UAV in smart cities – integration in the aviation system and solutions for safe operations

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Abstract

UAVs have a wide range of applications that can contribute greatly to the development of smart cities, as their usage can be cost-effective, available on demand, and environmentally-friendly. However, several challenges and issues such as safety, privacy, and security arise. Mentioned opportunities and challenges are identified in the paper by performing a backcasting approach method. To achieve UAV benefits, appropriate solutions for UAV's safe integration into the aviation system are needed. The main paper's objective is to provide, based on an analysis of UAV's possible applications and requirements from aviation system, as well as outputs from backcasting analysis, suggestions of possible solutions for UAV's safe operations. It is concluded that it is needed to develop and implement solutions that cover operational, technical, and safety requirements. Solutions regarding needed infrastructure (airspace zones and routes, droneports, etc.), UAV management systems in smart cities, UAV technical capabilities for collision detection and avoidance, and safety risk management approaches are recognized as crucial to enabling UAV safe integration into smart cities.

Keywords*: UAV, Aviation, Smart Cities, Safety, Backcasting Approach Method*

1 Introduction

The Smart Cities of the future will be developing as a result of the merging of many new-generation technologies and solutions. Regarding smart city design, the main goal is to provide efficient and environmentally-friendly infrastructures and services at reduced costs [1]. UAVs (Unmanned Aerial Vehicles) are recognized as an important solution with many opportunities that will be very beneficial for the population, and contribute to the economic growth and development of smart cities. However, several challenges and issues such as safety, privacy, and security arise. Moreover, as UAV's operational environment is airspace, the main concern is related to the safety of other airspace users – manned aviation.

The UAVs can have a relatively minor impact on conventional aviation as long as manned and unmanned aircraft were operated in a segregated manner. However, as both industries are moving closer to each other, with an expanding operational interface and an increasing number of overlaps, it is intuitively clear that mentioned impact can be changed within the coming years [2].

To achieve UAV benefits in smart cities, appropriate solutions for UAV's safe integration into the aviation system are needed.

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Aviation regulatory agencies take great efforts to create needed regulations to ensure a safe environment. Thus, the European Union Aviation Safety Agency EASA publication [3] contains the rules and procedures for the operation of unmanned aircraft based on adopted EU regulations. However, it should be kept in mind that the regulatory framework that will cover certain areas of application or potential concerns related to UAV integration in the aviation system, such as the usage of UAVs in smart cities, is still under development. It is intuitively clear that regulation development is connected with the development of appropriate solutions by the aviation community.

Several research works [4], [5], [6], [7] proposed different solutions that will contribute to the UAV safe integration in smart cities from different perspectives, mainly related to Air Traffic Control (ATC) systems features.

This paper aims to identify mentioned solutions as strategies that should be applied in the coming years, considering different levels of UAV integration in smart cities in the next 15 years. Proposed strategies will contain technological and policy solutions for safe operations.

Placing technological and policy improvement, in relation to the level of UAV autonomy and different intended applications, for the safe integration of UAS (Unmanned Aircraft System- presenting UAV with involved personnel and systems) in common airspace with manned aviation, requires the creation of adequate steps or scenarios on the trajectory to desired future. For this research, three different scenarios, covering the look of smart cities in the next 15 years (5+, 10+, 15+ years), will be created.

2 UAVs in smart cities

2.1 Opportunities

UAVs, originally developed and used for military purposes, have found applications in many civil sectors during the last decade.

As cost-effective, available on-demand, and environmentally-friendly solutions, UAVs have a wide range of applications that can contribute greatly to the development of smart cities [8].

Namely, the main strengths of UAV usage in urban areas include shorter operations distance (which enables faster operations, and consequently less greenhouse gas emissions), extended connectivity, and real-time information, but also flexibility, mobility, and accessibility to remote areas which enable ad-hoc operations with a great level of precision, and reduced response time [8].

In addition, UAVs can be equipped with various sensors and cameras for doing intelligence, surveillance, and reconnaissance missions. Furthermore, when equipped with appropriate equipment UAVs can be used for specific missions such as firefighting, de-icing/anti-icing of infrastructure, gardening support, etc.

