to smart cities. The solution to the total transport system's recommended general optimization problem requires a series of sub-models to be applied. Three examples of sub-model developments are also provided in this chapter as the results of this study demonstrate the possible further research that supports the implementation of the introduced new approach to total transportation management. Some comprehensive discussions are given in the last subsection.

*Chapter 3: Drone-following models in smart cities*

Two types of drone-following models are presented in this chapter. The first model is
used to keep safe velocity according to the related position of drones, while the second one describes the situation that a safe distance between two drones is maintained due to relative speeds. These models also represent the one-by-one following drone process in the traffic flow, which can be considered one kind of microscopic model in the transportation system. The main results of the numerical simulation experiments on the SD and the Markov models are provided in this chapter. Besides, discussion and analysis based on these results are also provided.

Chapter 4: Simulation and testing

This chapter includes four main parts. Based on the concept requirement given in the first part, the concept verification is presented in the second part. The third part provides simulation results and a discussion about the landing process of UAVs. The testing with real drones for evaluating the proposed framework is given in the last part of this chapter.

Chapter 5: Conclusions

A summary of the thesis contents and its contributions is given in the final chapter, followed by recommendations for future works.
Chapter 1

Smart city total transport management system overview of references

1.1 Smart city

1.1.1 Background

Recently the world has witnessed a rapid urbanization process, which has become a worldwide phenomenon. According to the United Nations Population Fund, 2010 marked the year when more than 50 percent of all people lived in urban areas, a figure expected to rise to 70 percent by 2050 (Fig 1.1). In Europe, 75 percent of the population already lives in urban areas, and the number is expected to reach 80 percent by 2025. The metropolitan regions’ importance as a global phenomenon is confirmed by the diffusion of megacities of more than 40 percent, 80 percent, 40 percent of people in Asia, Latin America, and Africa, respectively.

![Figure 1.1. Percentage of Population Living in Urban Areas by Region, 1950-2050 [1]](image)

Figure 1.1. Percentage of Population Living in Urban Areas by Region, 1950-2050 [1]

Today, most resources contributing to economic importance are consumed in cities, but they also contributed to the low environmental performance. Cities are responsible for significant shares of global greenhouse gas (GHG) emissions caused by consuming between 60 percent and 80 percent of the total energy. However, the energy is more consumed for electricity and transportation when the urban density is lower because of CO₂ emissions per capita drop with the increase of urban area density.
Besides, Gartner 2018, “Hype Cycle for IT in the Gulf Cooperation Council (GCC)”, identified smart city frameworks is one of six technologies that will achieve mainstream adoption in five to 10 years (Fig. 1.2) [2]. In addition, the Internet of Things (IoT), digital twins, and smart contracts should be focused on as these are overgrowing.

**Figure 1.2.** Hype cycle for IT in GCC, 2018 [2]

The process of urbanization has dramatically promoted the modern economy and increased the human ability to transform nature and bring significant increases to the standard of living. However, the process of accelerating urban development around the globe also brings many new problems, such as traffic jams, pollution, and pressure on natural resources; these problems are a unique set of challenges for cities in the 21st century [3]. To better solve these problems, the concept of “Smart City” was coined to refer to the process by which a city can make appropriate changes to meet those challenges.

These new challenges are required cities to find new ways to manage them. Several solutions that enable transportation linkages, mixed land uses, and high-quality urban services have been investigated and implemented with long-term positive effects on the economy. Many of the new approaches related to municipal facilities have been based on using technologies, including Information and Communication Technologies (ICT), on creating what some call “smart cities.” The smart city concept is far from being limited to the application of technologies to cities [4].

### 1.1.2 Definition

There are various definitions of a smart city, which have been given over the years. The original concept is the “information city”, and then evolving into an idea of the
information and communication technology (ICT) – centered smart city. There are six main dimensions of the concept: (1) a smart economy, (2) smart mobility, (3) a smart environment, (4) smart people, (5) smart living, and (6) smart governance [5], [6]. The smart city prefers to focus on human capital and education rather than the digital city or intelligent city.

The smart city concept's six dimensions were illustrated in the wheel by Boyd Cohen (Fig. 1.3) [7]. The author used to benchmark the world's major cities, which is well performed in a forward-looking way in these dimensions.

The concept and definition of smart cities have evolved gradually since first proposed in the nineties. The number of publications regarding this topic has considerably increased since 2010, after the appearance of smart city projects and support by the European Union (EU) [8]. A city's smartness can be as pure as a single function provided to a specific group of citizens or as complicated as an entire administration process, which represents the restructuring efforts of government procedure. However, there is still not a clear and consistent understanding of its meaning [9], [10], [11], [12].

The literature of the definitions of the smart city is given in table 1.1.

Table 1.1. The definitions of smart city in the literature

<table>
<thead>
<tr>
<th>Source</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>Lee et al. (2012) [5]</td>
<td>A smart city is defined as being “smart when investments in human and social capital and traditional (transport) and modern (ICT) communication infrastructure fuel</td>
</tr>
</tbody>
</table>
Chapter 1: Smart city total transport management system overview of references

<table>
<thead>
<tr>
<th>Author(s) and Year</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harrison et al. (2010) [13]</td>
<td>A smart city is as connecting the physical, IT, social, and business infrastructures to leverage the city's collective intelligence.</td>
</tr>
<tr>
<td>Al-Hader et al. (2009) [14]</td>
<td>The concept of smartness is represented by transmitting and receiving data using communication protocols to and from the network elements. The sending and receiving of data is the basis of monitoring and controlling the functional operational framework needed for the smart management of network assets.</td>
</tr>
<tr>
<td>Washburn et al. (2010) [15]</td>
<td>The use of smart computing technologies made the critical infrastructure components and services of a city – which include city administration, education, healthcare, public safety, real estate, transportation, and utilities – more intelligent, interconnected, and efficient.</td>
</tr>
<tr>
<td>Balakrishna (2012) [16]</td>
<td>A smart city can be identified along six main dimensions: Smart economy, smart people, smart governance, smart mobility, smart environment, and smart living.</td>
</tr>
<tr>
<td>Neirotti (2014) [17]</td>
<td>Smart cities are characterized by the pervasive use of Information and Communication Technologies (ICT), which, in various urban domains, help cities make better use of their resources.</td>
</tr>
<tr>
<td>Barrionuevo et al. (2012) [18]</td>
<td>Being a smart city means using all available technology and resources in an intelligent and coordinated manner to develop urban centers that are at once integrated, habitable, and sustainable.</td>
</tr>
<tr>
<td>Stamato et al. (2019) [19]</td>
<td>A smart city is based on intelligent exchanges of information that flow between its many different subsystems. This flow of information is analyzed and translated into citizen and commercial services. The city will act on this information flow to make its broader ecosystem more resource-efficient and sustainable.</td>
</tr>
<tr>
<td>Hall et al. (2000) [20]</td>
<td>A city that monitors and integrates conditions of all of its infrastructures (including transport, communication, water, power, buildings) can better optimize its resources, plan its preventive maintenance activities, and monitor security aspects while maximizing services to its citizens.</td>
</tr>
<tr>
<td>Ismagilova et al. (2019) [21]</td>
<td>Smart cities use an IS centric approach to the intelligent use of ICT within an interactive infrastructure to provide advanced and innovative services to their citizens, impacting the quality of life and sustainable management of natural resources.</td>
</tr>
<tr>
<td>Zhuhadar et al. (2017) [22]</td>
<td>Smart cities have the most excellent quality of life and economic well-being of their citizens.</td>
</tr>
<tr>
<td>Yeh (2017) [23]</td>
<td>A city is designated as smart if it balances economic, social, and environmental development and links it to democratic processes through a participatory government. SC involves implementing and deploying information and communication technology (ICT) infrastructures to support social and urban growth by improving the economy, citizens' involvement, and government efficiency.</td>
</tr>
<tr>
<td>Rana et al. (2019) [24]</td>
<td>Smart cities can be defined as a technologically advanced and modernized territory with a particular intellectual ability that deals with various social, technical, economic aspects of growth based on smart computing techniques to develop superior infrastructure constituents and services.</td>
</tr>
<tr>
<td>Hussain et al. (2015) [25]</td>
<td>Smart cities are using digital technologies to enhance the quality and performance of urban services.</td>
</tr>
<tr>
<td>Guo et al. (2017) [26]</td>
<td>A smart city is an urban development vision to securely integrate multiple ICT solutions to manage a city’s assets. It includes E-home, E-office, E-health, E-traffic.</td>
</tr>
</tbody>
</table>

Several definitions of smart cities are existed, which is often achieved by replacing the term "smart" with alternative words, for example, "intelligent" or "digital." The label "smart city" is a fuzzy concept and is used in ways that are not always consistent.

Furthermore, it can be noted that there is no general agreement about the term “smart cities” is that the name has been applied to two different kinds of domains. On the one hand,
it has been used in hard fields such as buildings, energy grids, natural resources, water management, waste management, mobility, and logistics, where ICT can play a decisive role in the systems’ functions [17]. On the other hand, the term has also been applied to soft domains such as education, culture, policy innovations, social inclusion, and government. The application of ICT is not usually decisive [4].

In essence, it can be summarized that there are two mainstreams in the present smart city discussion: 1) the ICT and technology-oriented approach, and 2) the people-oriented approach. This dimension of smart cities is ranged from hard infrastructures (i.e., transport, water, waste, and energy) to soft infrastructure and people (i.e., social and human capital, knowledge, inclusion, participation, social innovation, and equity) [27].

1.1.3 Similar term

There are terms analogous to “smart cities” that add to the cacophony of terms relating to this phenomenon. Possible confusion of a smart city's technology perspective comes from the top-down and company-driven actions taken for creating a smart city. However, it also comes from the confusion with other similar terms, such as a digital, intelligent, virtual, or ubiquitous city. These terms refer to more specific and less general levels of a city, so smart cities’ concepts include them.

For example, a digital city refers to “a connected community that combines broadband communications infrastructure to meet the needs of governments, citizens, and businesses” [28]. A digital city's final goal is to create an environment for information sharing, collaboration, interoperability, and seamless experiences anywhere in the city.

The notion of the “intelligent city” emerges at the crossing of the knowledge society with the digital city [29]. According to Komninos [30], intelligent cities make conscious efforts to use information technology to transform life and work. The label “intelligent” implies the ability to support learning, technological development, and innovation in cities. Every digital city is not necessarily intelligent, but every smart city has digital components. However, the “people” component is still not included in a smart city, as it is in a smart city.

A “ubiquitous city” is an extension of the digital city concept in terms of full accessibility. The word “ubiquitous” in this context is derived from “ubiquitous computing” [31]. It makes ubiquitous computing available to urban elements everywhere [32], [33]. Its characteristic is creating an environment where any citizen can get any service anywhere and anytime through any device. The ubiquitous city not only reproduces urban elements by visualizing them within virtual space, but it is also created by the inclusion of computer chips or sensors in urban parts [5].

The component that is missing in previous terms is that of people. These are the protagonists of a smart city, who shape it through continuous interactions. For this reason,
other names have often been associated with the concept of the smart city [4].

Creativity is recognized as a critical driver to a smart city, and thus people, education, learning, and knowledge have central importance to a smart city. A creative city is a humane city with multiple opportunities to exploit its human potential and lead a creative life. Social and human infrastructure, such as creative occupations and workforce, knowledge networks, voluntary organizations, crime-free environments, entertainment economy, is a central axis for city development.

A smart city is also a learning city, which improves the competitiveness of urban contexts in the global knowledge economy. A smart city is a centre of higher education and better-educated individuals. Similarly, a smart city is full of skilled workforces. The knowledge worker and the high tech knowledge sensitive industries migrate into highly liveable communities. The smartness of the workforce diverges between cities. Along with the inflow of smart people, new creative culture driven by them drives urban development.

The learning city provides a concept of being innovative, smart, skillful, creative, networked, connected, and competition has become critical ingredients of knowledge-based urban development [34].

1.1.4 Architecture

Due to the ambiguous definition of smart cities, their architecture is diverse without unified criteria. As a result, many smart city architectures can be found in the literature focusing on different aspects, such as technology, human-system interaction, and logic. Here we present a list of famous structures to understand a smart city's fundamental components better.

Komninos summarized the architecture for smart cities from the perspective of technology, in which a smart city is divided into three different layers [35]. First, the information storage layer stores all kinds of digital content. The second layer is the application that provides relevant services for users by organizing digital content. The user interface is the third layer, which exposes this functionality through various web applications by using maps, 3D images, text, charts, and other interface tools. There is another administration layer responding to providing proper access right for users to digital content.

Al-Hader et al. proposed a five-level pyramid architecture for smart cities from a human-system interaction perspective [14]. The smart infrastructure is the bottom layer that includes electronics, water, natural gas, fire protection, electronic communications, and network. The second layer is the smart database resource layer, which contains spatial databases, database servers, and complete data resources. The smart building management systems is the third layer that consists of automotive control networks. The fourth layer is the smart interface layer containing a common operational platform, integrated web services,
etc. The top layer of the architecture is a smart city layer that combines and integrates the underlying four layers.

Anthopoulos and Fitsilis proposed a five-layer generic smart city architecture [36]. The stakeholder layer describes the potential users, including citizens, user groups, and servants. The service layer contains releasing information to the public and providing information to the citizens and businesses through application software. The business layer defines the rules and policies to allow the smart city to understand how to operate. The infrastructure layer includes the first network and other access points. The information layer is designed to produce and store data correctly.

Luca et al. proposed a smart city architecture in which they divided smart cities into two parts: Knowledge Processors (KPs) and Semantic Information Brokers (SIBs) [37]. The information is stored in the SIBs, which serve as servers for KPs. Once KPs are connected to SIBs, operations are triggered by the Smart Space Access Protocol (SSAP). Through SSAP operations, KPs can manage sessions and transactions between producers and consumers.

Besides, Harrison et al. believe that a smart city model should predict the behavior of individuals, communities, and even the entire city [13]. Although people can focus on technical progress alone, it is difficult to determine what these technologies bring to a city’s finances and living. The proposed framework intends to take the data from the infrastructure and resident groups and establish a useful model to predict future behavior.

Moreover, Lugaric et al. proposed test architecture for the smart city architecture from the platform's perspective for emergent phenomena [38]. This architecture contains three parts: the physical network, the communications infrastructure, and the information flow. Conceptually, the system brings data exchange results and processing through the simulating communications infrastructure to the physical system in an integrated way. The results are forwarded to the data centre so that a network component can react quickly to rapid equilibrium data throughout the system. This is an iterative process to ensure the entire system’s dynamic equilibrium.

Chourabi et al. proposed a framework from a systems perspective to provide a comprehensive understanding of the smart city [10]. They divide influencing factors into two groups. External factors include the governance, people and communities, the natural environment, infrastructure, and economy. Internal factors are technology, organization, and related policies.

Al-Hader and Rodzi divide smart cities into two significant parts from monitoring and development [39]. The first layer is the monitoring layer providing surveying and data communication updates. Some devices are needed for surveying and data communication, such as ground-penetrating radar, cable locators, programmable logic controllers, and
communication modems. The second layer is the development layer, which contains geospatial applications and the network data model. Geospatial applications include the network analysis model, facility sitting model, and the maintenance and operational model. Network data models for electricity, communication, water, gas, sewers, and storm provisions are included.

In reference [40], the authors proposed architecture of a smart city consisting of six layers, such as Events, Domain Services, Support, Storage and Vitalization, Data Transportation, and Data Acquisition, all aspects of a smart city. With the set of critical success factors, this proposed smart city architecture focuses on the right areas of security and administration in a smart city’s infrastructure. This architecture also offers further community insight and a reference to current critical thinking in affecting a thriving smart city.

Another smart city architecture was proposed to enable the integration and implementation of a set of the different and heterogeneous scenarios for the Internet of Thing/Internet of Everything (IoT/IoE) paradigm in mobility and transport, which related to safety-critical aspects [41]. A complete experiment provided a smart modality to manage the dynamic management of a one-way road segment, including dynamic signage and corresponding synchronizations.

The smart city will provide a broader technology context within which connected and autonomous vehicles will operate. One aspect of the smart city will be the use of the Internet of things (IoT). As connected and autonomous vehicles have emerged, interest has grown substantially in the IoT. It is viewed as the next generation of the Internet, and it is predicted that it will go beyond connecting computers and smartphones to joining a multitude of different devices, including refrigerators, air conditioning systems, homes, offices, retail systems, and financial systems [42].

1.2 Smart city total transportation management system

1.2.1 Background

While giving a better service to the inhabitants by fulfilling personal demands in an easy to use, flexible, and cost-efficient way, smart transport expects to reduce pollution and the related health risks to improve urban areas' quality of life [43]. The current traffic situation and operating grade have to be captured to enable predictions on future conditions to hedge decisions made by actors and decision engines to allow active traffic management.

The significant issue while implementing those kinds of systems is providing a reasonable basis for a decision. The best foundation for decisions is knowing about the current state of the overall system. Therefore, the autonomic transport management systems
(ATMS) have an essential aspect: data acquisition and the networks transporting the information about the field's current situation. It was evident that the reliability of data is essential and an essential requirement for the ATMS. Establishing an autonomic system gives some significant advantages in increasing the safety of the overall operations.

Traffic planning is powered by online timetables calculating the optimal way to use public transport regarding time and costs. The travel planner can use a typical graph for all requests and generate lookup tables to guarantee short answer times. Since the upcoming megatrends smart cities, personalized medicine, and personalized production by industry 4.0, the ATMS used to establish smart transportation that solves a wide range of new transport requirements. Moreover, smart transit provides personalized mobility and goods transportation.

However, users prefer to share content than to interconnect themselves to remote devices. Thus, the trend of the imminent possibility of the future smart cities will affect enhancing services that will be given and employed [44].

Contract-based and priority transportation management approaches are relatively new ones. Consequently, very little academic literature deals directly with such managing types applied in city transport. In the only relevant research paper on the topic, [45] presented a case study based on blockchains. This research is a case study for blockchain-based real-time ride-sharing services. The newly developed parallel transportation management systems are built based on blockchain, considered secure and trusted architectures.

In the level of priority transportation management, an adaptive control algorithm for pre-signals tailored to real-time private and public transportation demands was developed and established the necessary infrastructure to operate an adaptive pre-signal [46]. They suggested that buses' travel times in cities can be reduced by using the pre-signal approach to public transport. The primary purpose of this method is to allow buses to jump the car queues upstream of the intersection while cars can still use all the lanes at the primary signal to utilize the capacity of the intersection fully. In this way, the bus delays are reduced, while the intersection capacity is minimized.

The operation buses on signal-controlled using special lanes were also evaluated [47]. The results showed that bus lanes with intermittent priority did not significantly reduce street capacity but increased the average traffic density at which the demand is served, and therefore, increased traffic delay. Thus, they proposed the homogeneous system, which is estimated travel and arrival times reduction.

The above literature suggests that the real-time dynamic roadway routing problem on instrumented networks is unique. Communication between drivers and system managers (or service providers) is needed to promote optimal solutions. The real-time information is necessary to choose an effective route. Although drivers can aid with routing decisions, they
are not capable of handling significant data needs. They must rely on the knowledge network to gather needed information from the system. Thus, it is necessary to establish the contract between demand (drivers) and supply-side (service providers) because both attain efficient capacity allocation network-wide and satisfy each driver’s routing needs and preferences.

### 1.2.2 Supporting services

#### 1.2.2.1 Internet of Thing devices

Everything in a smart city is tied together by the Internet of things (IoT), one of the essential components of any smart city. The smart cities work based on the data created by sensor networks that gather and share useful information. The cities can be managed in real-time with this information and minimize unintended consequences with sufficient integration data. Because dependence on sensors grows, it is the need for sensors to be reliable and that the systems to which sensors are connected will be able to put up with the inevitable failures.