Authors in their research [1], [8] list possible UAV applications in urban areas. Applications such as Geo-spatial and Surveying activities, Civil Security Control, Traffic and Crowd Management, Natural Disaster Control and Monitoring, Environmental Management, Wireless Communications, Commercial activities (like package deliveries), and Urban Air Mobility (UAM), are some of the expected usages of UAVs in future smart cities.

2.2 Challenges

Following the industry's tremendous development in recent years, the need for a system to support the safe and efficient integration and management of UAV into airspace has become essential. In Europe, main effort and plan to develop this system is called U-space and it is based on establishing U-space airspaces in which a minimum and mandatory set of services will be provided [9].

The document Concept of Operations (ConOps), developed by the CORUS-XUAM project team tries to answer the basic question "How does U-space work" and in doing so provides a common basis for discussion of details. The ConOps provides terminology and a general model of the overall system of U-space [10].

Because of the fact that aviation is the most vulnerable industry, since UAVs and aircraft share the same airspace and therefore potentially catastrophic consequences if collisions occurred, mentioned efforts start from the aviation sector.

However, as the way to a desired future will take a long path, to achieve mentioned benefits, it is also important to develop smart city

management systems and involved appropriate stakeholders. There are many questions that need to be addressed like providing adequate infrastructure, monitoring and controlling UAV operations, provision of information and assistance services to UAVs operator, emergency response plan, etc.

Accordingly, in comparison to the U-space concept, analysis within this research will be oriented also from the smart cities side, with aim of identifying strategies that needed to be developed and implemented for a safe aviation system with the presence of autonomous UAVs.

Detailed opportunities and challenges will be covered in the paper by using the backcasting approach, i.e. by imaging the future containing mentioned opportunities, and by analyzing requirements for a such look – challenges that need to be solved via different strategies.

3 Methodology

Backcasting is holistic approach, focusing on targets and desirable future [11]. It starts with defining a desirable future and then works backwards to identify strategies- policies and technologies that will connect that specified future to the present.

Backcasting methodology includes four steps [11]:

I. Identification of problem and targets
II. Definition of a baseline scenario
III. Design of future scenarios
IV. Analysis and assessment of technologies and policy packages (strategies) that could serve as pathways from the present to the targeted period.

Before starting with methodology steps, it is important to define system boundaries. For the purpose of this research, "full integration of UAV in the aviation system" is related to UAVs serving smart cities. Thus the use of airspace will be virtually vertically limited to the heights on which UAM operations in smart cities are expected because the heights that commercial manned aircraft use in the cruise will not be needed. This means that overlapping will be at airspace lower levels.

3.1 Identification of problem and targets

In this research, the target or desired future is smart cities with autonomous UAVs fully integrated into the aviation system (looking 15 and more years from now), in a way that the safety of the other airspace users (manned aviation) will not be compromised.

To achieve this and set appropriate solutions for safe operations, it is needed to consider different scenarios (in the paper it will be S1, S2, and S3) that will be expected in the following years (5+, 10+, 15+), i.e. steps on the path to desired future. The assumption is that the mentioned scenarios overlap due to unevenness in the development and integration of UAVs in different parts of Europe, and that is why the "year+" designation is used.

The problem can be formulated as: "What are solutions to create, organize and provide safe operations of autonomous UAVs in smart cities, fully integrated into the aviation system?".

Each scenario will be described with features regarding infrastructure look (operations environment), flight authorization service, operations identification and monitoring service, other information services, involved stakeholders, interaction with manned aviation, etc.

From the mentioned features of smart cities design in three designed scenarios will be, in the backward path manner, extrapolated requirements for such look i.e. strategies (policies and technologies) that will connect the specified future to the present, as illustrated in the figure below (Figure1).

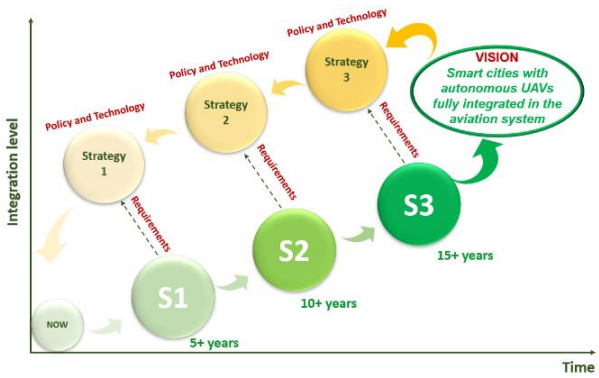

Fig. 1. Backcasting approach for UAVs in smart city

3.2 Definition of a baseline scenario

The baseline scenario, representing "now", includes several assumptions but also overlapped with S1 because of the mentioned unevenness in the development of UAV innovation and integration across Europe countries. Namely, following assumptions and features exist:

- A very small number (or without) of UAVs perform tasks that serve smart cities.