The transfer usable could be challenged since cities improve from millions to billions and the trillions of devices. It is noticed that the need for a user-selected can be fulfilled nearby, by which the convenience will be presented without tying up some of the bandwidth of the carrier data networks.

Using data and sensor technologies to present insight is at the core of what it means to be an intelligent transportation system (ITS). However, just having data is not enough; data points themselves are merely information. It is good to have, but hardly useful by itself. So, a transport system that can connect data points can build a picture of its users. A knowledgeable transport system combines enough data to make unique practices better. Because more and more objects become joined through the Internet of Things (IoT), so they accumulate more data that can be used to inform planning tailored to individuals and populaces. It is estimated that 50 billion objects will be connected by 2020 for an added economic value of US$19 billion [48], [49].

#### 1.2.2.2 Information and communication technology – cooperating transportation

Information and Communication Technology (ICT) platforms became the ground floor of the Smart City foundation. Thanks to their capability to offer advanced ITS services, environmental and energy monitoring, building management, healthcare, public safety and security, remote working, and e-commerce domains [50]. Therefore, ICT plays a vital role by interconnecting all the actors of a Smart City [51] and supporting seamless, everywhere services [52].

Advances in ICT enable the transportation community to anticipate dramatic improvements concerning more efficient, environmentally friendly, and safe traffic
management. One potential traffic management system is a cooperative system with methodological concerns following the development of such systems [53]. The cooperative traffic models were used as a framework to simulate. The simulation results have shown: i) with a high amount of cooperative vehicle, only fewer lane changes occur because the cars are organized around an equilibrium state; ii) the defined cooperative strategy presents a higher impact than adaptive cruise control (ACC) for low penetration rates; iii) the transition between congested and free flow states appears smoother with the cooperative strategy than the ACC system; iv) the trust layer reinforces the homogenization effect and this approach provides the best performances.

Furthermore, Information-Centric Networking (ICN) is a concept that has risen as a hopeful candidate for the design of the future Internet [54]. The ICN provides the use of in-network caching and multicast mechanisms by indexing information at the network layer. Therefore, the facilitation is efficient, and the delivery of the data to the users is opportune. They provided seven ICN approaches to provide a unified view of the alternative proposals by defining a set of core ICN functionalities, e.g., name resolution and data routing, mobility, and security.

However, even though the current Internet architecture corroborates the communication among all of these technologies, it appears a set of conditions related to the decoupling of materials from the knowledge of their location, security aspects, and services scalability.

The future Internet can contribute solutions to many requests that the transport management system has to face. However, this system can give a unique experimental environment for probing future Internet architectures' advantages and disadvantages in various application domains.

Each of these technologies works together to make a transport system even more improvement. Because the world’s population grows and more people move into urban areas, the need for a more improved transport system will increase to make the best use of available sources.

In our terminology, the non-connected vehicles are the non-cooperative vehicles. The connected ones are cooperating vehicles. The cooperation might be realized on a regional basis (as is shown in Fig. 1.4) or globally when the transport management is harmonized from the control center. Generally, the cooperating vehicles publish and use their vehicle performance, travel goal, and (GPS) positioning data.
1.2.3 The transportation management system

1.2.3.1 System description

The developing traffic-managing system (TMS) is that net-centric uses the military-strategic command concept in the highest level called C4ISR (Command, Control, Communications, Computers and Intelligence, Surveillance, and Reconnaissance). The system uses a vast distributed network of sensors for surveillance and recognition of the different cooperating and non-cooperating vehicles, extreme traffic situations (Fig. 1.5). The sensors are mechanical, optical, electromagnetic, and biological sensors. Extensive wireless communication transfers the sensed data to the system center (working as a command point). The intelligent system generates controls for avoiding extreme and dangerous situations, managing the more useful, greener traffic, and supporting the contracting vehicles and priority traffic. The controls are realized through the traffic controls (control lights, control signalization, and actuators integrated into the infrastructure). There is no principal difference in cases when the vehicles are moving autonomously or driver-controlled. A driver screen may show the position of the other vehicles, obstacles around the vehicle.
Figure 1.5. The traffic-managing system architecture (NCV - non-cooperative vehicle, CV - cooperative vehicle)

The system has three layers: physical, info-communication, and control generation. The physical part including all the vehicles, the available infrastructure, the sensor network, and traffic controls integrated into the infrastructure. The infrastructure takes part in the system entirely. That means, for example, a series of signal lights are built into the line dividing the lanes. The communication is based on the wireless system, partly on using the Internet. The control layer is a hierarchically organized software set. It is used to recognize and classify vehicles, traffic situation awareness, conflict detection, and resolution, including the sense and avoidance of obstacles, other vehicles, people, etc. The system uses the simulation evaluation of the systems and developing the required traffic and vehicle controls.

1.2.3.2 Concept of operation

The system is working as a single system, while it deals with four different classes of tasks.

Handling the non-cooperative vehicles.

The system collects all the available and measured information about the traffic infrastructure condition, traffic intensity, complexity, and all the vehicles regardless of whether they are cooperative or non-cooperative vehicles. Here, vehicles mean all the types of vehicles, including the road or railway, water transport vehicles, that may be individual, personal vehicles, or vehicles of mass transport systems. This information is the primary input (data of primary surveillance).
Chapter 1: Smart city total transport management system overview of references

The system identifies the non-cooperative vehicles and classifies them depending on their size, mass, predicted performances (as acceleration, turning radius), and predictable goal of trips. The optical, infrared, ultrasonic, radar sensors built into the traffic infrastructure, into the road, lampposts, traffic lights, nearby buildings, etc., as the first surveillance elements provide the inputs. The system applies this information in a short time forecast of the traffic intensity and complexity and information provided by the cooperating vehicles. The goal is to evaluate where the traffic jam might appear and which direction will increase the traffic. With managing such traffic situations and traffic jams, the developing system will support even non-cooperative vehicles' drivers. For example, the four lanes road might be dynamically controlled: two lanes supporting the traffic into the more intensive traffic direction and one, only, for the other direction, while one lane will dedicate to the contract-based and priority traffic.

Traffic management based on the cooperative vehicle information.

In air traffic management, the aircraft have transponders that reply to each interrogation signal by transmitting a response containing encoded data identifying the given aircraft. This approach is secondary surveillance. In a smart city, net-centric transport managing system, the cooperating vehicles continually provide information about the type of vehicle, motion condition (velocity, changing in velocity, direction, etc.), and actual (GPS) position. This method is simple, first-level cooperation. The connected vehicles provide this information to the nearby vehicles, too, and harmonize their motions.

The second level of cooperation is characterized by sending information about the goal and target (geographical positions) of trips to the traffic-managing center. The vehicles applying the third level cooperation send data to the traffic managing center about the nearby vehicles, infrastructure, traffic situations, etc.

The inputs from primary and secondary surveillance allow introducing total traffic management. Of course, traffic management may support cooperating vehicles directly.

Contract-based traffic management.

Nowadays, many researchers, cities are working on developing exceptional support the smarter transport. These activities deal with developing the information systems for mass transport, supporting the mode choices, developing optimal transport modal systems, developing the control for connected vehicles, organization, and management of information control for groups of vehicles, supporting the car-sharing, information on parking availability, autonomous control of vehicles, etc.

The contract-based traffic management (CTM) introduces a new service opening new market segments for people who would like to reduce their travel time. That possible services may start from the dedicated parking areas at P+R systems, through the special small buses
transport from the parking place to the city business centers, drop off car system. When the driver stops the car anywhere in the city and the traffic-managing system will park it at the nearest parking place. Later the system will transfer the car to the driver defined place. The system may use the remote control, or the car may have the required information from the transport-managing system and may pay autonomously.

The CTM is a supporting service that brings together drivers and service providers (SPs) of transportation services to increase both driver’s and SP’s operation efficiency. This service benefits drivers because they are the first people who have essential information, thereby increasing their satisfaction and obtaining their goals. SPs may benefit from contract-based by gaining profit from this contract, allowing for efficient operation increasing supply competition.

The CTM model uses goals rather than positions to achieve an efficient reallocation of network-capacity over time and space without seriously violating any individual driver’s preferences for routing, departure, and arrival time. The goal is to achieve more efficient metering of low roadway capacity by steering drivers toward paths that will satisfy their individual needs while also improving overall network execution. The right solution derived from CTM will result in drivers being satisfied that their needs and preferences were achieved by their resultant trip itinerary and the SPs being satisfied with the improved system-wide performance.

Figure 1.6 presents the CTM for roadway routing. It is proposed that if drivers and SPs pursue a collaborative, problem-solving approach to negotiate trip planning, better results will be realized on both sides. Drivers will be able to follow a trip itinerary that better meets their travel objectives.

![Diagram](image_url)

**Figure 1.6.** Conceptual view of contract-based transport management

The SP receives traffic data and driver information from the network managers and, in
return, provides the network managers with information on current and anticipated roadway use gathered from its driver base. Drivers rely on the SP for giving traffic advisories and seek to negotiate trip plans. However, since the SP has a cooperative arrangement with the system, and the system-side traffic management objectives may differ from those of the individual driver, there is always an element of distrust among drivers.

The top-level of contract-based traffic may include a “semi priority” system. By using this principle, contract-based vehicles may use, for example, bus lane opening provisionally (for a short time) if it was not disturbing the bus transport. In such cases, the drivers will have information from the transport-managing centers about the recommended shortest ways and possible shorting the traveling time. At the same time, they will see unique commanding signals on the road (appearing for a short time and the given vehicles).

The contract-based transport may work based on a first come – first served without disturbing the existing transport concept and system, and even – in case of extra service – it may apply as the personalized taxi.

**Priority transport management.**

The developing transport management system uses all the available information about the transport infrastructure, vehicles, traffic complexity, appeared in traffic situations and may simulate the transport and determine the future optimal, more efficient transportation. Therefore, it may manage priority transport, too.

Generally, the transport-managing system uses passive methods for monitoring the non-cooperative transport, semi-active methods (for partly controlling) the cooperating transport, active method for supporting the contract-based transportation, and proactive approach for managing with priority transport.

The priority transport (as police, fire machines, ambulances, traveling the protected persons, etc.) might be supported by opening them the free lanes, freeways by the total transport-managing system.

**1.2.3.3 Benefits**

At a conceptual level, the CTM and priority transport management (PTM) can be regarded as operational ways of achieving users’ and service providers’ satisfaction. They represent a possible means by which all the operators can share a unique and impartial view of each other’s priorities. Thus, they ensure a standard translation and representation of the performance targets achieved by the overall transport chain.

At a second more operational level, CTM unequivocally identifies the transfer of responsibility areas between partners. At the same time, they organize a way of controlling doubtfully and monitoring disruptions. Measurement of compliance with CTM established
during the negotiation process could represent a new and reliable metric for assessing a provided service quality.

CTM and PTM concepts are expected to directly bring the following substantial benefits to the transport management system:

Firstly, more punctuality at the destination: The CTM and PTM are designed to achieve an ultimate goal: arrival on time at the destination places. Through the CTM and PTM, the users, drivers, and service providers share the same goal for the vehicles represented by an agreed contract. The synergy between the service providers and users is thus reinforced. Users will reduce delay-related costs and optimize their cars. Service providers will be able to optimize their operations and maximize profits. Even though the efficiency design target identified by IoT and ICT services applies to on-time, a strong correlation between punctuality at departure and the destination exists. It would be interesting to evaluate this correlation during the assessment process, especially in the real-time process.

Secondly, improved predictability: The CTM and PTM are designed taking into account vehicle technical constraints, with built-in scope for disruption management aiming to achieve the ultimate target of the objectives, which is arriving on time at the destination. Each operator knows it is part of the contract, i.e., those contracts it must fulfill. Drivers will build on their programs, as predictability will be improved, and they should get a better payoff from their fleet. The management centers will also be able to rely on their schedules. Optimization of their operations will be possible, which will enhance the quality of service delivered to users and improve the infrastructure pay-off.

Thirdly, reduced overall costs: Drivers will be able to place more trust in scheduling, which will allow them to mitigate delay-related costs and thus improve the operational costs of vehicles. Providers will get a better approach and better scheduling of their operations. They will, therefore, be able to dedicate the right number of resources to service equipment, which will lead to cost-efficiency.

Finally, reduced environmental impacts: like cost reductions, environmental benefits are mostly linked to the better use of resources (e.g., real-time information, capacities of traffic system) and improved predictability. Drivers will state their preferred routes by economic business models, thus minimizing fuel/energy consumption and improving the “distance/fuel consumption” ratio.

1.3 Drones in smart city

1.3.1 Background

Drones were initially only utilized for military applications. However, they have
recently been widely used in civil applications in many domains such as disaster management [55], delivery good [56] and information [57], search operations [58], surveillance [59], managing wildfire [60], relay for ad hoc networks [61], wind estimation [62], civil security [63], agricultural and remote sensing [64], and traffic monitoring [65].

The UAV market was achieved USD 19.3 billion in 2019 and is expected to reach USD 45.8 billion by 2025 [66]. The growing use of drones for various purposes, such as monitoring, surveying and mapping, precision agriculture, aerial remote sensing, and product delivery, contributes to the growth of the UAV market. However, the most significant factors projected to drive the UAV market's growth are the rise in the military UAVs application by defense forces worldwide.

Based on the region, the UAV market has been segmented into North America, Europe, Asia Pacific, the Middle East, Latin America, and Africa. In 2019, the largest market for UAV was North America, where it is estimated to be continuously the largest market in the next few years (see Fig. 1.7). The use of drones for border and maritime surveillance activities has been increasing in countries like the US and Canada, which drives the UAV market's growth in North America.

![Figure 1.7. The UAV market by region (USD billion) [66].](image)

Besides, business drones' requirement is being directed by such circumstances as spreading industry use events, affordable hardware and assistance, high definition (HD) aerial imaging and sensing, integrated data intelligence. According to Tractica, it is expected that the commercial drone market will continue overgrowing over the next few years while giving vital chances to several industry cooperators, reaching a global income of $13.7 billion by 2025 (see Fig. 1.8) [67].

The business drone market is concentrating on core solutions where drones excel. The capacity to illustrate such useful solutions is the essential determinant of which corporations can obtain long-term leadership and which may fall by the wayside.
Moreover, one of the most evolving areas of drones is their involvement in smart cities nowadays. A smart city is an urban region that is highly advanced in overall infrastructure, sustainable real estate, communications, and market viability. A smart city's benefits apply to everyone, including citizens, businesses, government, and the environment.

Drones are flexible and fast mobile platforms that can be used for many applications in smart cities, such as traffic and crowd monitoring, environmental monitoring, civil security, merchandise delivery. Unlike human-crewed planes, drones can be more cost-effective. They are more flexible and can operate in various locations and situations, including challenging or posing high risks for humans. They can also fly very close to target objects, which allows for maximum measurement accuracy and better-targeted actions. These features provide advantages if drones are used for smart city applications.

### 1.3.2 Opportunities for drones and its applications in smart cities

The challenges and opportunities for drones in smart cities were discussed [68], [69], [70]. Drones can play a vital role in a smart city environment, bringing innovative ideas to life and accelerating economic development. Drones can replace the current practices and have the potential to introduce and create new opportunities that were previously not possible.

**Package Delivery**

Smart City technology often starts with providing product delivery services more efficiently and precisely at the doorstep to the residents. In this context, drones can carry not even a heavy payload but can deliver it autonomously and quickly to the clients [56].

The authors in references [71], [72] proposed a cooperative truck-and drone delivery system, which integrates drones with truck-based delivery operations by the innovation of the customer waiting time. This system will enhance the efficiency of a conventional
delivery system and more sensitivity and higher computing efficiency than the heuristic approach.

Several companies, including Amazon, Alibaba, and Google, have been run practical trials to investigate drones' use for parcel delivery [73]. DHL Parcel has also started testing a drone delivery service to deliver medications to one of Germany’s North Sea islands [74], [75]. In these practices, the drone flew autonomously but still had to be continuously tracked. It is expected that drones will be able to operate autonomously and safely in urban environments thanks to rapidly advanced technologies in obstacle detection and avoidance.

UPS tested successful automatic drone delivery in Florida [76] from a company electric van's roof on October 2, 2019. Amazon created a vast competition to legalize its drone delivery project named “Prime Air” by getting a patent from the U.S. Patent and Trademark Office to drop packages from drones into consumers via parachutes.

**Traffic Monitoring**

Real-time traffic monitoring and analysis is also a potential application in which drones can replace intensive labor and complicated observational infrastructure. Traffic monitoring via drone presents a new perspective that could help optimize road traffic systems by overcoming the limitations of traditional monitoring methods because of its mobility and capability to cover a large area.

The increasing traffic volume in cities requires a state-of-the-art intelligent traffic monitoring system by providing accurate information about traffic flow and road accidents to reduce traffic congestion [77]. Roads and Transport Authority (Dubai) also decided to deploy drones for traffic monitoring and road accidents in Dubai city during the second quarter of 2017 [78]. In Lyon, France, a company named “Elistair Tethered” offers a real-time traffic flow at rush hours by using the “Data From Sky” traffic analyzer to process information about different types of vehicles [79].

Another application of drones in an urban area used a swarm of 10 drones in Athens to record traffic streams in a congested area [65]. A complete dataset can allow an in-depth investigation of critical traffic phenomena. This experience will create a unique observatory of traffic congestion that researchers can use to develop and test their models.

**Traffic patrolling**

Regarding the transport management system, drones can cooperate with ground vehicles to complete multiple traffic patrolling tasks such as road patrolling [80], [81], [82], [83], traffic monitoring [84], [85], and using a drone to enhance efficiency [86], [87]. This approach can be performed by a framework that the vehicle released and recovered the drone while the vehicle performs mission visits. This method was also useful for the long-distance driving ability of vehicles and the high mobility and wireless remote-control aspects of
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drones [88]. This approach also creates a new problem of cooperating between a drone and a vehicle during the patrol tasks.

However, this cooperation is a complex optimization problem that involves many challenges in vehicles and drones' path planning. For example, the traffic patrolling routing problem with drones (TPRP-D) was oriented toward complex tasks [81], [89]. In these practices, the vehicle needs to stay and wait for the drone to complete its operation.

**Policing**

As one part of smart cities, smart police systems shifting from traditional will be equipped with the latest technologies to solve the city's critical and complex security issues. That police system can use a drone as the latest and beneficial device in high-risk missions and trace burglary suspects.

“Devon and Cornwall police forces” are the first dedicated police drone unit in the U.K., began testing the drone with Dorset police in November 2015, and the unit has now fully established with permanent full-time staff [90]. More than a quarter of the 43 forces in England and Wales are now considering introducing drones for criminal investigations [91]. In China, at least 1000 drones have been put into operation by police to help track suspects and locate opium farms until 2017 [92].

**Large-scale disaster management**

Situation and emergency response management in large-scale disasters such as earthquakes, floods, volcanos, fires in forests or large infrastructures, and terrorist attacks are challenging. In such circumstances, drones can be utilized effectively [93], [94]. They can be used as flexible, reliable, and safe tools to monitor and provide real-time information about the current situation. There were no other than drones to track the location of these disasters [95]. Drones can be allocated to different places to get more real-time information to analyze better and assess the situation. UAVs can also perform some actions to control the case in some disasters [96]. Besides, drones can launch alternative communication systems to substitute the damaged ones for emergency use [97]. Furthermore, drones can help locate survivors, transport medical supplies and equipment, and may even function as ambulances to transfer the injured.

**Firefighting and rescue operation**

Drones are one of the most promising technologies to improve firefighting response and conduct rescue operations safer, faster, and more efficient than traditional human-crewed held services. Because drones can fly autonomously, can access hard-to-reach areas, and perform data-gathering tasks impossible for humans [98]. The emergency management organization of Dubai [96], and the firefighting department of New York [99] introduced drone applications for fire-fighting and rescue operations.
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*Drone-aided wireless communications*

The availability of reliable and scalable wireless connections is essential in providing many successful interactive services in smart cities [100]. Drones equipped with wireless communication support devices can be deployed to provide primary or additional coverage for different smart city services [101]. Also, drones can assist in offering wireless connectivity between distant areas to continue providing interactive smart city services [102].