- The use of UAVs is exclusively limited to segregated volumes of airspace due to the absence of appropriate protocols needed for their integration into the auspices of the Air Traffic Management (ATM) system [12].

- Before UAVs start to access civil airspace, there is a need to be systematically and functionally recognized in terms of regulations. In the baseline scenario, the regulatory framework regarding UAV classification and airworthiness standards is settled by European regulatory agencies, and UAVs need to be certified. Similarly, UAV operators should be licensed by National Civil Aviation Authority (NCAA) after completing adequate training.

- Request for authorization for operations is submitted to NCAA enough time (days) in advance. On the day of operations, the UAV operator needs to conduct a self-briefing before each operation (for example by approaching MEUH- *Meteorology, Environment, UAV and Human* check, which includes pre-defined checklists with limitations) to decide whether to start with operations or not.

- It can be said that the overall system safety management approach is mainly reactive, in terms of if an unsafe situation occurs, the UAV operator needs to report it to the NCAA which will later analyze it and propose further measures to keep the system safe. The proactive side can be connected with the effort od European regulatory agencies through the development of standards and recommended practices (SARPS) that NCAA needs to incorporate within national regulation.

- Regarding involved stakeholders, NCAA has a central role and needs to communicate with ANSP to make a decision to authorize operations or not. This means that capacity in terms of processing requests for operations is limited.

3.3 Design of future scenarios

The following three scenarios are developed within the research:

I. *Scenario 1*: The future smart cities with remotely-controlled unmanned aerial vehicles used for on-demand government-related and security purposes, like emergencies (medical and firefighting applications), public security (police monitoring and patrolling), and recreational purposes, and operating outside the manned civil aviation airspace. The S1 considers the next 5 (+) years from now.

II. *Scenario 2*: The future smart cities with both remotely-controlled and partly-autonomous unmanned aerial vehicles used for a wide range of commercial applications (like package delivery), not fully integrated into civil aviation airspace. The S2 considers the next 10 (+) years from now.

III. *Scenario 3*: The future smart cities with swarms of autonomous unmanned aerial vehicles for different purposes including people mobility- air taxi, fully integrated into the aviation airspace. The S3 considers the next 15 (+) years from now.

The following Figures (Figure 2, 3, and 4) illustrates mentioned scenarios and are followed by a description in terms of their main features.

3.3.1 Scenario 1 (S1)

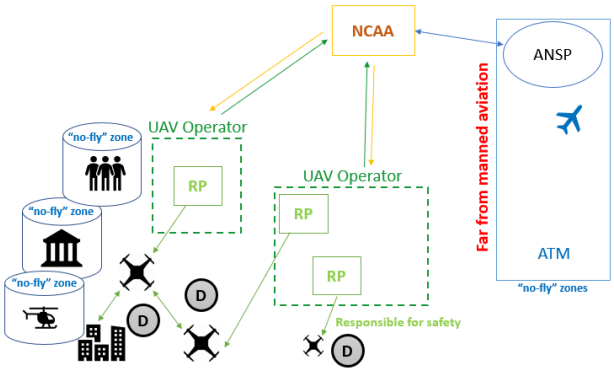

Fig. 2. Scenario 1

Within S1, all UAVs used for intended applications in smart cities (except recreational under defined criteria) need to be registered, and UAVs operators licensed, by NCAA. UAV operator request authorization for each operation from NCAA. The NCAA provides rules for flying including maps with pre-defined restrictive or "no-fly" zones, but also provides advisory services to UAV operators on request. The remote pilot (RP) is directly responsible for operations safety.

Airspace configuration includes segregated zones- for manned aviation, for UAV operations, and restricted zones. Airspace, where UAV operations are intended (uncontrolled airspace.), is far from manned aviation, and airports are presented as "no-fly" zones for UAVs. Other "no-fly" zones in smart cities include locations where a large number of people is expected (like schools) and buildings of importance (like state assembly).