1.3.3 Challenges for drones in smart cities

Despite the significant advantages of drones discussed above, several serious challenges need to be highlighted [68], [69], [70].

*Safety*

Drones have been applying for various civilian applications, which raises serious safety issues due to enormous damage caused by the crashing of drones. The technical malfunction and inadequate maintenance of equipment, mid-air collisions, and its operation misuse maybe are the reasons for the drone accident [103]. Other aspects concerning drones falling in public areas are weather conditions such as turbulence, lightning, and battery life lift capacity. Furthermore, there is also a severe risk of airborne collisions because of sharing airspace with other commercial planes in urban areas. If the trajectory of the drone is outside the protected area, it is considered to be safe. Whereas, if the path goes within the protected area, it needs to be detected and brought down outside of the protected zone [69].

*Security*

The technology inside of drones is the most significant security concerns of using a commercial or civilian drone. Because these technologies could be hacked or destroyed by attackers, which can disrupt services [69], a drone's navigation system based on GPS can be easily spoofed because of the open nature of unencrypted and unauthenticated GPS signals [104]. A drone's communication system based on Wi-Fi Jamming is a possible attack, which could cause the loss of control consequences seriously for nearby people.

The author in [105] has designed and developed a secure communication protocol for UAVs. This study presented and discussed different communication protocols, such as UranusLink, UAHCAN, MAVLink. The authors also provided their critical analysis of the structure and working mechanism of these protocols. Based on these protocols' pros and cons, the authors have identified that MAVLink is the most widely used protocol for UAVs communication. However, MAVLink lacks a security mechanism to encrypt messages and can have severe consequences, even if it provides better communication than others. Therefore, there is a need for a secure communication protocol to ensure the required security standard sets for communication between drones and the ground control station.
(GCS). Development of the secure communication protocol with the help of an artificial intelligence agent will get input from a GCS and measure the mission's criticality and application security accordingly to obtain both efficiency and security simultaneously.

Privacy

Privacy is one of the significant concerns related to the use of commercial drones. Drones hold a distinctive range of agile access methods that differentiate them from other privacy infiltrating gadgets. Drones carry high-precision cameras, sensors, and recorders that can be remotely controlled to perform surveillance tasks precisely. However, they bring with them concerns about privacy and personal data protection. Malicious software can be installed on a drone to harvest personal data and track and profile individuals using wireless localization techniques.

Cybersecurity

Cybersecurity refers to technologies, processes, and practices that protect devices, systems, computers, networks, programs, and data from malicious attacks, damages, or unauthorized access [106], [107]. Moreover, cybersecurity is known as information technology security or electronic information security. Furthermore, cybersecurity is related to protecting networks, devices, and data from unauthorized access, cyber-threats, or illegal use to guarantee confidentiality, integrity, and information availability [108]. There are several cybersecurity elements; for example, network security, application security, data security, information security, operational security, end-user education, and disaster recovery/business continuity planning. Although drones offer many benefits, they also face many cyber-threats and cyber-attacks. These consist of global position system jamming and spoofing, Wi-Fi security issues, sensor security concerns, Bluetooth security UAV network security, malicious software/hardware, and privacy leak of photos.

Drone operation areas in smart cities

According to the Federal Aviation Administration (FAA), operating drones are classes of activities or specific operations that are usually prohibited for commercial drone applications. However, the airspace and equipment approval can be achieved depending on who you are and how you want to fly. This procedure is more straightforward and more flexible for operating commercial drones. Besides, a “phased-in approach” has been carried out to integrate drones with a national airspace system. Moreover, the drones can be used for specific applications in restriction areas, such as atmospheric research.

In the aviation industry, especially the air traffic control, the increasing number of drones poses new challenges, which endanger the flights operated in the airspaces. Therefore, a unique operating aspect has to be created to protect regular flights regarding safety and fulfillment. Sandor proposed UAV traffic management systems (UTM) that support the flight's accomplishment for managing the total air traffic efficiently [109]. Such
a system can keep the separation between the UAVs and the conventional aircraft and the order in the traffic flow in the very low-level airspace segments. This system is operated independently of the air traffic management systems due to the data coming to this system.

In recent years the interest in drones has increased among commercial entities and recreational flyers. Therefore, there is a need to ensure safety for people, properties, and other airspace users like helicopters during drone operations. The authors in [110] evaluated the height limit for drone operations in urban airspace with the available technology enablers, categories of drones, and the application's purpose. Then they introduced drone lanes/tunnels or routes concepts, which are enabled for safe drone operation in urban areas.

1.4 Drone management

In this section, several scientific reports regarding the management of drones in smart cities are reviewed. However, the operation of a drone must follow the International Civil Aviation Organization (ICAO) [111], [112].

According to the Federal Aviation Administration (FAA), operating drones are classes of activities or specific operations that are usually prohibited for commercial drone applications. However, the airspace and equipment approval can be achieved depending on who you are and how you want to fly. This procedure is more straightforward and more flexible for operating commercial drones. Besides, a “phased-in approach” has been carried out to integrate drones with a national airspace system. Moreover, the drones can be used for specific applications in restriction areas, for example, atmospheric research.

All drones must be managed and controlled as aircraft according to the FAA regulations [69], which are categorized as the following: 1) Model Aircraft operators; 2) Those holding 333 Exemptions; 3) Public Operators; 4) Public operators can choose to operate under Part 107.

In European countries, while the Joint Aviation Authorities (JAS) is responsible for operations and licensing, the European Aviation Safety Agency (EASA) is responsible for regulating airworthiness and maintenance issues [113], [114], [115], [116].

In the aviation industry, especially the air traffic control, the increasing number of drones poses new challenges, which endanger the flights operated in the airspaces. Therefore, a unique operating aspect has to be created to protect regular flights regarding safety and fulfillment. Sandor proposed the UTM that supports the flight's accomplishment for managing the total air traffic efficiently [109]. Such a system can be used to keep the separation between the UAVs and the conventional aircraft and the order in the traffic flow in the very low-level airspace segments. This system is operated independently of the ATM due to the data coming to this system.
Based on the scientific results obtained from the creation of an extensive road network model, the authors in [117] proposed a new air traffic model, a powerful new tool in air traffic network modeling and has all the specialties. Such a system is considered an extensive stochastic dynamic system that would describe the processes of land traffic. Because the traffic network is very complex and characterized by different rules, geometric data, and seasonality, the authors developed a new air traffic system model. The development of a new model became possible, which leads to non-linear systems in mathematics. The control point of view was shown by applying the Lyapunov function method that in a domain bounded by an arbitrary closed curve, the autonomous system is asymptotically stable. The authors used static route parameters to achieve minimized delays in the field of air traffic control. The model was used in this research is a macroscopic model and based on a linear time-invariant homogeneous differential equation system. This model's optimization objective is the minimization of total delay; for example, the landing of the aircraft should take place in the shortest time utilizing the appropriate choice of control parameters. Thus, the solution of significant network problems and the application of new control options are obtained. For instance, it would sometimes occur that two aircrafts flying close to each other along the same route want to travel at the same altitude. In this case, the air traffic controller who wants to keep the required separation offers level change primarily. If it is agreed, which is usually accurate, there is no need for speed restriction. If the other flight levels or altitudes are occupied, the crew may be asked to maintain a certain speed.

A case of studies regarding drones' legal use is presented in [118], which has its perspective in the Slovak Republic. Generally, the increase in the use of drones will generate a new competitive environment for operating companies and cooperative enterprises. However, the recent legislation regarding drones’ applications does not satisfy this challenge because of drones' flexible legal use, such as monitoring of employees and delivering of documents.

The highlights of drone regulations are presented in reference [103], which includes a global overview and primary criteria discussion. Based on the data utilized and analysis techniques applied, the author provided the perspective of past, present, and future trends of drone regulations' status. In this way, privacy, data protection, and public safety were investigated and discussed in the legal frameworks for operating drones.

Another scientific report provided a summary of drones’ applications for managing transportation [119]. The authors focused on the theoretical and practice of Unmanned Aircraft System (UAS) in transportation and traffic engineering. This survey indicated that drones in transport must guarantee safety and effectiveness and energy efficiency aspects.

Syd Ali [120] proposed an architectural framework for UTM based on the UTM system's definition and its six main envisioned functionalities, and Communication, Navigation, and Surveillance (CNS) technologies supporting the UTM system. The UTM
system is defined as a research software application prototype that aims to safely and efficiently enable UAS operations in the low altitude airspace [121]. The process of this UTM system is based on: i) allowing UAS operators to submit flight plans to execute a specific task; ii) determining how to safely enable single or multiple UAS operations either within visual line-of-sight (VLOS) or beyond visual line-of-sight (BVLOS); and iii) coordinating airspace services across many operators. This study also provided six primary functions of the envisioned UTM, including airspace flight plan processing, operation and management, wind and weather integration, congestion management, separation management, and contingency management.

Some preliminary studies already focused on the regulation of drones’ impacts on behavioral privacy [122], and public safety [123], as well as data protection and ethics [124], [125] were presented.

In recent years the interest in drones has increased among commercial entities and recreational flyers. Therefore, there is a need to ensure safety for people, properties, and other airspace users like helicopters during drone operations. The authors in [110] evaluated the height limit for drone operations in urban airspace with the available technology enablers, categories of drones, and the application's purpose. Then they introduced drone lanes/tunnels or routes concepts, which are enabled for safe drone operation in urban areas. Figure 1.9 illustrates possible passageways for drone operation, whether it is followed along with water bodies around the area or along the downtown area’s shoreline. These passageways do not affect the existing helicopter operations, disrupt transportation services, nor intervene with industrial and maritime activities.

![Figure 1.9. Possible drone lanes/tunnels over high raised urban residential areas [110]](image)

The routes or lanes/tunnels for drone operations over the urban environment are demonstrated in Fig 1.10. These routes are above or adjacent to land transportation infrastructures in the modern metropolitan cities while keeping a safe distance from moving...
vehicles and nearby buildings.

![Image](image1.png)

**Figure 1.10.** A city skyline with designated drone lanes [110]

To prevent a drone from flying into the safety areas such as airport area, military installations, or other restricted areas, “Geo-fencing” was introduced and identified. The Geo-fencing methodology provides a virtual boundary for the geographical regions which the drones are not supposed to fly over. This technology remotely oversees geographic areas surrounded by a virtual fence (Geo-fence), and involuntary detects the mobile objects that enter or exit these areas.

![Image](image2.png)

**Figure 1.11.** Geo-fencing of critical airspace [110]

Figure 1.11. demonstrates the Geo-fencing of some protected areas in a city area such as the government building and airport area. Drones are not allowed to fly near or enter the airspace of these areas. Suppose they try to get into these areas. In that case, the Geo-fencing technology prevents their intrusion by forcing the drones to take a new path or land outside these areas by a UAV traffic controller, who takes over the aircraft’s control.

However, this study is considered as an initial step for enabling drone operation in urban airspace with safety and reliability as the first feature.
Another framework for managing drones in urban airspace called AirMatrix was proposed by Low Kin Huat [126]. This approach is based on multi-layered in altitude and air blocks in latitude and longitude. Figure 1.12 shows a possible framework for managing drones in a city, including four layers classified by altitude. The first and second layers are above buildings used for high-speed drones operated at the height of 600ft and 500ft. The third and fourth layers use for drone applications in city airspace, which are 300ft and 200ft altitudes, respectively. When drones fly at low-altitude, they will follow selected waypoints, in which drones can change the height to change direction. This framework can allow: i) UTM operators to study and design different airspace structures; ii) the extraction of essential geometric data for analytical studies; and able to simulate traffic of drone operations and to analyze airspace performance, such as capacity, efficiency, and safety.

![Airspace Structure Design](image)

**Figure 1.12.** A framework structure for urban airspace management

With the above literature reviews, it can be noted that drones' management is a significant issue not only in the transportation system but also in the air traffic system in smart cities. Firstly, the transport system is a complex system, which becomes the essential tasks, which can be widely observed, analyzed, and managed by using an extensive distribution network of sensors and actuators integrated into a system communicating through the internet. Secondly, aerial transportation will continue to increase and face new challenges such as more capacity, more efficiency, and more safety. Thus, the hottest topic of integrating UTM with a total transport-managing system is the management of drones in urban areas. The primary identified problems are passive surveillance, possible very high traffic intensity, and conflict detection and resolution, including conflicts with built obstacles. The solutions for these problems require the full integration of UTM into the urban transport-management systems and the development of unique methods for managing many vehicles in formation flight.
Chapter 2

Intelligent total transportation management system for future smart cities

2.1 Introduction

Nowadays, society and policymakers are continuously working on smart city developments, while the economy found it a well-implanted future business [127], [128]. Depending on the researchers’, developers’ point of view, smart cities have 5–8 significant components: smart infrastructure, transportation, environment, services, governance, people, living, and economy [4]. From these, smart mobility, smart transportation is one of the most important for society and the economy. It uses 30.8% (the year 2017) of energy from total energy consumption in the EU-28 [129].

Transportation is one of the numerous requisite characters of modern society and a vital enabler of the many other notions that define and characterize a smart city. Nikitas et al. [130] presented the six interventions, such as autonomous and connected vehicles, electro-mobility, bus rapid transit, hyperloop, shared-use mobility, and mobility-as-a-service, which can be in the future part of the smart city’s urban transport system. Autonomous and connected vehicles (ACVs) can be the most robust intervention in the history of mobility and the capacity to transform urban development with a revolution in urban landscape and legislation. ACVs could dramatically change the ground transport and have an enormous economic, social, spatial, and mobility impact. Electric vehicles (EVs) have a critical role in how smart cities become more energy-efficient and less polluted because the oil economy’s future is unsustainable and very limited. Although owners do not need to pay carbon-related taxes, EVs are high private costs. With the special features, EV technology is expected to change the future cities. Bus rapid transit (BRT), referred to as schemes that apply rail-like infrastructure and operations to bus systems in expectation of offerings, such as high service levels, segregated right-of-way, station-like platforms, is a mobility revelation that already prospers in 164 cities across the world. Hyperloop is projected to use magnetically-levitated pods running inside tunnel systems free of air resistance, which offers services traveling faster than commercial flights. Shared use mobility (SUM) is a way of rethinking and repositioning transport on the urban landscape. In SUM systems, the physical assets, such as cars, bicycles, vans, motorbikes, are accessed sequentially by multiple users on a pay-per-use basis. Mobility-as-a-service (MaaS) is a more radical solution that replaces privately-owned transport and optimizes the use of
mobility resources. MaaS platforms provide an intermodal journey planner (e.g., car-sharing, car rental, underground, rail, bus, bike-sharing, taxi), a booking system, easy-payment, and real-time information. Due to MaaS is a new mobility service, and its implementation is limited, there is a lack of research that managed to identify the impact of MaaS on travel behavior.

Smart mobility, intelligent transportation includes (i) smart infrastructure (roads, rails, tracks, waterways, bridges, tunnels, stations, (ii) smart people, smart economy, (iii) smart vehicles, (iv) smart info-communication and control system (from traffic lights, up to operation centres), (v) optimization principles, and (vi) smart policy-making and legislation [131], as traffic rules, which can solve several transportation problems, such as traffic jams, accidents, pollution, fuel cost, or high insurance costs. According to the investigation of the IDEA-E project [132], [133], [134], smart transportation is a slightly larger system, including all the transportation means, all infrastructure covering roads, rail tracks, tunnels of underground transportation, bridges, or multi-modal transport hubs.

By the analysis of the stakeholders’ interests, the users’ expectations, and the application of the terms (i) connected vehicles (introduced by smart city, smart transportation operators), (ii) non-cooperative and cooperative targets (introduced by the developers of the primary, radar surveillance), (iii) contract-based service (implemented by air traffic management), the transportation system can be set up as a single system classified in hierarchically structured layers. This paper introduced the term and focused on the single intelligent transportation system, with seven essential sections: leisure, private, public, business, freight, product distribution, and special transport (e.g., services, emergency cars). From the management point of view, the transportation system is recommended to be classified as (i) passive or non-cooperating, (ii) semi-active or simple cooperating, (iii) active or cooperating, (iv) contract-based, and (v) priority transports, as well as (vi) supporting partners. This approach can also be applied to the passengers of public transportation. For example, an important decision can be made from a statistical or even in-depth learning analysis of the smart travel card data [135].

The transportation system can be widely observed, analyzed, and managed using an extensive distribution network of sensors and actuators integrated into a system communicating through the Internet, as a real Internet of things (IoT) system [136], [137].

The rapid transportation technology development, the changes in social mobility (e.g., the rise of on-demand transportation), the shift in the economy (globalization – re-industrialization), and the available novel IT technologies (data-driven intelligent systems in the IoT domain) push smart cities to the next-generation transportation systems. As known, after Cohen [138] three smart city generations are identified as (i) technology-driven, (ii) technology enabling, and (iii) citizen cooperation. The smart city will provide a broader technology context within which connected and autonomous vehicles will operate. From the
technology and management point of view, smart city and its smart transportation generations can be defined as (i) passive (based on the available new technologies like e-cars), (ii) dynamic (using real measured data), and (iii) active (using real data in real-time management). An outstanding EU project, titled SmartSantanders [139], [140], introduced the last, active management of smart transportation. This project aims to establish a unique world city-scale experimental research facility to investigate and demonstrate a possible internet of things-driven service for future smart cities. They applied more than 12,000 IoT devices integrated into the experimental area. The project developed urban-scale ICT platforms with three main core functionalities: (i) urban communication abstraction, (ii) unified urban information models, and (iii) open urban service development. Future Internet in the smart city environment covered three core areas: (i) Internet of Things (IoT), (ii) Internet of Services (IoS), and (iii) Internet of People (IoP). It could introduce two critical abilities of the future smart cities: (i) the use of large sensor and actuator networks integrated into the infrastructure and (ii) establishing easy-to-use services by redeveloping new solutions and applications collected information.

IoT is the essential supporting technology in smart city and smart transportation developments due to the numerous benefits. It might be a core part of the next generation transportation systems [141], which will be determined by a series of disruptive technologies and social innovation [142], such as social media and digital platform, big data, artificial intelligence, Internet of things, or robotics and drones.

In future transportation systems, connected and autonomous vehicles emerged, and therefore interest grown substantially in the IoT. It is viewed as the next generation of the Internet, and it is predicted that it will go beyond connecting computers and smartphones to joining a multitude of different devices [143]. With IoT and highly automated systems, transportation management is shifting from active control to passive observation. In addition, traffic management to reduce congestion is a crucial topic in the smart city context, and numerous studies related to this topic were published [144], [145].

The smart transportation system, or intelligent transportation system (ITS), focuses on economy and society interest, the reduced travel times [146], arrival on time [147], the fuel consumption, pollution, as well as improving traffic safety. Several smart transportation system applications rely on the Internet of Things (IoT), including smart roads [148], intelligent parking systems [149], real-world connected vehicle data [150]. The authors of [151] summarize the surveyed studies in urban mobility analysis and sensor data type.

Numerous studies deal with the environmental impact of smart cities, smart transportation, including life-cycle analyses [152], [153], and the stochastic shortest path problem [154], while just a limited amount of papers discuss the possible environmental reduction by optimizing total transportation. Instead of that, some parts of transportation and optimization are investigated, like the impact of using electric vehicles [155].
This study aims to deal with traffic as a single system and offers its total management, including systematic description, hierarchical approach, general optimization method, sensing, technologies, and data processing. Here, single means all types of motion of people (from pedestrian up to luxury car driving) and goods, all types of transport (bicycle, trains, inland water navigation, air transport, emergency transport), work in one single system, supported by, e.g., the transportation infrastructure, transportation services, logistics, or controlling elements. The total transportation management controls the defined single transportation system using the described above hierarchically defined connected vehicles and predefined optimization rules. According to smart city programs, the transportation system is also smart and/or intelligent. In general, smart and intelligent are similar terms. Smart might solve the problem (as solving the mobility and transportation tasks with the available technologies and theories), while intelligent might provide a different solution to the same problem, depending on the exact circumstances and characteristics.

The study shows a possible method to link the gap between the solutions developed for the system elements (like control of junction, smart parking, optimization of changing the transport means at multi-modal transport centres) and the total system's management. This study's overall objective is to introduce a vision and a concept of managing the total transportation system by defining the concept, the methodology, and the required sub-model developments for the future intelligent transportation related to smart cities.

The introduced vision to optimize the total transportation management is a novel approach that can be applied already. However, it needs further developments in the observation of the vehicle motions, the evaluation of the transport size and intensity, and new software and management concepts. Due to the length limitations of this section, several aspects might need further explanation, justifications. However, the implementation of this new approach might be initiated already, even in this limited form.

### 2.2 Methodologies

#### 2.2.1 Systematic description of the urban transportation system

The urban transportation system is a sub-system of the overall transportation system that guarantees the safe, environmentally friendly, effective, and sustainable mobility and transportation of goods in urban/city areas. It is a sub-system, only, but it has fast interconnections with the global transportation systems, including, e.g., the highway passing through/nearby the city, railways having a station in the city, airports connecting to the cities.

Urban transportation might be classified depending on the transportation means and on the observation and management applied.

Figure 2.1 shows all the transportation means such as road, rail, water, and air
transports operated by the cities. The transportation means may include very different vehicles, solutions. For example, the rail transportation operates trams, underground, overhead, cogwheel railway, railway in urban areas, high-speed rail passing in/nearby city, trains, rail/magnetic rail connecting the airport with city centres. Nowadays, the pedestrian transportation, small personal vehicle (bicycle, scooters, segway), standing vehicle transportation (parking) and new forms of transport as urban air transportation (drones, air taxies) are the elements of the urban transportation system. Such elements must be integrated into the total transportation/total transportation management.

![Image of urban total transportation system](image)

**Figure 2.1.** Urban total transportation system: I- industrial area (factories), II- Forest area, III- urban area, IV- airport area, 1- underground, 2- road, 3- upper ground, 4- path, 5- railway, 6- highway, 7- freight transport, 8- urban air transport, 9- water transport.

In the future, with the introduction of autonomous vehicles in everyday operations and highly automated traffic management systems, the operator roles will be shifted from active control to passive observation and make active control in case of exceptional and emergencies only. Such management is required to collect enough data to make the management of the total transportation system in an optimized form. The distributed sensor systems might be organized into a single, smart transportation IoT based system.

### 2.2.2 Hierarchical approach to total transportation management

While this study deals with smart urban transportation as a single significant, ecological-socio-technogenic system, there are many different types of vehicles and forms of transportation used. Their primary characteristics are distributed in extensive ranges (as significant geometry measures from 20-30 cm up to 50-100 m, mass from 0.5 kg up to hundreds of kg, or performance as velocity from 1-2 km/h up to 800 km/h, or fuel consumption since zero up to 30-2000 L/100 km).

There are several classification methods of the transportation systems being used. Figure 2.2a represents a cube of the transportation system. From a user point of view,
transportation might be classified as the following horizontal parts of the total system:

- leisure transportation - walking, running, using scooters, bicycles in parks, drafting, yachting, hot balloons, parachutes, hang glider, autogyros caravans, etc.
- private transportation - pedestrian, using scooters, bicycles for traveling, operating personal vehicles, cars, boats, small personal aircraft with well-defined traveling goals,
- public transportation or mass transportation - metro, trams, busses, scheduled boats,
- business travel - taxi cars, boats, air taxi, business air transport,
- freight transportation - lorries, truck, trailer trucks, container lorries,
- product distribution - pick-ups, fast carriers, distribution of goods by drones,
- special transportation - monitoring by drones, emergency cars, fire cars, police, VIP vehicles,

![Figure 2.2. Hierarchical classification of the vehicles and primary information transmissions (a) cube of hierarchical structure, (b) system interconnections.](image)

Figure 2.2. Hierarchical classification of the vehicles and primary information transmissions (a) cube of hierarchical structure, (b) system interconnections.

Often, the same vehicles might be used for different purposes in different segments of the transportation system. For example, the same bicycle might be used for leisure or sport and traveling in a way to work, or operating as bike couriers.

This classification of the transportation segments also uses a hierarchical concept. However, vehicles can be grouped depending on their ‘participation’ in the transportation system (Fig. 2.2a), namely on the level of their cooperation with the operation centre (Fig. 2.2b). Eight classes can be identified:

i) non detected - objects not appearing on the surveillance screen;

ii) appearing on the surveillance screens, but it is unknown whether it is passive or non-cooperating vehicles or participants like pedestrians - that has no connection with the operation centres, and they might be shown up on the monitor of surveillance as an
un-known object or non-cooperative targets, (generally, it might be humans, animals, vehicles not providing information to the operation centres);

iii) semi-active or simple cooperating - object, participants in city transportation from which some information is available at the operation centre. For example, by video, the object is identified as a small or medium car or van;

iv) active or cooperating - vehicle, or service providers (city mass transportation company, taxi companies) that report information on the objects, vehicles moving, operating in the city, the available information should contain data on the type of the vehicle (and of course its performance), its identification number, load, (possible state characteristics available in onboard systems), the instantaneous position of the given vehicles (for example by using the GPS positioning data), purpose and final destination of travel;

v) connecting vehicles - work together passively (using, for example, sonic or radar measurements to keep the following distance) or actively (exchanging all the available data on boards), and even they may harmonize their actions (like moving in formation, or using the conflict detection and resolution based on the exchanged information);

vi) contract-based vehicles - may have some preferences in the transportation system (like temporary opening the bus lanes or giving them green lights as possible) served based on a first come - first serve, and they must pay (low fees) for serving;

vii) priority transport - should have priority lanes, control (as for police, emergency cars, traveling of VIP persons);

viii) supporting partners - starting by continuous weather forecast reporting up to emergency management organization having the highest priority.

As in any classification, here, some of the categories could overlap. For example, public transportation may have an enormous influence on the other classes. On the other hand, public transportation is partly prioritized transportation because of the introduction of bus lanes, the control of the traffic lights to reduce the mass transport traveling time.

2.2.3 General optimization method

At first sight, the required optimization methods can be defined simply as a nonlinear optimization problem. The mathematical representation can be given in a simple form:

\[
\min f(\mathbf{x})
\]

subject to: \( g_i(\mathbf{x}) \leq 0 \) for each \( i \in \{1, 2, ..., n\} \) \hspace{1cm} (2.1)

and \( h_j(\mathbf{x}) = 0 \) for each \( j \in \{1, 2, ..., m\} \)
where $x \in X$

where: $x$: the vector of variables, $f(x)$: objective function, $g_i(x)$: non-equality constraint functions, $h_j(x)$: equality constraint functions and $X$: space of the variables.

The formulation of this optimization problem dealing with a single total (overall) transportation system seems too ambitious. Millions of solutions to such optimization problems are reduced to a part of the transportation systems, to a given type of sub-systems. The main reason for reducing the problem is the use of a fully and well observable system. However, the latest results of sciences and technologies allow solving the optimization of the total transportation system. For example, big data analysis and soft computing make it possible to estimate the sub-systems of transportation being composed of non-cooperative or semi-cooperative vehicles (people), from the external information provided, e.g., by smart cards or video surveillance.

The most important novelties of the introduced optimization problem are not related to a single transportation system’s focus and not to the optimization of the total system. The classification of the transportation system causes novelties. As described in the above subsection, there are horizontal and hierarchical classifications of the total transportation system. This classification allows us to define special objective functions for a part of the total transportation system and introduce more constraints.

By adapting the total impact concept [156], [157], the objective function can be defined in several different forms depending on the management’s objectives. One of the most critical primary objectives is the minimization of the energy used by transportation. Total energy consumption, $E_t$, used by total urban transport system related an hour or day (or season) can be defined as

$$E_t = f(x) = \frac{1}{\tau} \sum_{i=1}^{N} \int_{t_{s_i \geq 0}}^{t_{f_i \leq \tau}} w_{v_i} e_{v_i} (r_{v_i}, p_{v_i}, p_{v_{d_i}}, o_{v_i}, x_{v_i}, z_{v_i}, ..., \xi_{v_i}, t) \, dt,$$

(2.2)

$$x^T = [r_{v_i}, p_{v_i}, p_{v_{d_i}}, o_{v_i}, x_{v_i}, z_{v_i}, ...] \in X$$

where $\tau$ is the time, frame of reference, $i = 1, 2, ..., N$ number of vehicles, $w, e, r, p, o, x, z, \xi,$ and $t$ are the weighting coefficient, energy consumption, real pathway, parameters, operational characteristics, vehicle motion characteristics/performance, environmental characteristics, noise vector and time, while the indexes $t_{s_i \geq 0}, t_{f_i \leq \tau}$ mean motion starting and finishing times (forgiven $i$-th vehicle), $v$- given vehicle ($v_i$ depicts the $i$-th vehicle), $vc, v_{d}$ are related to the vehicle instantaneous consumption and a human vehicle driver. Here, $r_{v_i}$ vector characterizes the real pathway (slopes, curves of the road, track) along which the given $i$-th vehicle moves during $[t_{s_i \geq 0}, t_{f_i \leq \tau}$ time period. Vectors $p_{v_i}, p_{v_{d_i}}$ are completed
from the vehicle (types, sizes, empty mass, engine, engine performance) and drivers characteristics (dynamics, reaction time). The operational characteristics \( o_{v_i} \) contains all the available real data, the real condition of the given \( i \)-th vehicle as load factor, age, used size of tires, pressure in tires. The real motion of the \( i \)-th vehicle is characterized by a vector, \( x_{v_i} \). The environment as air temperature, raining, fog, are defined by the vector \( z_{v_i} \) according to the \( i \)-th given vehicle. Finally, the noise vector contains the random noise as traffic jam, accident, road reconstruction) related to the given \( i \)-th vehicle and its pathway.

Equation (2.2) seems solvable; nevertheless, it deals with many vehicles reaching even some millions in large megacities. A more detailed evaluation of Equation (2.2) shows nearly impossible to solve the problem (2.1).

- At first, the objective function is nonlinear. It is enough to underline that the fuel consumption depends on the vehicle’s drag, which is a function of the vehicle velocity square. Furthermore, fuel consumption depends, e.g., on the number of stops, accelerations, or the duration of rush hours. Fuel consumption of the same types of cars might differ by 50-80% depending on the drivers (“young dynamic” or “old lady” type drivers).

- At second, vehicles’ motion might be started and finished in any local places or at the investigated city areas’ borders. The given \( i \)-th vehicle may take part in traffic several times (moving–parking–moving).

- At third, the situation may change dynamically because of the accident, tropical rain, or simple traffic conjunction.

- At fourth, demand and demand in given transportation means are changing quickly. Transportation networks are planned and built based on demand forecasts that used available data on a given time of social and economic requirements. Therefore, the networks were planned for mass transportation and motorized vehicles. Nowadays, the system is weak in parking and bicycle or scooter lanes. On the other hand, it is good news that the young generation does not prefer to have a car, and young people like to use car-sharing systems and advanced e transportation solutions.

Because of the difficulties in possibly solving the optimization problem (2.1), several methods are developed to solve the traffic optimization problem by simplifying and reducing size.

At first, instead of the nonlinear objective Function (2.2), a simplified linear function might be applied:
\[ E_t = f(x) = \frac{1}{\tau} \sum_{i=1}^{N} w_{vt} e_{v_{isf}} \]  

(2.3)

where \( e_{v_{isf}} \) minimum energy used by \( i \)-th vehicle during its moving from start to the final position.

Figure 2.3 shows the possible calculation of \( e_{v_{isf}} \). It covers a part of the city road system. Ellipses give junctions, and lines show roads between the junctions. The \( i \)-th vehicle starts its motion at junction \( s \) (red state, \( j, l-4 \) in Fig. 2.3), and finishes at state \( f(j+2, l) \). The energy used for passing the junction \( (j, l) \) and moving to next junction \( (p, r) \) for example to \( (p = j + 1 \) and \( r = l - 2 ) \) is defined as \( e_{v_{ij,lp,r}} = e_{v_{ij,lj+l-2}} \). The red lines show the path from junction \( s \) to junction \( f \) with minimum energy used. The minimum energy path does not necessarily equal to minimum time, minimum cost, or minimise environmental impact. (For example, electric or electric-hybrid vehicles may even generate energy during the decelerations. Therefore, \( e_{v_{ij,lp,r}} \) can be even negative.)

![Figure 2.3. Graph model of a road system fragment.](image)

In Equation (2.3), the weighting coefficients, \( w_{vt} \), take into account the real operational conditions as load factors (as how many passengers are in the car). It is clear that the minimum energy used elements, \( e_{v_{ij,lp,r}} \), to complete a special minimum energy used matrix, \( E_{\text{min},v_i} \), for each \( i \)-th vehicle.

Instead of a road system network, a grid can be defined for covering the urban area in a very generalized form. Of course, the minimum energy used matrices must be determined for the grid representation.

The number of vehicles might be reduced by the definition of a series of standard vehicles. For example, depending on the required accuracy, 10-25 personal cars can be
defined with different sizes, engine, and drivers.

The minimum energy used matrices must be predetermined for any changes in the environmental (weather) characteristics, \( z \), and noise vector, \( \xi \), (defining the road construction, accident, or traffic jump occurrences).

Traffic intensity and situations can be changed very quickly. Therefore, the minimum energy used matrix must be recalculated at least every minute, depending on the real traffic situation. Most developed traffic management systems may use simulation and forecast of future traffic. It is a short term forecast that may use the statistical data measured. However, the cooperative vehicles' data might be applied to make a better, more accurate forecast - this approach is required to use the hierarchical approach to monitor and manage the traffic.

Traffic management may use partial optimizations of particular parts or sub-system elements like traffic lights or conjunction optimization of the supply chains, optimizing deliveries of goods, and optimizing priority vehicles.

By taking into account all these discussed aspects, the total energy consumption is

\[
E_t = f(x) = \frac{1}{N_T} \sum_{i=1}^{N_{sv}} w_{sv_i} \sum_{k=\tau_{sv_is}^f/T}^{\tau_{sv_if}/T} e_{visf} \left( E_{\min,sv_isf}[k] \right) + \Delta e[k] \tag{2.4}
\]

where \( T \) is a time step, \( N_T = \tau / T \) number of steps, index \( sv \) depicts the standard vehicles, \( N_{sv} \) is the number of standard vehicles, \( \tau_{sv_is}, \tau_{sv_if} \) time of starting and finishing the motion of \( i \)-th standard vehicle, \( k \) is the number of time step \( (k = 1, 2, \ldots, N_T) \) and \( \Delta e \) extra energy consumption caused by managing with priority vehicles.

Nevertheless, the optimization problem is reduced in size, and depending on partial objectives, the active and dynamic optimization of the traffic needs real information on the traffic condition. Such information might be measured and collected by widely distributed sensors and integrated into one system as IoT.

The recommended concept is total transport and total management system. It means that all motions of people and goods (including walking, sport, travels, freight transport) are realized by any vehicles (from electric scooters up to the supersonic business jets) as elements of the single transportation system are monitored and controlled by a particular hierarchical concept. Such a system (Fig. 2.4) has three levels:

- physical levels including all the objects, vehicles, and even stakeholders,
- digital level that transmits the data, information and uses it for multi-directional info-communication, and
• the virtual or computational centre supports the operation centre and situation awareness, evaluation, decision making, and realized active dynamic control.

**Smart city total transport management**

<table>
<thead>
<tr>
<th>Data collection / preliminary processing</th>
<th>Data processing, situation awareness</th>
<th>Solving the optimisation problem</th>
<th>Decision making, actions</th>
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<td>1. 2. 3. 4.</td>
<td>5. 6. 7. 8.</td>
<td>9. 10. 11. 12.</td>
<td>13. 14. 15. 16.</td>
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</table>

**Figure 2.4.** Representation of the management with smart city total transportation system.

In such a system, especially nowadays, the sensors and their integration in the transportation system represent a central problem. The digital level realizes the IoT concept. The third level is fully integrated into the total transportation system; namely, it uses computing and ubiquitous computing (when computing may appear locally anywhere, anytime).

### 2.2.4 Sensing and technologies in total transportation management

Smart city developments are driven by accelerating technology developments, defined by technology laws, studied by technology foresight and forecast techniques, as well as technology identification, evaluation, and selection methods [134], [158], [159]. The most crucial future and emerging technologies that enable the development of smart city solutions and especially smart city total transportation management are:

- disruptive technologies including new methods of design and production process planning, new optimized transport network planning, new (lightweight) materials (as full composite vehicles), new solutions as (as electric vehicles), new unconventional solutions (as an autonomous vehicle, pilot-less taxi drones);
- covering new sensors MEMS (micro-electric-mechanical-system) based sensors and actuators, enabling traffic monitoring and active control;
- new info-communication technology based on wireless technology, Internet,
cloud, internet of things concepts;
• including further data processing, situation awareness-evaluation-decision making 
  by the methods of soft computing, artificial intelligence;
• improving the new concept of total transportation, total management.

The new and emerging technologies enable to create of new microsensors that might 
be integrated into the
• vehicle structures and systems;
• operators’ working environment, and more particularly in the drivers’ cockpits and 
  monitoring/control rooms;
• infrastructure of the transportation system, and
• general info-communication systems.

The transportation monitoring and management systems include the sensors, data info-
communication, data collection and data processing, situation awareness, and evaluation 
decision-making. Sensors provide (mostly electric analog or digital) signals depending on 
the investigated objects’ condition. They may use physical, chemical, and recently biological 
principles [160]. Sensors are classified as:

• passive sensors - that not require own or external power supports (like 
  thermocouple, electric field sensing, piezoelectric sensors, chemical, and infrared 
  sensors, or video camera, infrared camera);
• active sensors - sensing devices that require an external source of power to operate 
  (GPS, radar, ultrasonic detectors, Lidar, blood pressure sensors).

This study recommends using passive and active condition monitoring and detection 
where
• passive system uses signals measured by sensors in case of out of control actions, 
  in quasi-steady operation modes;
• active system applies predefined inputs, trajectories, special loads, or test signals 
  (including, for example, recognition-decision action time for braking or delay in 
  braking, deviation from predefined trajectories as curved lanes).

By implementing this monitoring classification approach, the following methods can 
be applied:

• passive monitoring of the operational conditions: built in the environment from a 
distance to the vehicles or the operators, monitored objects, using passive and 
active sensors like video cameras, signal transmitters, or eye tracking, infrared
cameras, microwave radars;

- passive monitoring by sensors integrated into the working environment for direct sensing of the operators’ behaviors, as hearth rate, skin resistance, built in the operators’ control elements, or their clothes, integrated into the infrastructure as road construction, rail tracks, bridges, tunnels, to measure the size of the vehicles, their weight, or to detect the deformation in the structural elements;

- semi-active sensing and monitoring: measuring some characteristics as the reaction of operators on some signals, information, the action of vehicles while passing small obstacles, load, stress and/or deformation of bridges under heavy vehicles;

- active monitoring and detection: passive or active sensors that measure the vehicles' reactions, operators on the specially generated signals (including signals initiated to test the vehicle systems, transportation infrastructure, or operators).

### 2.2.5 Data processing

The total transportation management uses a particular data processing and decision support sub-system. It is unique because it synthesizes the latest computing methods (artificially intelligent) with ubiquitous computing (locally distributed partially optimized, embedded sub-systems) to reach the high ambition goals: operate an effective, sustainable transportation system that meets the needs of the society and economy, and has a minimum impact on the environment, while being safe and secure.