The several locations created as start/ return positions for UAV operations will exist, named for this research as "droneports".

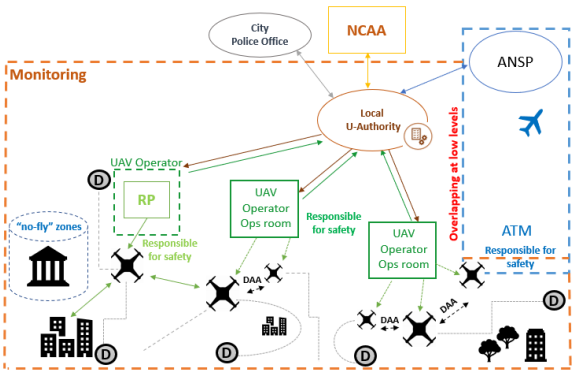

Fig. 3. Scenario 2

3.3.2 *Scenario 2 (S2)*

Within S2, there will be a specifically created organization, for example (proposed by authors), "Local U-Authority" consisting of representatives from the NCAA, Air Navigation Service Providers (ANSP), and the City Police Office, which will be responsible for monitoring and partly controlling UAV operations in smart cities.

Namely, "Local U-Authority" will have a role to incorporate interests from manned aviation, UAV operators, and local city police, with aim of maintaining the safety of all the actors (aircraft, UAV, people). The role of "Local U-Authority" will include UAV operator registration and operations authorization, but also the provision of available routes (pre-defined routes for specific UAV applications), daily operation plans, and traffic information service, all at the tactical level.

Within the operational level, "Local U-Authority" will have a traffic monitoring role, with channels for real-time communication with UAV Operators' operations room, while the procedural interface with ANSP will also exist because the airspace overlapping with manned aviation is expected at low levels near/ at airports (for example cargo terminals at landside airport zone).

The "no-fly" zones will remain for specific locations (buildings of importance). As mentioned, within the smart city's airspace, pre-defined routes for specific UAV applications will exist. Droneports will exist in more locations than in S1. The presence of some partly-autonomous UAVs is also expected. UAV operator is directly responsible for safety but in the overlapping airspace, safety responsibility is also on the "Local U-Authority" and ANSP.

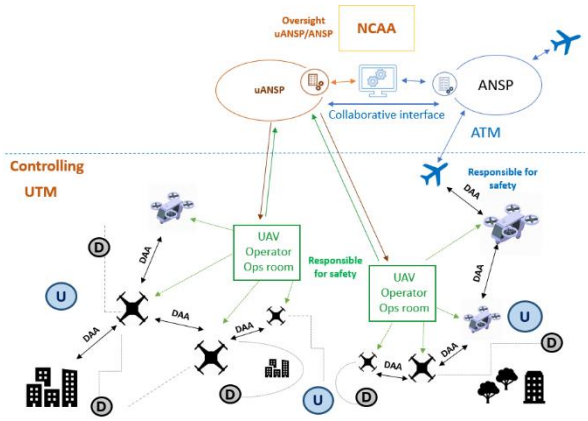

Fig. 4. Scenario 3

3.3.3 *Scenario 3 (S3)*

Within S3 there will be Air Traffic Management (ATM) and UAS Traffic Management (UTM) in one common airspace, with two responsible authorities - ANSP and, for example, "uANSP"(unmanned-ANSP), or ATC (Air Traffic Control) and "u-ATC" (unmanned-ATC), with a collaborative interface. Mentioned authorities will provide more services for UAS operators like real-time traffic information, weather information, etc.

Flight plans should be automatically processed via appropriate systems, enabling both higher

capacity and prevention of possible conflict situations.

Free routes airspace, but also, pre-defined routes and airspace corridors with points for creating new ones will exist. The droneports, and supporting objects are widely dispersed, for UAM there will be "U-ports" (like droneports but with specific supporting infrastructure such as passenger terminals). The "no-fly" zones will be replaced with airspace restrictions published in „uAUP" (UAV Airspace Use Plan).

As mentioned, in this paper is assumed that airspace overlapping is expected at low (take-off and landing) and medium heights (approach and climb), but not at cruising heights, because to serve smart cities, high levels for UAVs is not needed (maximum are tallest city building with an added safety buffer). Mentioned heights will be for UAM as enabling the shortest travel distances, while lower levels will be for commercial and other applications serving people in smart cities.