Total transport management uses sensors integrated into the infrastructure, environment, cooperating and contract-based vehicles, drivers, enterprises, institutions, surveillance systems, and technology developments. The information depending on its value, is used in different management concepts as follows:

- Passive control: applies data provided by the stakeholders (including historical data and transportation system network capabilities);

- Active control: uses the additional information obtained from real traffic measurements (namely passive monitoring, primary surveillance, information available at stakeholders, users, like a mobile for positioning);

- Dynamic management: uses information from the secondary surveillance (provided by the cooperative and contract-based vehicles, drivers, companies), passive and active monitoring;

- Proactive management: as top management that uses the results of predictive simulations (on the possible occurrence of the traffic jam caused by accident, weather changes, demonstrations) as feedforward, or internal model control, as well as using free routes for prioritized vehicles or simulating the vehicle motion
in exceptional environmental cases.

Generally, such computing system must solve the following cascade of computing (Fig. 2.4) independently on the role and size of computing being used locally to sub-systems, elements (even to the individual vehicle or cross-section), or the entire system:

- Data collection/preliminary data processing:
  1. data collection and noise filtration - reducing effects of noise on measurements,
  2. primary (preliminary) warning - detecting the crosses of signals their defined borders on tolerance zones, appearing not prescribed situation (that may result in an error, accident),
  3. data harmonization - conversion of the measured records to comparable forms of data, selecting windows on data series with the same time frames,
  4. statistical analysis - assess the primary statistical values trends and save them from permitting further investigations.

- Data processing, situation awareness-simulation-evaluation:
  5. automated situation awareness - the perception of the environment with time and space, predicting the state shortly,
  6. study of particular situations - situations being out of the normal operational circumstances like accident,
  7. simulations - using the available simulation software to simulate local event or sub-system operation, or total system,
  8. evaluations - study the simulation results, providing inputs for optimization.

Situation awareness forms the critical inputs to the operator’s decision making. If situation awareness is incomplete or inaccurate, the decisions will be wrong. At the same time, a drive may accurately understand what is occurring in the environment.

Based on the data collection/preliminary processing, the environment's picture is assessed with a comprehensive set of objects and events. Information grouping should tie multiple attributes to each object while minimizing the number of objects presented. For example, the other vehicles' position, obstacles around the vehicle are displayed on the driver’s screen.

The system trains special situations, allowing predicting the future state of the environment to ensure focused attention after pre-attentive processing. The design of the information displays should allow reorientation to the situation in the event of real-world information. With advanced technologies, the quality of information has been satisfied, directly providing users with higher-level situation awareness.

Finally, no matter how carefully a given system is designed, the evaluations of situation awareness are needed to investigate, based on what was happening in the
simulation. The comparison of the real and perceived situations provides an objective measure of system situation awareness.

The optimization problem (as the simulation methods) might be solved for the entire system, sub-system, or elements. However, all the optimization solutions must be harmonized. This goal can be reached by three types of hierarchy: (i) hierarchy in the system (system structure), (ii) hierarchy in transport (vehicle) classification (e.g., first come first serve, prioritization) and (iii) situation prioritization (disaster response, significant accident).

- Solving the optimization problem:
  9. objective function definition - the total system must be optimized for minimum energy consumption (Functions (2.2)-(2.4)) or minimum total cost,
  10. constraints definition - the constraints might be defined for technical, technological operation, economic, societal, environmental impact, safety and security aspects (like an actual problem, social distance in mass transport),
  11. optimization problem solution - with linear or non-linear programming or artificial intelligence,
  12. result evaluation - check the applicability of the results.

The objective function, total energy consumption, can be calculated with Equation (2.2). The objectives were determined based on the traffic condition’s real information, the active and dynamic optimization of the traffic. Therefore, the optimization problem, like (2.4), can be solved. The results should be evaluated by comparing them with the real-traffic condition.

- Decision making and actions:
  13. automated decision making - it might be applied to the small optimization problems like the control of traffic lights at given cross-sections, and it can be determined as a recommended decision for the total traffic management,
  14. decision making for special situations - caused by unwanted events (accident) of planned situations like protests, essential sports event,
  15. decision making for emergencies - in case of, e.g., disaster, flood, when lifesaving is the primary objective,
  16. actions - the realization of the decision.

The results of the optimization problem were considered as an input for the decision-making and action process. In this process, several situations were determined based on situation awareness, including optimal energy consumption, special situations, and emergencies. Then, the users can usually choose the solution that satisfies the real-traffic environment.
Chapter 2: Drone management in smart city

2.3 Results - Examples of sub-model developments

The implementation of the described approach to smart, intelligent total transportation management requires the integration of a large number of distributed IoT devices in one system and the development, and usage of a series of sub-models, new data processing methods.

The introduced general optimization Problem (2.1) can be applied after defining the objective functions and constraints. Therefore, several sub-models must be developed and applied. For example, the microscopic model as a car-following model determines the vehicle density in lanes, tracks. The integration of drones in the urban transportation system might be supported by developing formation flights and obstacle avoiding systems. Similarly, further studies are required for the management of different classes of vehicles/transportation subsystems.

In this section, three primary references as examples demonstrating the further sub-model developments will be presented, which can be applied in the proposed intelligent total transportation managing system.

2.3.1 A new car-following model

One of the essential microscopic model applied by transportation management systems is the car-following model [161], [162]. It describes the one-by-one following process of vehicles in the traffic flow. The first car following models was developed in the 1950s’ [163]. Several concepts are behind the firstly applied, classic models [164], [165]:

- stimulus-response model;
- safe distance model;
- psychophysical model;
- cell-based model (cellular automata model);
- optimum velocity model;
- trajectory-based model.

For the last decade, new transfer, stochastic, and intelligent models were developed.

Generally, the vehicle’s motion in the traffic flows can be described with active dynamic nonlinear models. The vehicle motions are activated by the drivers’ decisions based on the available traffic information, traffic conditions, situation awareness, and knowledge of the driven cars’ performance, personal practice, skills, available resources. Principally, vehicles' motion is disturbed by stochastic effects and drivers reacting on the vehicles depending on their subjective decisions.
After analyzing the drivers’ decision-making processes in selecting the vehicle’s appropriate velocity, we become convinced that the drivers calculate the required changes in speed based on the relative distance and speed between the vehicles. In addition, the driver should also consider the vehicles’ performance. Altogether, these aspects result in a randomly composed real stochastic process that can be represented as a diffusion process:

\[ a = \dot{v} = f(v, t) + \sigma(v, t)\eta(t) \]  

(2.5)

This controlled stochastic process - as known - can be approximated by a Markov chain process that leads to the following simple model

\[ a[k + 1] = b_{dv}(v_{n-1}[k] - v_n[k]) + b_{dx}[(x_{n-1}[k] - x_n[k]) - \Delta x_{pdn}] + \varepsilon[k] \]  

(2.6)

where, \( a \) is the acceleration of the vehicle; \( \eta \) is the noise disturbing the process; \((v_{n-1}[k] - v_n[k])\) and \((x_{n-1}[k] - x_n[k])\) are the relative velocity and relative distance between the two \((n - 1)\)-th and \(n\)-th vehicles, respectively; \(b_{dv}\) and \(b_{dx}\) are the sensitivity coefficient, which can depend on the time and given vehicle and driver behaviours; \(\Delta x_{pdn}\) is the predefined safe distance between the vehicles; \(k\) is the number of step in the chain \((t = k\Delta t)\); \(\varepsilon(k)\) is the random value disturbing the speed decision and maintaining process.

The introduced Markov model can be easily adapted to the real observed traffic by estimating the sensitivity coefficients.

Different approaches can be applied to the calibration and validations [166]. In this study, the concept of the model was validated by comparison evaluation of the Markov car-following Model (2.6) with the GHR (Gazis-Herman-Rothery) Model (2.7) and the S-curve Model (2.8) solved in a simulation environment.

The GHR model was presented by Gazis et al. [167] as follows:

\[ a_n(t + T) = \lambda_{l,m} \frac{[v_n(t)]^m}{[x_{n-1}(t) - x_n(t)]^l} [v_{n-1}(t) - v_n(t)] \]  

(2.7)

where, \( m, l\) are parameters for speed and distance headway; \(\lambda_{l,m}\) is a constant showing the characteristics of the drivers.

Because the driver sensitivity curve is very similar to the Gompertz curve, we decided to use the modified Gompertz curve [165] to define the coefficient \(\lambda_{l,m}\) in Equation (2.8):
\[ a_n(t + T) = \left\{ a_1 e^{-a_2 \frac{[v_{n-1}(t) - v_n(t)]^q}{[x_{n-1}(t) - x_n(t)]^2}} \right\} \]
\[ - a_4 \left( \frac{[v_n(t)]^m}{[x_{n-1}(t) - x_n(t)]^T} [v_{n-1}(t) - v_n(t)]^q \right) \]

Equation (2.8) is called the S curve model.

2.3.2 Managing drones as a formation to avoid obstacle in smart cities

In this section, an approach to control and manage a drone formation with avoidance collision was presented, applied in the total transportation management system.

2.3.2.1. Formation Model

Formation motion means a group of vehicles moving together and following a leader vehicle. In such a case, the group of vehicles' motion can be managed by only controlling the leader vehicle, as initially developed for advanced air traffic control. The formation flight modes are considered more than relevant for drones' coordination, as conventional air traffic management techniques and tools are powerless in dealing with such a high number (and complexity) of movements. The model can be relatively easily adapted to the road or urban traffic systems.

Consider a multi-drone system consisting of N drones and a leader. The motion dynamics of each i-th drone can be represented by a simple system of the linearized equation:

\[ \dot{s}_i = Ps_i + Qu_i \]  

(2.9)

where, \( s_i \in \mathbb{R}^n \) is the drone i’s state, namely it is a state vector and \( u_i \in \mathbb{R}^n \) is the drone i’s input, input vector, which can only use local information from its neighbour drones. Matrix \( P = [p_{ij}] \in \mathbb{R}^{n \times n} \) is a diagonally dominant matrix or state transition matrix, which means that

\[ |p_{ii}| \geq \sum_{j=1, j \neq i}^n |p_{ij}| \]

for all \( i = 1, \ldots, n \). The matrix \( Q \) is of full column rank.

The leader drone, labeled as \( i = 0 \), has linear dynamics as follows:

\[ \dot{s}_0 = As_0 \]  

(2.10)

where, \( s_0 \in \mathbb{R}^n \) is the state of the leader drone. It can be noted that the leader’s dynamics
is independent from the others.

With the assumption that the pair \((P, Q)\) is stabilizable, the drone Formations (9) and (10) is said to be achieved if, for each drone \(i \in \{1, \ldots, N\}\), there is a local state feedback \(u_i\) of \(\{x_j: j \in N_i\}\) such that the closed-loop system satisfies \(\lim_{t \to \infty} \|s_i(t) - s_0(t)\| = 0\) for any initial condition \(s_i(0), i = 0, 1, \ldots, N\).

The control law for drone \(i\) is given as follows:

\[
    u_i(x) = \sum_{j \in N_i} \|s_j - s_i - d_{ij}\|^2
\]

where, \(d_{ij}\) is the desired inter-distance related to the position vector. A drone \(j\) is the neighbour of drone \(i\).

2.3.2.2. Obstacle Avoidance Model

Along with drone applications' spreading trend, the drone collision’s flight safety with buildings, helicopters, and the landscape becomes an urgent issue for civil and defense agencies. A collision avoidance system is necessary for drone flights, especially for autonomous drones in dense airspace shared with other aircraft to guarantee airspace security. Conflict detection and collision avoidance is also a valuable tool for highly automated and autonomous vehicles.

It can be noted that the research on collision avoidance for drones has a high failure cost because the collision may destroy the drone if the avoidance fails. Therefore, several simulation systems for algorithm testing are designed in laboratories. The obstacle model is one of the critical parts of these systems, described as the following.

Let \(B\) be the set of all obstacles for a given drone within its operating space. Assume that each obstacle is prescribed in a cylinder with the center \(C_{Bl}\) and radius \(r_{Bl}\), as shown in Fig. 2.5.

The surfaces of cylinders can then be used to form constraints for obstacle avoidance. Accurately, the safe distance \(d_{si}\) from the obstacle \(l\) is calculated from the cylinder center to its surface at the flying height as follows:

\[
    d_{si,l} = \begin{cases} 
    \sqrt{r_{Bl}^2 + (Z_{Mi,k} - Z_{Cbl,l})^2} & \text{if } Z_{Mi,k} \leq Z_{\text{max},Cbl} \\
    \sqrt{r_{Bl}^2 + (Z_{\text{max},Cbl} - Z_{Cbl,l})^2} & \text{if } Z_{Mi,k} > Z_{\text{max},Cbl}
    \end{cases}
\]

where, \(Z_{\text{max},Cbl}\) is the height of the obstacle \(l\).

To compute the violation cost between each generated path and obstacle centres, we
first assumed that the formation is rigid and can be fit within a sphere with the radius:

\[ r_{s,l} = r_d + d_{s,l} \]  \hspace{1cm} (2.13)

where, \( r_d \) is the radius of the drone, including propellers.

The violation cost can be now derived as follows:

For the \( l \)-th obstacle, compute the distance from its center \( CBl \) to the segment \( P_{i,k}P_{i,k+1} \):

\[ d_{l,k} = \sqrt{(x_{Mi,k} - x_{CBl})^2 + (y_{Mi,k} - y_{CBl})^2 + (z_{Mi,k} - z_{CBl})^2} \]  \hspace{1cm} (2.14)

where, \( Mi,k = \{x_{Mi,k}, y_{Mi,k}, z_{Mi,k}\} \) is the midpoint of the segment as shown in Fig. 2.5. At a given flying height \( z_{Mi,k} \), \( d_{l,k} \) is then compared with the safe distance to the obstacle. The comparison results in the following violation function:

\[ V_{l,k} = \sum_{l=1}^{B} \max (1 - \frac{d_{l,k}}{r_{s,l}}, 0) \]  \hspace{1cm} (2.15)

This function ensures that the distance \( d_{l,k} \) must be larger than the safe distance for obstacle avoidance. The violation cost is then computed for all obstacles as:

\[ V_l = \frac{1}{B} \sum_{l=1}^{B} V_{l,k} \]  \hspace{1cm} (2.15)

**Figure 2.5.** Obstacle representation and safe distance calculation.
For all $m$ segments, the final violation cost on average is represented as:

$$Q = \frac{1}{m} \sum_{i=1}^{m} V_i$$ (2.16)

2.3.2.3. Formation Control Strategy

**The Centralized Control Strategy**

This approach is primitively proposed, where a central processor exists (see Fig. 2.6). The central processor is responsible for collecting data of subsystems and return decisions to them. This control strategy is usually considered a simple, easy implementing, and efficient approach, but it has weak robustness for the central processor’s fault. This weakness may cause severe problems in large-scale practical systems. The standard leader-follower formation configuration is intuitively considered a centralized method, where the leader is independent of the followers.

![Centralized control strategy for large-scale systems](image)

*Figure 2.6. Centralized control strategy for large-scale systems. (a) Pure centralized structure, (b) Hierarchical centralized structure.*

**Decentralized Control Strategy**

Concerning the complexities and difficulties of the research on the overall system, there is more interest in the approach that can divide the global system's analysis and synthesis into independent or almost independent subsystems (see Fig. 2.7a). The idea is that each subsystem in the whole system has its processing unit and makes its own decisions based on its measurements. Decentralization allows the overall system to take advantage of labor division by sharing the subsystems’ decision-making load. In a decentralized control system, the whole system is no longer controlled by a single controller but by several independent controllers, consisting of decentralized controllers implemented on each module. In general, decentralized control is used in a large-scale system, which has a couple of subsystems.

In a drone formation, if each drone has its controller and moves according to its measurement (detection or sensing), the formation control strategy is decentralized.
Distributed Control Strategy

This approach evolves from the decentralized control with sharing local information (see Fig. 2.7b). The distributed control is promising to be superior to centralized control when data delays are present. Distributed control is related to the areas of decentralized control and large-scale systems with communication issues. The decentralized control extensions contain communication among subsystems, local controllers, and communication in the feedback loop.

If each drone communicates with all the other drones in the drone formation, the control strategy is not distributed. Therefore, in a multi-drone system, if the communication issues are considered in the decentralized control design framework, the formation control strategy is distributed. The behavior-based formation configuration is regarded as a decentralized method or a distributed method depending on drones' communications or interactions.

![Figure 2.7. Decentralized and distributed control strategies (S-system and C-controller). (a) Decentralized control strategy, (b) Distributed control strategy.](image)

2.3.3 Intelligent total transportation managing system in smart cities

The introduced new concept, addressing the intelligent total transportation management system, has essential novelties related to the hierarchical classification of the transportation system and the application of the own management methodology to each class, and the overall system. Here, a short description of the possible management with the significant classes of vehicles are introduced.

2.3.3.1 Management of Non-Cooperating Vehicles

The system collects available and measured data on vehicles and weather conditions; such data is used as the primary surveillance input. The non-cooperating vehicles are identified by sensors such as optical, infrared, ultrasonic, radar, built in the traffic infrastructure. These vehicles are then classified depending on their size, mass predicted performances and predictable goal trips. This information is used in a short time forecast of the traffic intensity and complexity, together with the cooperating vehicles' information. Accordingly, the system evaluates and monitors where, which direction will increase the
traffic, where the traffic jam might appear, which support even the drivers of the non-cooperating vehicles.

2.3.3.2 Management of the Cooperating Vehicles

There are three levels of cooperation, such as follows:

- In the first level - called primary cooperation, the cooperating vehicles provide information on the vehicles, motion condition, and actual position using information networks. These vehicles also provide this information to the nearby vehicles and harmonize their motions;

- In the second level, called secondary surveillance, the cooperating vehicles send the information on the goal and target of trips to the traffic management centre that may directly support these vehicles;

- In the third level, these vehicles send data to the traffic management centre, e.g., the nearby vehicles, the infrastructure condition, and traffic situations.

2.3.3.3 Contract-Based Traffic Management

Contract-based traffic management is a supporting service that increases the efficient operation of both drivers and service providers. Accordingly, drivers are the first to receive the essential information; Service providers might also benefit from this service by gaining profit from this contract, allowing for efficient operation increasing supply competition.

The contract-based traffic management may consist of a “semi priority” system. In such a case, the drivers will have information from the transport management centres on the recommended shortest ways, and possibly shorten the traveling time while seeing individual commanding signals on the road for a short time.

2.3.3.4 Priority Transport Management

The total transportation managing system uses passive methods to monitor the non-cooperative vehicles, semi-active methods for the cooperating vehicles, an active approach to support the contract-based transportation, and a proactive approach for managing priority vehicles.

The priority vehicles, such as police, fire machines, and ambulances, might be supported by free lanes and freeways by the total transportation managing system.

2.4 Discussion on the possible use and preliminary evaluation of the concept

2.4.1 Applicability of the concept
With the fast development of Information Technology (IT) technologies, the Intelligent Total Transport Management (ITTM) concept could be a solution for urban transport management, however, coupled with the efficient application of IoT technologies. The fast development and implementation of smart technologies for various applications are certainly opening new ways towards smart transportation.

The main idea of the ITTM concept is to provide more effective and efficient services in urban transportation, improve safety and security, and enable a general quality of the environment in cities for working and living. The ITTM could increase user comfort, security, reduce traffic jams, save energy by providing users with real-time data regarding traffic reports, rerouting traffic, and adjusting speed limits based on this information. Moreover, drivers will no longer search vacant parking spots because of smart parking solutions to visualize this information in real-time through their smartphones.

The intelligent transport total management system (ITTMS) needs to update the traffic information of a single road section in time and provide relevant traffic flow data for the connected signal ports. Refer to the traffic flow information in the upper-level area to provide an optimal route, which can control traffic flow and convert the intersections and other road sections to each other.

The ITTMS will involve many aspects of the design, and all need careful consideration in the design of the city transportation management system. In this way, an ITTMS suitable for the city and the urban area can play a role in alleviating urban environmental impacts and promoting urban energy management development. For example, a total transportation management system in smart cities being operated as an ITTMS.

ITTMS was mainly used for urban transport management. It is integrated with drones, which plays a vital role in improving urban transport management, alleviating urban environmental impact, and optimizing urban energy management. Such a system would bring benefits for safety and security areas and the local users with optimal route planning, reduced energy consumption, carbon dioxide emissions, and decreased environmental impact.

The research and design of an ITTMS are imperative. It is a necessary guarantee for promoting economic and social development and raising the level of urbanization. Through the extensive application of artificial intelligence technology with an optimization algorithm, smart IoT devices can effectively alleviate the current status of urban transport management, which effectively promotes the coordinated development of the various traffic management departments in the city. It is essential to increase the research and development of the system design and use the Internet to build a more systematic and comprehensive intelligent traffic control/management system. It is the only technique to ease the pressure of urban transportation further, improve the level of ITTM, and realize the strategic requirements for
the sustainable development of the ITTMS. For example, judging from the current
development situation, the overall operational level of the ITTMS should be improved, and
efforts should be made to achieve the coordinated development of related industries.

2.4.2 Concept comparative evaluation

The proposed total transportation management concept is developed for smart cities as a sub-system integrated into the city operation management.

The transportation system's evaluation is a rather complicated duty, as all stakeholders (policymakers and regulators, vehicle developers, system developers, system operators, users) have their preferences. Therefore, hundreds of (performance) indicators can be defined [168]. For the entire system evaluation, the transportation system must be classified into several comparable groups, and overall indexes should be developed and applied. Because this study deals with the ICT, IoT based future transportation system, the transportation system classification is studied from the ICT point of view [169]. By using this concept, the transportation system can be classified depending on their monitoring and management as

- first generation: with few data from individual vehicles, interactions of infrastructure and vehicles through the traffic rules, control signals and management based on empirical models;
- second generation: early intelligent transportation system with some vehicles providing data; maintaining a balance between the supply and demand, using dynamic models and management;
- third generation: rich data exchange; mixed human and automated driving, active management;
- fourth generation: application of wireless technology, full monitoring, active communication between the infrastructure, vehicles, operation center, cloud computing, IoT, pro-active management.

More complex investigations lead to the following alternative classification:

- transportation with severe limitations – existing in old cities or in cities with large historical centers that generate significant limitations on the transportation systems;
- transportation with passive management – using traffic rules and traffic signals, only, including safe bus lanes, lanes for bicycles), this is a traditional transportation system;
- transportation with semi-dynamic management – implementing dynamic
management (as control of the traffic signals depending on real traffic, use of green lane concept, mass traffic control depending on the real passenger demand, changing in traffic direction depending on the traffic intensity, providing free routes for emergency transportation) in dedicated regions of the city; such system uses remote sensing (like video, sensors being integrated into the infrastructure, real-time data processing;

- transportation with dynamic and/or semi-active management – that – at least partly - is supported by a transportation system operational center, using cloud computing, IoT, dynamic or active control of motion of semi cooperating, connected and cooperating vehicles (starting from simple, smart parking up to active control on lane directions, multimodal transport hubs, total district transportation);

- transportation with active management (and partly intelligent) – that requires harmonization with the city operation center;

- intelligent total transportation management - as described above.

These different transportation systems can be compared by evaluating their performances and/or using indicators or transportation index(es). Based on the general KPIs of innovative transportation systems and the core indicators defined in transportation-related strategic documents, white papers, these indexes could cover the following major areas: (i) vehicle, infrastructure and transport system performance, (ii) amount and nature of support systems, (iii) legal control, (iv) economy, (v) society, (vi) environment, (vii) cultural aspects and (viii) future generation (future society needs).

Table 2.1 shows a straightforward quantitative comparative analysis of the chosen traditional (passively managed) transport, actively managed transport, and the proposed intelligent total transport management. All these areas are well investigated. For example, society needs, demand, and acceptations are studied by numerous references. The general assessments can be studied using an overall sustainable transportation index, which might be defined as total life cycle cost related to the unit of usage, as a unit of time. In such an index, all the cost means direct, indirect external cost and penalties taking into account the interest of the future generation must be evaluated.

**Table 2.1. Simplified comparative analysis of different transportation systems**

<table>
<thead>
<tr>
<th>Areas and indicators</th>
<th>passive</th>
<th>active</th>
<th>intelligent</th>
</tr>
</thead>
<tbody>
<tr>
<td>vehicle, infrastructure, and transportation performance (compared to traditional transportation) (e.g., vehicle speed, fuel consumption, operational cost)</td>
<td>100%</td>
<td>110-120%</td>
<td>115-130%</td>
</tr>
<tr>
<td>supporting systems (% of vehicles, drivers supported by service providers)</td>
<td>5 – 10%</td>
<td>15 – 30%</td>
<td>95 %</td>
</tr>
</tbody>
</table>
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| (e.g., mass transport, service provided, energy support system, parking availability, accessibility, multimodal transport hubs, emergency, accident handling) |  
| legal control (% of regulation the problems, aspects) (e.g., traffic rules, requirements for infrastructure, legal control of autonomous transport) | 35 – 50 % | 50 – 80 % | 75 – 95 % |
| economy (compared to the intelligent system = 100 %) (e.g., supply chain support, just in time arrives, delays) | 40 – 80 % | 75 – 90 % | 100 % |
| society (% of society needs being considered/covered) (e.g., demand, affordability, door-to-door speed, acceptance, safety, security) | 40 – 70 % | 60 – 90 % | 85 – 96 % |
| environment (change in the environmental impact using the recently available vehicles and infrastructures, compared to the traditional transportation solution) (e.g., emission, noise, greenhouse impact, energy sources, the energy mix in sources) | 100 % | 80 – 95 % | 70 – 85 % |
| cultural aspects (% of service provided for non-business travels) (e.g., recreation, health, sport, transport) | 20 – 40 % | 35 – 65 % | 60 – 80 % |
| future generation (ratio of the common solution compared to the solution optimized as a sustainable transport) (e.g., used materials, used energy) | 50 – 75 % | 70 – 90 % | 85 – 95 % |

The table above gives preliminary expert projections and requires further investigations. For example, the possible evaluation of society's needs or expectations during the last 40 – 60 years, society demand changed considerably. About 50 years ago, society's needs were mostly focusing on safety, while presently with the more complex transportation systems it is extended with, e.g., security, cost-efficiency, sustainability, on demand operations with higher door to door times.
Chapter 3

Drone-following models in smart cities

3.1 Introduction

Drones are regularly recognized as unmanned aerial vehicles (UAVs), exponentially growing over the past two decades. Many research papers have been reported in the field of UAVs and their applications.

Drones are gaining more popularity in the commercial sector and have found applications in many areas. For example, drones are used to detect areas of weeds and support for herbicides and fertilizers sprayed out over a low yield [170]. In this way, farmers not only save much money but also prevent touching the chemicals. Besides, a drone is developed, allowing operators to monitor pollution, the weather, and climate, especially hazardous areas like volcanoes [171]. Moreover, film companies use drones to capture aerial shots that one may see in the latest films and TV programs [172].

Another drone application strives to satisfy the transportation manager’s requirement for collecting trajectory data from main roads, in which drones have been used as a “bird’s eye view” [173]. This application is considered a novel and cost-effective solution for traffic management. ThIELS et al. proposed a package delivery system based on UAVs to transport medical products [174]. This system is expected to be an effective solution for transportation. However, the authors did not show the saved cost of this program than a conventional approach, although it seemed to be significantly lower.

At present, drones have been developed for their applications in smart cities, which can be reviewed in academic papers [175], [176], [177]. With the need for delivering services more rapidly and more efficiently to residents, drones are the best resolution because they have an enormous quantity of potential to help cities better serve the residents [68]. Drones are not only being used to improve city life but also are expected to increase significantly. However, this potential trend would bring both advantages and new challenges for theoretical and practical aspects.

Nowadays, drones have become an essential factor in connected smart cities [69]. Several aspects of drones regarding privacy and safety, as well as cybersecurity, were presented.

Wu et al. mentioned the concept of a swarm of UAVs that were used for urban sensing around the city [175]. However, this approach may raise new challenges of using and
managing drones in the traffic flow, such as collision avoidance and navigation. Several studied reports relating to these challenges can be found in [178], [179].

Besides, the delivery services must be quicker and more efficient to meet the demands of smart citizens. These demands can be satisfied by applying drones for delivering packages [180]. In this way, the customers may receive the purchased item within minutes, and the delivery cost is less than that provided by the traditional logistic networks.

It is expected that commercial drones will increase in the future due to their increase in recent years. For example, drones were introduced as drone-enabled services in 2015, in which the revenue was a more significant opportunity and would grow to $8.7 billion annually by 2025 [181]. The FAA also predicted that 30,000 drones could be flying in U.S. skies in the near future [182].

However, the larger the number of operating drones, the more accidents in the sky. It not only endangers civil aviation regarding security and infrastructure but also decreases traffic safety. Therefore, it is necessary to manage drones in traffic flows. The present study proposes a novel approach for the management of drones called the drone-following models. Such models are based on the initial idea that drones flight towards a leading drone in the traffic flow. A relative distance and velocity functions are used to describe such models. It is a new approach for managing a group of drones in smart cities to the best of our knowledge.

The next section presents a method for managing drones in the air transport system based on the drone-following models. The approach uses the follow-the-leader theory that is applied to dense traffic flow.

### 3.2 Drone-following models

In this section, we propose drone-following models. This approach is based on the theory that has been developed as a mathematical description of traffic flow. The states of drones are determined from the traffic flow data by identifying the coefficients in the equation system of motion. According to the theory, two drone-following models are proposed. The first model is used to keep safe velocity according to the related position of drones, while the second one describes the situation that a safe distance between two drones is maintained due to relative velocities. These models also represent the one-by-one following drone process in the traffic flow, which can be considered one kind of microscopic model in the transportation system. In addition, the drone-following models are expected to play essential roles in the development of intelligent transport systems and collision avoidance.

A structure of the drone-following model is described in Fig. 3.1. The state of the followed drone is determined by its characteristics and velocity, relative distance to the drone
Chapter 3: Drone-following models in smart cities

ahead, controller parameters, and weather conditions. Therefore, the followed drone’s velocity and position are mostly calculated from the traffic situation related to the drone’s velocity and position ahead.

Figure 3.1. A structure of the drone-following model

The drone-following models are proposed for the following purposes:

i) producing the realistic speed profiles;
ii) ability for generating the real traffic streams;
iii) stable realization of the traffic situations;
iv) simulation of traffic situations implemented by a different combination of drones and controller parameters;
v) ability to apply them in traffic control systems.

3.2.1 The safe distance model

The first drone-following model is based on the principle that keeps a safe distance according to relative velocity (SD). Such a model describes situations that the drone’s velocity depends on the traffic situation, namely on the distance to the drone ahead and its velocity. This approach has led to the linear models assuming that its controller controls the followed drone's acceleration to keep zero relative velocity to the drone ahead.

\[ m_n \ddot{X}_n(t + T) = \lambda \left[ \dot{X}_{n-1}(t) - \dot{X}_n(t) \right] \]  \hspace{1cm} (3.1)

where \( m_n \) is the mass of \( n \)-th drone; \( \ddot{X}_n(t + T) \) is the acceleration of \( n \)-th drone after a reaction; \( \dot{X}_{n-1}(t) - \dot{X}_n(t) \) is relative velocity of \( (n-1) \)-th to the \( n \)-th drone in time \( t \); \( T \) is delay time of a controller; \( \lambda \) is a weight coefficient related to the controllers.

Then, the SD model is given as follows:

\[ \ddot{X}_n(t + T) = \lambda \frac{[\dot{X}_n(t)]^p}{[\dot{X}_{n-1}(t) - \dot{X}_n(t)]^q} \left[ \dot{X}_{n-1}(t) - \dot{X}_n(t) \right] \]  \hspace{1cm} (3.2)

where \( p, q \) are parameters related to velocity and distance of the drone ahead; \( X_{n-1}(t) - X_n(t) \) is relative distance between the \( (n-1) \)-th drone and the \( n \)-th drone.

It can be noted that (3.2) describes a steady-state that satisfies the small velocity disturbances. Besides, the relative distance between drones contributes to (3.2) in matching experimental data. However, the spacing term is essential in mathematical models based on
an optimal control approach. This approach is to formulate an algorithm as a model of the following system, in which a safe distance between drones will be satisfied. It is expected that the method is more efficient when the drones fly in a row in the traffic flow.

If the model is used for a simulation environment, the historical data, such as acceleration, velocity, and position, will be stored for subsequent recalculations. Besides, it can be assumed that when the leading drone is held suddenly, the followed drone can maintain safety because of its controlled velocity.

The SD model is deduced by setting limits on the controller and drone's performance and using these limits to calculate a safe distance related to the leading drone. Such a model has the following characteristics:

i) the speed of the followed drone will accelerate if the drone ahead accelerates;
ii) the velocity of the followed drone will decrease if the drone ahead decelerates.

This model will be evaluated in a numerical environment with a small-time increment. The state of the drone ahead can be changed at each time increment. For example, if its velocity accelerates at a given rate at time $t$, it accelerates at another rate at the next time $t + \Delta t$. The velocity and position of the followed drone are then updated after each time increment.

### 3.2.2 The Markov model

The SD model is used and improved for different traffic situations in a numerical simulation environment. However, this model has two disadvantages:

i) the coefficients applied in the models intensely depend on the real traffic situations, the performance of drones, and the quality of controllers;
ii) this model does not take into account the advanced controllers.

The drone-following models do not describe a deterministic process, but they can be used as a stochastic process. The characteristics of advanced controllers, including relative distance and actual reaction time, are added to the control close-loop. This approach leads to an improved model called the Markov model.

The Markov model is based on the approximation of the stochastic process of velocity decision. One advantage over the SD model is that the inputs of the controller are different velocities and deviations in relative distance between the drones, which can be described as follows:

\[
\dot{X} = f(\dot{X}, t) + \sigma(\dot{X}, t)\eta(t) \tag{3.3}
\]

Using the Markov chain process, the developed model can be derived as follows:
\[
\dot{X}[k + 1] = c_v (\dot{X}_{n-1}[k] - \dot{X}_n[k]) + c_x [(X_{n-1}[k] - X_n[k]) - \Delta X_{pdn}] + \varepsilon[k] \quad (3.4)
\]
where \(\eta\) is the noise disturbing the process; \(c_v\) and \(c_x\) are coefficients which can depend on the time, given drone and controllers; \(\Delta X_{pdn} = [\dot{X}(t)]\) is the predefined safe distance between the drones; \(k\) is the number of steps in a chain \((t = k\Delta t)\); \(\varepsilon(k)\) is the random value disturbing the process.

The improved model is called the Markov model. It should be noted that the first term on the right side of (3.4) represents the bias of velocities, while the second part describes the deviation of the predefined safe distance \(\Delta X_{pdn}\).

As the predefined safe distance is a nonlinear function, we can use a linear function in the developed model as follows:

\[
\Delta X_{pdn} = \beta V_F, \quad \text{where} \quad V_F = \dot{X}_{n-1} \quad \text{is the velocity of the following drone;} \quad \beta \quad \text{is a positive constant.}
\]

Using discrete-time \(z\) defined as \(T = z\Delta t\), the acceleration on the left side of (3.4) can be substituted by \(\ddot{X}(k + z)\). Therefore, the Markov model is referred to as being a discrete-time stochastic process, which can be improved by using:

i) parameters, \(c_v\) and \(c_x\), for relative velocities and distances;
ii) time reaction, \(T\), depending on the actual relative distances, \(\Delta X_n(k)\);
iii) controller’s parameters depending on the real reaction time;
iv) estimated nominal values, \(\Delta X_{pdn}\) for the relative distances.

The improved model can be used to simulate the chaotic processes that depend on the parameters applied in the drone-following models. In the present study, the controller's delay time is the leading cause of the chaos in the drone-following process.

3.3 Simulation results and discussion

The main results of the numerical simulation experiments on the SD and the Markov models are provided in the present section. Besides, discussion and analysis based on these results are also provided.

The SD model assumes that the coefficient \(\lambda\) is inversely proportional to the distance between the drones. Therefore, this coefficient is constant in the study.

The values of parameters used in the numerical simulation are shown in Table 3.1.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
</table>

Table 3.1. The parameter values
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<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of drones</td>
<td>15</td>
</tr>
<tr>
<td>Initial velocity of drones</td>
<td>20 m/s</td>
</tr>
<tr>
<td>Safe distance</td>
<td>50 m</td>
</tr>
</tbody>
</table>

The values of the coefficients in the models are given in the figures below. The effects of changes in these parameters and initial conditions are also analyzed in the study.

Figure 3.2 demonstrates the acceleration of the leading drone.

![Figure 3.2. The acceleration of the leading drone.](image)

The following figures demonstrate the simulation results with SD and Markov models regarding the accelerations, velocities, relative velocities, distances, relative distances of followed drones. The model parameters are given in the figures.

![Figure 3.3. The accelerations of the followed drones.](image)
Figure 3.4. The velocities of the followed drones.

Figure 3.5. The relative velocities of the followed drones.

Figure 3.6. The distances of the followed drones.
It can be noted that there is no accident and no unrealistic deceleration. The velocity of the followed drone is changed according to the speed of the drone ahead. However, the followed drone can react quickly compared to the leading drone's reaction because of the difference in its acceleration. Such situations described the drone-following models precisely.

Even though the SD and the Markov models are quite similar, the followed drone's reaction in the SD model is earlier than that in the Markov model. Besides, the motion of the followed drone indicates that the stable state is slower in both models. In comparison with the SD model, the Markov model considers the changes in relative distance between drones. Moreover, in the Markov model, the more significant the variation of the followed drone's velocity, the much smaller the relative distance between drones.

In the present study, the difference in parameters is introduced to investigate these models' performance thoroughly. The results of numerical simulation are shown in Figs. 3.8 – 3.12 for the SD model, and in Figs. 3.13 – 3.17 for the Markov model.

Generally, the results show that when the parameter values are changed, the followed drones react slowly, which indicates that the time increment is increased. The impact of the SD model parameters on the results is shown in Table 3.2.

Table 3.2. Impact of SD Model Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decreasing $p$</td>
<td>Accelerations and velocities of the followed drones are decreased. These parameters are changed slowly. Time increment is increased.</td>
</tr>
<tr>
<td>Changing $p$, $q$ together</td>
<td>Accelerations and velocities of the followed drones are changed quickly. Time increment is reduced.</td>
</tr>
<tr>
<td>Reducing $\lambda$</td>
<td>Velocities of the followed drones are decreased. Time increment is increased. Relative distances are increased.</td>
</tr>
</tbody>
</table>
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Figure 3.8. The impact of SD model parameters on the acceleration.

Figure 3.9. The impact of SD model parameters on the velocity.

Figure 3.10. The impact of SD model parameters on the relative velocity.
Compared to the Markov model, the results changed significantly. It can be seen in Fig. 3.13–3.17.

By observing the results, it can be concluded that the state of motion of the followed drone depends on the model coefficients. This dependence is shown by the changes of accelerations, velocities, distances, and relative velocities and relative distances of the followed drones.

A summary of the impact of the Markov model parameters on the results is presented in Table 3.3.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increasing $c_v$</td>
<td>Accelerations and velocities of the followed drones are decreased. Time increment is decreased.</td>
</tr>
<tr>
<td>Increasing $c_x$</td>
<td>Relative velocities and relative distances are reduced significantly.</td>
</tr>
<tr>
<td>Changing $c_v$, $c_t$ together</td>
<td>Accelerations and velocities of the followed drones are changed quickly. Time increment is reduced.</td>
</tr>
</tbody>
</table>
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Figure 3.13. The impact of Markov model parameters on the accelerations.

Figure 3.14. The impact of Markov model parameters on the velocities.

Figure 3.15. The impact of Markov model parameters on the relative velocities.
The study results also show the impact of the initial conditions, which can be seen in the figures above.

Figure 3.16. The impact of Markov model parameters on the distances.

Figure 3.17. The impact of Markov model parameters on the relative distances.

Figure 3.18. The impact of the initial conditions on the acceleration.
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Figure 3.19. The impact of the initial conditions on the velocity.

Figure 3.20. The impact of the initial conditions on the relative velocity.

Figure 3.21. The impact of the initial conditions on the distance.
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Figure 3.22. The impact of the initial conditions on the relative distance.

It can be noted that the followed drones keep a safe distance to drone ahead even if the velocities are changed. When the initial velocity is reduced, the changes in accelerations and velocities between drones in the SD model are significant than those in the Markov model. It indicates that the performance of the Markov model is better than that of the SD model.

Based on the simulation results and analysis above, several suggestions are given.

i) Safe distance is measured not only the drone directly in front but also two drones beside;

ii) The controller outputs are based on the estimation of the state of the system at a particular time, which can be used to control the followed drones;

iii) Several situations, such as the increasing number of drones, or one drone can get in or get out of the traffic flow, should be introduced to evaluate the performance of the SD model and the Markov model more accurately.
Chapter 4

Simulation and testing

4.1 Concept requirement

Drones should be integrated into the ITTMS safely and proportionately. This integration should foster an innovative and competitive drone industry, creating jobs and growth, particularly for Small and Medium-sized Enterprises (SMEs). The proposed concept, ITTM integrating with drones, should set a level of safety and environmental protection acceptable to the society and offer enough flexibility for the new industry to evolve, innovate, and mature. This concept, motivated by the increasing of drone applications, urban total transport system, and UTM development, has demonstrated a good performance in dealing with complex and dynamic traffic flows.

Firstly, through the forehead research discussions, it can be remarked that drones' management is a vital concern in the city transportation system and the urban air traffic management system. Firstly, the transport system is a complex system, which becomes the essential tasks, which can be widely observed, analyzed, and managed by using an extensive distribution network of sensors and actuators integrated into a system communicating through the Internet. Secondly, aerial transportation will continue to increase and face new challenges such as more capacity, more efficiency, and more safety. Thus, the hottest topic of integrating UTM with a total transport-managing system is the management of drones in urban areas. The primary identified problems are passive surveillance, possible very high traffic intensity, and conflict detection and resolution, including conflicts with built obstacles. The solutions for these problems require the full integration of UTM into the urban transport-management systems and the development of unique methods for managing many vehicles in formation flight.

Secondly, advances in sensor technologies in hardware, software, and communications have created new opportunities for developing an ITTMS. The integration of sensor technologies with the transport infrastructure will enable a better, safer traveling experience and migration to ITTMS, which focuses on fundamental principles: sustainable mobility, integration, safety, environmentally friendly, effective, and responsiveness. These principles will play an initial role in obtaining the main objectives of the ITTMS, including access and mobility, environmental sustainability, and economic development. Besides, the advanced sensor technologies have extended the requirement to the ITTMS, such as road, water, train, and air transportation. For example, the new sensors MEMS (micro-electric-mechanical-system) have developed based on sensors and actuators, enabling them to apply a distributed
sensors networks, monitor the situations, and realize active control of the transport as a whole. Furthermore, using passive and active sensors like infrared cameras, video cameras, eye tracking, microwave radars, and signal transmitters, the ITTMS can be operated in passive monitoring of the operational conditions or active monitoring and detection modes. These sensors were built into the vehicle structures and systems, transport infrastructure, and operators’ working environment to measure the vehicles’ and operators’ reaction and generate unique signals and information.

As a result, the ITTMS are integrated with various communication and navigation systems that emerged with sensing technologies. Therefore, each object of the ITTMS is connected with others. The contract-based transport management concept gained much attention with the notion of total transport management. This method applied particular new types of control for urban traffic management, such as temporarily opening the lane crossing for the contract-based and priority vehicles. By obtaining real-time communication capabilities, contract-based transport management became capable of acting efficiently based on real-time information.

Finally, the development of the UTM has focused on the safe and efficient operation, including framework architecture [120], software application supported the decision-making process [183], evaluation of the UTM concept through flight-test activity operating multiple beyond-visual line-of-sight [184], flight planning tool for safe urban operations [185], operating regulations [186], cybersecurity [187], and collision avoidance based on cloud-based architecture [188].

In these platforms, drones were used as teleoperated vehicles through the Internet or radio-link, based on low-level services directly related to the basic drone movements. However, controlling and managing drones through the Internet or radio-link poses new challenges, which means that many drone applications, particularly airspace, raise the need for drone traffic management or, in general, UTM.

Therefore, UTM development for the urban drone operation must be reached the requirement for fully integrating UTM into the urban total transport-managing system and the development of unique methods for the management of various vehicles in traffic flow.

4.2 Concept verification

4.2.1 Investigation of the landing process of unmanned aerial vehicles

4.2.1.1 Principles of UAVs landing process

A UAV can be landing from any position in the air. However, landing for a UAV that is recovered by a parachute can be described as follows. The UAV receiving the landing command at current point M (Fig. 4.1) must land at predefined point 0. The approach and
landing process might be constructed from the straight lines and orbit curves. The distance from the point M to the end of reaching the landing coordinates, E, just before opening parachute, may contain two arcs of radius $R_{\text{min}}$ (MA and BE) connected by an AB line. From point E, the UAV descends the altitude (line EF) and declines the speed (line F0).

![Figure 4.1. The UAV landing approach process](image)

Therefore, the UAV landing areas include three zones as follows.

i) **Deceleration zone**: this is the smallest circle on the horizontal plane containing the projection of the orbit of the UAV, which flies straight with decreasing speed during the landing approach. Then, the shape of the deceleration zone is a circle with centre 0 and radius $R_1$ (see Fig. 4.2);

ii) **Descending altitude zone**: this is the smallest circle on the horizontal plane containing the projection of the UAV's orbit, which flies in the process of reducing altitude. This area is a circle with centre 0 and radius $R_2$ (see Fig. 4.2);

iii) **Directive zone**: this is the smallest circle in the horizontal plane containing projections of two circles with radius $R_{\text{min}}$ which two circles tangent to each other at the opposite of wind direction (see Fig. 4.2).

The $R_{\text{min}}$ is the smallest rounding radius of the UAV. Thus, the directive zone is the circle with centre 0 (the parachute opening point) and the radius $R_3$ (Fig. 4.2).
4.2.1.2 *The stages of the landing process and determining the landing areas*

Landing trajectories of aerial vehicles generally consist of approach, glideslope, and flare [189]. A successful landing would depend upon the excellent selection of landing trajectory and closely following it.

UAVs' landing stages consist of three stages: the directive stage, the descending altitude stage, and the deceleration stage. These stages are determined when the UAV is into each landing zones.

The most common method is to investigate UAVs' kinetic dynamics by solving the system of differential motion of aircraft, which is used to determine the landing zones. We only study UAV dynamics to calculate the deceleration zone, then use the analytical method to identify the remaining landing areas.

Landing zones will be determined by knowing the radius of each region.

*Calculating the radius of the deceleration region $R_1$.*

Based on the above analyses, the differential equations of motion of the UAV in the deceleration zone are described as following:

\[
\frac{dV}{dt} = \frac{-X}{m} \quad (4.1)
\]

\[
\frac{dx_0}{dt} = V_0 = V - w \quad (4.2)
\]
The above equations can be solved by using the fourth-order Runge-Kutta method and MATLAB software.

*Calculating the radius of descending altitude area $R_2$ is described in the following steps.*

The radius $R_2$ is determined from the conditions: descending altitude from $H \leq 500m$ to $H_{min} = 35m$ and speed $|V_y| \leq 5m/s$.

The time to decrease altitude from $H \leq 500m$ to $H_{min} = 35m$ is:

$$t = \frac{H - H_{min}}{V_y}$$ (4.3)

The distance of UAV is:

$$S = t(V - W)$$ (4.4)

The radius of the lowering altitude is:

$$R_2 = R_1 + \sqrt{S^2 - (H - H_{min})^2}$$ (4.5)

Calculating the radius of directive area $R_3$.

$$R_3 = R_{min} + \sqrt{R_{min}^2 + R_2^2}$$ (4.6)

Calculating the smallest radius of turning around $R_{min}$.

$R_{min}$ is the smallest rounding radius of the UAV and determined from the condition of the inclined angle of UAV $\gamma_{max} = \pm 20^0$.

$$R_{min} = \frac{[V - Wcos(\psi - \beta)]^2}{g.tg\gamma}$$ (4.7)

Where, $\psi$ – the direction angle of the UAV compared to the axis Ox.

$\beta$ – the wind direction compared to Ox.

$\gamma$ – the angle of inclination of the UAV.

*4.2.1.3 Determining the desired landing orbit on which the landing direction is opposite to the wind direction*

As the UAV can turn left or right to connect with the $R_{min}$ circle on the left or the right (following the wind’s direction), the UAV from a position with any vector speed can fly to
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the standard location for landing in four different orbits. After calculating four orbits, we compare them to choose the shortest one, determined by the desired landing orbit.

**Situation 1:** The turning left to reach the left circle (the orbit is MABEO, see Fig. 4.3)

![Figure 4.3. Landing approach connected to the left circle](image)

Table 1 shows the formulas used for calculating the distance of landing orbit.

**Table 4.1. Formulas used for calculating the distance of landing orbit.**

<table>
<thead>
<tr>
<th>The circle of left turning</th>
<th>The circle of left connecting</th>
<th>Angles</th>
</tr>
</thead>
<tbody>
<tr>
<td>( X_p = X_M + R_{min} \cdot \sin \psi_0 )</td>
<td>( X_B = X_C - R_{min} \cdot \sin(\eta + \frac{\pi}{2}) )</td>
<td>( \varphi = \arctg \frac{Z_p - Z_C}{X_p - X_C} )</td>
</tr>
<tr>
<td>( Z_p = Z_M - R_{min} \cdot \cos \psi_0 )</td>
<td>( Z_B = Z_C + R_{min} \cdot \cos(\eta + \frac{\pi}{2}) )</td>
<td>( \eta = \arccos \frac{R_{min}}{FP} )</td>
</tr>
<tr>
<td>( FP = \frac{1}{2} \sqrt{(Z_p - Z_C)^2 + (X_p - X_C)^2} )</td>
<td>( \psi_1 = \arctg \frac{X_p - X_M}{Z_M - Z_p} )</td>
<td></td>
</tr>
<tr>
<td>( X_A = X_p + R_{min} \cdot \sin(\eta + \frac{\pi}{2}) )</td>
<td>( \psi_2 = \arctg \frac{X_A - X_M}{Z_M - Z_p} )</td>
<td></td>
</tr>
<tr>
<td>( Z_A = Z_p - R_{min} \cdot \cos(\eta + \frac{\pi}{2}) )</td>
<td>( \psi_3 = \arctg \frac{X_C - X_B}{Z_B - Z_C} )</td>
<td></td>
</tr>
</tbody>
</table>
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\[
\psi_4 = \arctg \frac{X_C - X_E}{Z_E - Z_C}
\]

Based on these formulas in table 4.1, the distance of the landing orbit, in this case, can be calculated as follows.

\[
L_1 = R_{\min}(\psi_1 + \psi_2 + \psi_4 - \psi_3) + \sqrt{(Z_A - Z_B)^2 + (X_A - X_B)^2}
\]

(4.8)

**Situation 2:** The turning right to reach the left circle (the orbit is MA’B’EO, Fig. 4.3)

With similar calculations, in this case, the landing distance is:

\[
L_2 = R_{\min}(\psi_1 + \psi_2 + \psi_3 - \psi_4) + \sqrt{(Z_A - Z_B')^2 + (X_A - X_B')^2}
\]

(4.9)

**Situation 3:** The turning left to reach the right circle (the orbit is MABEO, Fig. 4.4)

![Diagram](image_url)

**Figure 4.4.** Landing approach connected to the right circle

The formulas used for calculating the distance of landing orbit, in this case, are shown in table 2.

**Table 4.2.** Formulas used for calculating the distance of landing orbit.

<table>
<thead>
<tr>
<th>The circle of left turning</th>
<th>The circle of right connecting</th>
<th>Angles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formula 1</td>
<td>Formula 2</td>
<td>Formula 3</td>
</tr>
<tr>
<td>----------</td>
<td>-----------</td>
<td>-----------</td>
</tr>
<tr>
<td>$X_P = X_M + R_{\text{min}} \cdot \sin \psi_0$</td>
<td>$X_B = X_C + R_{\text{min}} \cdot \sin \varphi$</td>
<td>$\varphi = \arctan \frac{Z_P - Z_C}{X_P - X_C}$</td>
</tr>
<tr>
<td>$Z_P = Z_M - R_{\text{min}} \cdot \cos \psi_0$</td>
<td>$Z_B = Z_C - R_{\text{min}} \cdot \cos \varphi$</td>
<td>$\psi_1 = \arctan \frac{X_P - X_M}{Z_M - Z_P}$</td>
</tr>
<tr>
<td>$X_A = X_P + R_{\text{min}} \cdot \sin \varphi$</td>
<td>$\psi_2 = \arctan \frac{X_A - X_P}{Z_A - Z_P}$</td>
<td></td>
</tr>
<tr>
<td>$Z_A = Z_P - R_{\text{min}} \cdot \cos \varphi$</td>
<td>$\psi_3 = \arctan \frac{X_B - X_C}{Z_B - Z_C}$</td>
<td></td>
</tr>
<tr>
<td>$\psi_4 = \arctan \frac{X_E - X_C}{Z_E - Z_C}$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Based on these formulas in Table 2, the distance of the landing orbit, in this case, can be calculated as follows.

$$L_3 = R_{\text{min}} (\psi_1 + \psi_2 + \psi_4 - \psi_3) + \sqrt{(Z_A - Z_B)^2 + (X_A - X_B)^2}$$  \( (4.10) \)

**Situation 4:** The turning right to reach the left circle (the orbit is MA’B’EO, Fig. 4.4)

In this case, the distance of landing orbit is:

$$L_4 = R_{\text{min}} (\psi_1 + \psi_2 + \psi_4 - \psi_3) + \sqrt{(Z_{A'} - Z_{B'})^2 + (X_{A'} - X_{B'})^2}$$  \( (4.11) \)

Choose the situation with the shortest flight distance:

$$L_{\text{min}} = \min(L_1, L_2, L_3, L_4)$$  \( (4.12) \)

### 4.2.1.4 Determining the desired landing orbit following a given direction

**Landing in the shortest distance when there is no wind.**

When the wind speed is less than 1 m/s, it can be assumed that there is no wind. If the land area does not have any obstacles, it is allowed to land in any direction, and we should choose the shortest distance.

In this case, when calculating the landing orbit, we just put the wind direction from the position O (the coordinate) to the point M (the current point of UAV) and then usually calculate as when landing in the opposite direction of the wind.

**Landing with the given direction.**

In some cases, when the landing ground does not allow us to land in any direction, but in a certain one (even when wind speed is less than 1 m/s), we can keep the same calculation as to when landing in the opposite direction of the wind. In this case, we consider the estimated wind direction as opposed to a given landing direction. We should notice that it must be the real wind direction when calculating the radius of the turning arc.
4.2.2 Cloud-based drone managing system

The Cloud-based drone managing system (CbDMS) motivated by IoT and the Internet of Drones (IoD) technologies have shown exemplary performance in dealing with complicated and active traffic flows. This platform has three main layers as follows:

i) **physical layer**, including connected drones and fundamental infrastructure;

ii) **cloud layer**, including storage, computation, and interfaces, is based on the wireless system, using the Internet, and

iii) **control layer** is a hierarchically organized software set used to control and manage drones in the traffic flows (Fig. 4.5).

Because of the increasing number of drone applications in smart cities, employing CbDMS in air transport in smart cities cannot be denied. In the following subsections, each layer of the CbDMS is shed light.

4.2.2.1 Physical layer

The physical layer is referred to as drones. Drones can take their tasks, including surveillance, traffic monitoring, wireless network applications, delivery [190], [191].

This layer attaches multiple network components and co-operations, such as drone-to-drone (D2D) or drone-to-target (D2T). The physical layer is connected with the IoT cloud by wireless technologies, including two categories: short and long-range [192]. The drones receive control signals and information about traffic situations from the cloud layer to guide their responses due to the desired ground control station (GCS) in the control layer. In the drone era, this transition is simple due to integrating drones with the IoT world.

4.2.2.2 Cloud layer

The cloud layer has three main components, including storage, computation, and interface components. Providing storage can be used to collect data about the environment, location, and mission information from drones and captured by this layer. Depending on the application’s requirements, this data is stored in a regular Structured Query Language (SQL) database or in a distributed file system, which helps perform large-scale batch processing on
stored data. Data process on the cloud has two types: (i) real-time stream processing, using to detect critical events or possible threats; (ii) batch processing, applied to monitor critical situations by storing incoming data. Several computation algorithms, such as image processing, Map/Reduce jobs, and data analytics, are executed in the cloud, reducing the processing time and improving performance. Interface components include network and web services interfaces, which are used to communicate between the physical layer and the control layer.

The cloud layer is also acknowledged as the center of the CbDMS, which is the central management unit of network operations. The layer aims to transfer the data between the physical and control layers and handle network management and resource allocation. The control layer, initially, specifies the required policy to the central controller in the cloud layer, and the controller passes those requirements to the drones in the physical layer. This operation will be done with the interface components' help based on Internet protocols [193], [194]. Furthermore, communication plays an essential role in transferring data from drones to the control layer, which provides higher efficiencies than conventional communication such as telemetry wireless communication. The cloud layer can also be equipped with advanced sensors or controllers that can manage time consciousness and data heterogeneity, providing higher efficiencies.

Interfaces in this layer can use a variety of different communication protocols such as cellular, wireless local area network (WLAN), low-power wide-area network (LPWAN), and wireless personal area network (WPAN) [195]. Depending on each drone application, goal, and overall need, more than one connection system can be used for more reliable information, sincerity, and quality. A Wi-Fi transmission system is used for commercial drone operation, where drones communicate directly with the central station without an access point. Besides, long-range wide-area networks (LoRaWAN) and long-term evolution (LTE) provide better reliability and low latency communication systems compared to Wi-Fi [196].

4.2.2.3 Control layer

The control layer, referred to as the GCS, uses to control and manage drones in the traffic flows. The GCS is essential for monitoring drones from a place near to or inside the flying field. The GCS collects, progresses, and transforms the information from drones and gives it to different users in a similar network.

This layer consists of application software that can send the control signal to drones and receive drone data. The users can record drones, set and modify task parameters thorough data analysis implemented by the cloud-based on such software. This application also enables remote pilot monitoring and controlling the drones and their tasks remotely by connecting/disconnecting available drones.
4.3 Simulation results and discussion

In this subsection, the author used all mathematical tools combined with the MATLAB applications to build up the algorithm and the program for calculating the desired landing orbits for UAV. The flowchart algorithm is given in Fig. 4.6.

\[
\begin{align*}
X_M, Z_M, H, \\
\Psi_0, \beta, W, V
\end{align*}
\]

\[
W > 1 \quad \text{T} \quad \text{F}
\]

\[
W = 0, \\
\beta = \tan(Z_M/X_M)
\]

\[
\beta = \beta' + 180
\]

\[
R_{\text{min}} = \frac{V^2}{g \cdot tgy}
\]

Calculating \( L_{\text{min}} = \min(L_i) \) to determine the turning direction

\[
\begin{align*}
\text{Landing in any direction} \\
\beta = \beta'
\end{align*}
\]

\[
R_{\text{min}} = \frac{(V + W \cdot \cos(\theta - \beta))^2}{g \cdot tgy}
\]

\[
|R_{\text{min}} - R_{\text{min0}}| < \epsilon
\]

Determining parameters to plot landing trajectory

\[
\text{End}
\]

**Figure 4.6.** The flowchart algorithm for calculating the desired landing orbits.
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Figure 4.7. The framework of the calculation and simulation program.

With this algorithm, we build up the framework (Fig. 4.7) to calculate and simulate the desired landing trajectories in 4 cases as follows:

Case 1.

Input data:

- Southern wind, wind gust 3m/s at 500 [m]
- The UAV’s position (X_M, Y_M, Z_M) = (2000, 500, 1500) [m]
- Flight direction: 0 [deg]
- The UAV must land in the opposite direction of the wind.

The simulation result is shown in Fig. 4.8.

In the Southern wind and the UAV must land in the opposite direction of the wind; the desired landing orbit is shown in Fig. 4.8. At the altitude H = 500m, the UAV completes two times of turning with the desired roll angle γ ≤ 20°; between these two times is a straight flying with speed V = 40m/s. For finding out the right orbit in the opposite direction of the wind, the start step is lowering the altitude, then finally straight flying in decreasing speed. The simulation result given is reasonable and necessary to implement controlling orders.
Figure 4.8. Landing in the opposite direction of the Southern wind.

The altitude, roll angle, and vertical velocity, in this case, are illustrated in Fig. 4.9.

Figure 4.9. The altitude, roll angle, and vertical velocity over time.

_case_ 2_

Input data:

- Southern wind, wind gust 3m/s at 500 [m]
- The UAV’s position \((X_M, Y_M, Z_M) = (2000, 500, 1500)\) [m]
- Flight direction: 0 [deg]
- The UAV must land in the given direction: 30 [deg].
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The simulation result is shown in Fig. 4.10.

If the UAV must land in the given direction although there was Southern wind, the desired landing orbit consists of two curves and two lines.

![Simulation Result](image)

**Figure 4.10.** Landing in the given direction although there was Southern wind.

The altitude, vertical velocity, and roll angle are shown in Fig. 4.11.

![Altitude, Vertical Velocity, Roll Angle](image)

**Figure 4.11.** The altitude, vertical velocity, and roll angle when the UAV must land in the given direction although there was Southern wind.

*Case 3.*
Input data:

- No wind at 500 [m]
- The UAV’s position \((X_M, Y_M, Z_M) = (2000, 500, 1500)\) [m]
- Flight direction: 0 [deg]
- The UAV must land in any direction.

The simulation result is shown in Fig. 4.12.

**Figure 4.12.** Landing in any direction.

When there was no wind, and the UAV might land in any direction, the desired landing trajectory is given in Fig. 4.12. The result shows that the landing direction is the direction from the current point of the UAV to the desired landing point, and this landing distance is the shortest one.

The altitude, vertical velocity, and roll angle, in this case, are also shown in Fig. 4.13.
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Figure 4.13. The altitude, vertical velocity, and roll angle over time.

Case 4.

Input data:

- No wind at 500 [m]
- The UAV’s position \((X_M, Y_M, Z_M) = (2000, 500, 1500)\) [m]
- Flight direction: 0 [deg]
- The UAV must land in the given direction: 30 [deg].

The simulation result is shown in Fig. 4.14.

Figure 4.14. Landing in the given direction when there was no wind.

The altitude, vertical velocity, and roll angle, in this case, are also shown in Fig. 4.15.
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Figure 4.15. The altitude, vertical velocity, and roll angle over time.

The simulation results in case 2 and case 4 are the same. When the UAV has to land in the given direction, the desired landing orbits are not changed if there was or not wind gust.

Small UAVs play an essential role in scientific meteorological investigations. The landing process is the most crucial process of the UAVs’ flight. To determine the landing areas, solving the system of differential motion of aircraft is used to calculate the desired landing orbit. The simulation results show the shapes of the orbits in different initial conditions. Although the wind is considered, the wind impacts in real-time do not perform in the simulation results.

As it will discuss, the developed methodology applied depending on the real situations (wind direction, wind size, humidity, etc.) results in the shortest orbits with a considerable reduction of the required landing areas and environmental impact.

4.4 Experimental study and evaluation

4.4.1 Components of a drone

The drones are a complicated part of technology, a mix of mechanics, hardware, and software that ensures a safe and smooth flight. Today, the autonomous control system, such as self-driving vehicles, is possible because of integrating new generations of computational and physical systems. The IoT devices play the most critical role in transferring from offline location (hardware) to online cyberspace (software).

4.4.1.1 Software

The software part is recognized as the system's mind, while the drone's brain is the
flight controller unit (FCU). This component is needed to ensure the drone and the user's specific and stable performance, including multiple layers such as firmware, middleware, and operating system. These layers connect users to the drone hardware, also called flight controllers.

Nowadays, several flight controllers can be used in a variety of drones because of their open-sourced packages, including Ardupilot [197], Pixhawk 4 [198], iNav [199], Paparazzi [200], and LibrePilot [201].

Generally, the performance of the software is associated with the hardware platform. The software components are critical because more robust hardware cannot hide the software element's incompetence.

4.4.1.2 Hardware

The hardware has several components, which are demonstrated in Fig. 4.16. A drone can connect to the cyber world through this hardware. Two essential components of a drone are sensors and electronic speed controllers (working as an actuator). Sensors can be classified into [195]:

i) proprioceptive sensors, measuring information internal for self-monitoring;

ii) exteroceptive sensors, measuring information external such as distance and altitude;

iii) exproprioceptive sensors, correlating the internal and external state of the drone.
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4.4.1.3 Communication unit

Controlling and managing drones in smart cities are monitored through communication systems. The exchange of information between drones and the GCS is solved by several solutions, including wireless communication, Internet of drone (IoD) solutions. However, the wireless connection must be a reliable, robust, scalable, and fast system for drone applications.

Besides, the communication of multiple drones will become more challenging at the same time. Although the multi-drone, sometimes referred to as cooperative drones, drone formation, or groups of drones, has significant advantages compared with single-drone. Still, it can cause considerable challenges regarding the broken link, bandwidth limitation, and power. While 2.4 GHz to 5.8 GHz frequencies are assigned to inappropriate guiding of the civilian drones, satellites are used in large-scale and military applications. Several existing wireless technologies, such as IEEE 802, 3G/4G/LTE, can be deployed for multi-drone applications [203].
Several issues should be considered and evaluated in drone communication, including the drone's speed, energy limitation, limited onboard storage, and antenna angle. For an instant, the antenna’s characteristics may cause a lower data rate and reduced radio range.

4.4.2 Experimental study

This subsection presents an experimental study of monitoring and controlling drones via the Internet (4G D-com Viettel). This exploratory study aims to evaluate the real-time performance of monitoring and controlling drones. This framework is built on hardware on the drone (Pixhawk PX4) and software on the ground (Mission planner).

The drone used in the experiments was built from airframe Z450 and processor Pixhawk PX4 responsible for its low-level motor control and body stabilization. This drone is equipped with a companion computer (Raspberry Pi 3B) used for streaming data between the drone and GCS. This drone also has a camera (Raspberry camera V1) used for ground observation and management. The video stream from this camera can be obtained via a Wi-Fi connection to be processed on the companion computer.

Besides, this testbed platform is to validate the proposed CbDMS, which provides the management and control of drone applications for delivery, surveys, security, ambulance, and emergency response.

4.4.2.1 Experimental setup

We carried out tests with a drone to validate the proposed approach and assess its achievement - the test situation of following a set of waypoints with a real drone in a particular area.

The materials to setup hardware are demonstrated as the following:

- Flight controller: Pixhawk PX4
- Companion computers: Raspberry Pi 3B
- Micro SD card: 16GB
- Camera: Raspberry camera V1
- D-Com: Viettel
- UBEC: HobbyKing™ HKU5 5V/3A UBEC
- Direct Cable for connecting companion computer to the flight controller.

The diagram of this testbed platform is illustrated in Fig. 4.17.
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Figure 4.17. The diagram of the testbed platform

The connection between hardware components is shown in Fig. 4.18.

Figure 4.18. The connection between hardware components

Using a direct cable to connect the Pixhawk’s TELEM2 port to the RPi’s Ground, TX and RX pins as shown in Fig. 4.19.

Figure 4.19. The connection between companion computer and flight controller
Ground control station (Mission planner) connects to drone through 4G Wi-Fi router (D-com Viettel), which allows monitoring and controlling the drone. Besides, the drone will receive mission and command through MAVLink messages.

### 4.4.2.2 Experimental results

The experimental result is demonstrated in Fig. 4.20. Initially, the drone was placed at a home position. When it received the GCS command, it take-off and did a mission, visiting the created waypoints. It is seen that the desired trajectory and actual trajectory are correlated. The gap between the two trajectories represents GPS location because the drone receives the GPS location.

![Figure 4.20](image)

Figure 4.20. The difference between desired and real trajectories (pink line – desired trajectory, blue line - real trajectory)

The attitude information, including roll, pitch and yaw angles are shown in Fig. 4.21-4.24.

![Figure 4.21](image)

Figure 4.21. The pilot’s desired roll angle in degrees – red line, the drone’s actual roll – green line
Figure 4.22. The pilot’s desired pitch angle in degrees – red line, the drone’s actual pitch – green line

Figure 4.23. The pilot’s desired yaw angle in degrees – red line, the drone’s actual yaw – green line

Figure 4.24. The difference between desired and actual altitude of drone, green line – desired altitude, red line – actual altitude
It can be observed that proportional-integral-derivative (PID) control is entirely sufficient to follow set position at low speeds. Thus, the drone aerodynamic changes slightly (such as no wind disturbance). For initial test flights, proper tracking was achieved, even providing the following errors on the scale of 2 - 40 (Fig. 4.21 - 4.23).

It can be seen that the propellers are susceptible to the pitch and roll dynamics. The FCU has tried to control the drone moving accordingly to the required pitch.

It is illustrated in Figure 4.24 that a linear controller achieved the altitude flight control with the increase in the vertical speedup. The FCU has performed extremely useful in height control despite a minor gap between the desired and actual altitudes.

During the experiments, the drone's video streamed downwards facing the camera, which can observe and control the drone in a real-time environment.

These experimental results have demonstrated that the proposed CbDMS is a cloud solution that enables managing and controlling drones in a real-time environment. The monitoring efficiency can be increased by raising the regularity of refreshing GPS coordinates or adding filtering techniques (Kalman filters).

### 4.4.3 Discussion and future research directions

I have presented a CbDMS to manage and control a drone in a real-time environment. Experimental results using real video captured by a drone demonstrate that the proposed approach can determine the desired trajectory's primary position and orientation.

The CbDMS is an advanced approach for managing drones to meet critical features. The CbDMS associates to real-time streaming, Cloud computing, regularly refreshed information, and intelligent acknowledgment to dynamically varying situations. With CbDMS, complicated missions can be taken with efficiency, improving safety and applicability.

It is necessary to examine the limitations of the proposed method. Firstly, it can be noted that the performance of controlling and managing real-time drones over the network is highly dependent on a guaranteed quality of assistance. Controlling drones over the Internet has two typical constraints: rigid real-time and soft real-time controls, which impose a safe and extraordinary quality of co-operation networks. For instance, operating a drone through the Internet may cause harm or crash to the drone because of a missing authority or request delay. An intelligent onboard device is the best solution to avoid crashes if a command is not received to overcome this problem.

In our experimental study, a drone autonomously followed a list of waypoints sent to the drone through the Internet. This constraint is soft real-time, which means that the Internet can deliver offline commands to the drone.
Secondly, drones can detect obstacles and plan their paths using onboard sensors that receive information in real-time. It means that drones can survey and gather environmental information. Keeping this information up to date enables online managing and controlling drones, one of the most advantages of drone applications. However, one drawback may occur in online trajectory creating and collision avoidance, such as less accurate due to insufficient input data. Regarding path planning and trajectories, several criteria, including whole journey length, fulfillment time, coverage field, and maneuvers, are applied to assess the execution of drone applications.

Finally, a drone used in our experiment is one of the most current testbeds for small drone evolution. However, its aerodynamics is sophisticated and requires to be correctly modeled to allow accurate trajectory checks. Several suitable FCUs have been developed and announced in the literature, which concentrated on a smooth trajectory, attitude, and altitude control, in controlled outdoor environments.
Chapter 5

Conclusions

This chapter summarizes the work of this dissertation and proposes potential development in the future. The chapter is organized as follows. Section 5.1 summarizes the contents of the previous chapters. The dissertation's contributions are reviewed in section 5.2, and some future research problems are recommended in section 5.3.

5.1 Thesis summary

Chapter 1 introduces the issues raised in the smart city total transport management and drone applications. The motivation here is the demand for air traffic management integration with a total transport-managing system to create an operational link between air navigation actors and the traffic-management system. This approach represents a formal and collaborative commitment between all the actors in a total transport-management system. The chapter presents a brief overview of the smart city, urban total transport management, and drone applications in smart cities.

An intelligent total transportation management system for future smart cities is presented in chapter 2. Such a system uses IoT to integrate vehicles with infrastructure, apply big data surveys of demands, require sub-model developments for safe and optimized transport management, and implement the highly automated total management. The urban total transportation system may include very different vehicles, solutions, such as users, service providers, transport managing, infrastructure, nature/built environments, regulations, competence & knowledge centres, supporting sub-systems, and passive and active interactions with other essential systems. The transportation segments' classification partly used a hierarchical concept is presented in this chapter, including passive or non-cooperating vehicles, semi-active or simple cooperating, active or cooperating, connecting vehicles, contract-based vehicles, priority transport, and supporting partners. A developed optimization method to solve the traffic optimization problem can be applied to optimize the vehicles' energy during their operation from the departure until the arrival point.

Chapter 3 deals with drone-following models, including the SD model, to keep safe velocity according to drones' related position. The Markov model described how a safe distance between two drones is maintained due to relative velocities. These models also represent the one-by-one following drone process in the traffic flow, which can be considered one kind of microscopic model in the transportation system. The numerical simulation results are also presented in this chapter, demonstrating no accident and no
unrealistic deceleration.

Simulation and testing to verify the concepts are presented in chapter 4. Besides the concept's requirement, the UAVs’ landing process is investigated to show the trajectories' shapes in different initial conditions. Furthermore, the chapter introduces a cloud-based drone managing system to manage and control a drone in a real-time environment. Experiments have been conducted with the results demonstrating the validity and effectiveness of the proposed approach.

Although this study presented the intelligent total transportation management system for future smart cities, the development of the concept, the methodology, and required sub-model, more details and justifications must be provided, especially on the limitations balking the rapid utilization of this methodology. Therefore, four classes of limitations could be defined:

- constraints supporting the optimization - even in case of using a simple and well understandable constraint as a door-door speed for moderate traveling distance, the constraint depends, e.g., on the size of the city, social habits, economic developments - thus, the constraints must be adapted to the given system;
- system composition - the ratio of non-cooperative vehicles, a lack in sensing sub-system, insufficiency in supporting systems like energy support, or the information on parking vehicles;
- acceptance by the stakeholders - legal control, acceptance of high-level automation, acceptance of control and commands from the operational centres, acceptance of operating conditions like the delivery product to the shops at night time;
- requirements in further developments - as possible dynamic optimization depending on the real transportation, size, intensity, disasters, or developing a particular artificial intelligent classification of the non-cooperative vehicles.

5.2 Theses

**Thesis I:** I have proposed a total transport management system in smart cities.

✓ I proposed a system that used the vast distributed network of sensors for surveillance and recognition of the non-cooperating, cooperating, contract-based, and priority transport vehicles, including three layers: physical, info-communication, and control generation.

✓ I have analyzed and developed an ICT concept based on the wireless network as distributed sensors and actuators and the Internet as IoT, which integrated into vehicles, infrastructure, individual vehicles, and a conventional single control
I provided the control layer that is a hierarchically organized software set. It is used to recognize and classify vehicles, traffic situation awareness, conflict detection, and resolution, including the sense and avoidance of the obstacles, other vehicles, and people.

I have demonstrated the system allows us to optimize the total traffic depending on objectives practical or energy or environmental impact minimization.

Related publications: J-2, B-3, B-4, B-5, C-3

**Thesis II:** I have proposed an intelligent total transportation management system for future smart cities.

- I have introduced a vision and a concept of managing the total transportation system by defining the concept, the methodology, and the required sub-model developments for the future intelligent transportation related to smart cities.
- I have classified the transportation segments partly used a hierarchical concept, including passive or non-cooperating vehicles, semi-active or simple cooperating, active or cooperating, connecting vehicles, contract-based vehicles, priority transport, and supporting partners.
- I have developed an optimization method to solve the traffic optimization problem that can be applied to optimize the vehicles’ energy during their operation from the departure until the arrival point.
- I have presented the role of data processing, applying the big data survey and methods of soft computing and artificial intelligence.

Related publications: J-2, B-3, B-4, B-5, C-3

**Thesis III:** I have developed the drone-following models to manage drones for smart city air traffic flow.

- I have developed a model based on the principle that keeps a safe distance according to relative velocity.
- I have developed another Markov drone-following model based on the approximation with the stochastic diffusion process of speed decision.
- I have created the numerical simulation environment that demonstrates the safe distance between drones is maintained; namely, there is no accident in the traffic flow.
- This approach can be applied to dense traffic flow. In addition, the first model can
be useful for studies of local stability.

Related publications: J-1, J-4, C-4, C-6

**Thesis IV:** I have proposed a new managing system for integrating drone motion into urban air traffic using the cloud-based approach.

- ✓ I have created a framework based on cloud devices and services such as computation, storage, and web services.
- ✓ I have improved a communication approach that allows users to control and monitor drones as connected objects in a real-time environment, which provides the management and control of drone applications for delivery, surveillance, security, ambulance, and emergency response.
- ✓ I did an experimental study, aiming to evaluate the real-time performance of monitoring and controlling drones.
- ✓ This approach's development used increasing the frequency of updating GPS coordinates or adding filtering techniques (e.g., Kalman filters) that can improve the monitoring more accurate and reduce noise.

Related publications: J-1, B-1, B-2, C-6

**Thesis V:** I have developed a methodology for determining and calculating the landing stages for UAVs.

- ✓ I have improved the differential system equations of specialized UAV motion using a parachute system to determine the more accurate the landing areas with reducing environmental impacts.
- ✓ I have developed a particular fuzzy control based orbits-straight line trajectory for increasing the UAV landing accuracy.
- ✓ I have created the simulation in a Matlab environment that calculates the shortest landing orbit, which is a desired one.
- ✓ The created methodology can be applied to the more complex task landing in city areas and moving or oscillating platforms.

*Related publications: J-1, J-3, C-2*

### 5.3 Scope for the future study

Potential future works concerning this dissertation can be explored in three main aspects as the following.

Firstly, intelligent total transportation management can be implemented in the
Chapter 5: Conclusions

described form, while it needs further studies and developments to increase its effectiveness. Future works could be focused on developing sensing non-cooperating vehicles, the short term prediction of the future size and intensity of the transportation system (mainly including the non-cooperative transportation), the development of dynamic and adaptive control/management for total transportation. Particular attention should be made to the infrastructure, supporting sub-systems as parking, energy supply, harmonization of connection of different transportation means at multi-modal centers, and operation centers' development.

Secondly, several situations regarding drone management should be continuously studied in the future. For example, a safe distance is measured directly in front and two drones beside. The other case is that the number of drones is increased. Besides, to obtain statistical estimates of certain functions and parameters for a preliminary evaluation of the mathematical models, it is necessary to design and conduct an experimental study to collect quantitative information regarding drone performance in space (one drone cannot pass another).

Thirdly, the investigation of the multiple drone traffic based on drone-following models should be extended. Furthermore, this study's extensions can be conducted in future research, including improving the proposed method to ensure more accurate operation and experiment with a group of drones that one can be a leader and others as followers.
Bibliography


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