A large number of autonomous UAVs will be present, and the level of safety will mainly depend on the effectiveness of Detect and Avoid (DAA) solutions on UAVs.

4 Analysis and Results

Contrary to the manned aviation sector, the UAV industry capitalizes fully on the use of technology to favor automation instead of human interaction. However, the human factor cannot be excluded, as it will exist at some level through the role of RP, ANSP/"u-ANSP", etc.

By working backward to each defined scenario, the following policies and technologies are identified as three strategies (Strategy 1, 2 and 3) that will connect desired future to the present.

4.1 Strategy 1

Within Strategy 1, overlapping with the baseline scenario exists. But, to make the overall process of UAV operations efficient and safer in a considered period of time, improvements in terms of adopted technologies and policies should be incorporated.

Table 1 lists the policies and technologies proposed within Strategy 1.

The pre-defined risk assessment process, periodic knowledge refreshment for UAV operators to be familiar with the latest regulations, system of maps and rules for flying published by NCAA as a strategic operations management approach, will contribute to moving on a proactive safety management approach.

Regarding technological standards, the need for improvement is recognized both for UAV design (return-to-home maneuvers, color, and lightening standards, etc.), but also for "no-fly" zone solutions (anti-drone systems at airports and near state buildings, etc.).

Table 1. Strategy 1

Strategy S1
Policies and Technologies
1. Segregated airspace with zones
2. Rules for flying and appropriate maps issued by NCAA
3. Pre-defined return-to-home routes for UAV
4. Technological standards regarding UAV design (for example color and lightening, etc.)
5. Anti-drone systems at specific locations (at airports, near important state buildings, etc.)
6. UAS operator/ Remote pilot licensed by NCAA
7. Training for UAV operators with periodic knowledge refreshments
8. Operations authorization by NCAA according to defined procedures
9. Pre-defined risk assessment before each operation
10. Accident and Incident reporting to NCAA

4.2 Strategy 2

Within Strategy 2, the focus will be on the development of the UAV management system in smart cities. The creation of the proposed "Local-U Authority" will be one of the solutions (with the role described in detail within 3.3.1).

Besides, regarding infrastructure, it is proposed to define common routes for specific UAV applications, both because of safe operations, and to enable easy monitoring by "Local U-Authority".

DAA solutions need to be advanced in terms that are capable of maintaining a safe distance from other UAVs, buildings, and people.

With the proposed strategy, it can be said that Preventive Safety Management Approach will exist.

Table 2 lists the policies and technologies proposed within Strategy 2.

Table 2. Strategy 2

Strategy S2	
Policies and Technologies	
1.	Tactical capacity management system for smart city airspace
2.	Tactical flight planning (including adequate processing system) and Approval Concept
3.	Procedural interface with ANSP
4.	Tactical traffic information service
5.	Tactical conflict resolution system
6.	Monitoring system for initial tracking
7.	UAVs equipped with solutions that enable being visible on appropriate monitoring systems
8.	Channels for real-time communication with UAV Operators' ops room
9.	UAVs operator with the system to take control over the UAV in emergency situations
10.	Autonomous UAVs equipped with DAA solutions capable of maintaining safe distance from other UAVs, buildings, and people
11.	Contingency and Emergency Plan
12.	Real-time occurrence reporting system to "Local U-Authority"

4.3 Strategy 3

Table 3 lists the policies and technologies proposed within Strategy 3.

Within Strategy 3, a detailed UAV management system in smart cities will be incorporated into UTM. The main objective of the UTM must be safety, with a view of preventing collisions between UAV and manned aircraft and from one other along with preventing UAVs from colliding with buildings or obstacles and from falling on third parties on the surface.

Flight plans should be submitted to the automated flight plan processing system within "uANSP" for UAV operations and ANSP for manned aviation operations. Submitted flight plans need to be further automatically sent to a centralized processing system that checks the presence of possible conflict between intended operations of manned and unmanned aviation.

In this way, the proactive and predictive Safety Management Approach will be developed.

Regarding infrastructure, for free-route airspace, a high-level architecture with reliable and precision systems and links to support the UTM will be needed.

Table 3. Strategy 3

Strategy S3	
Policies and Technologies	
1.	Capacity management system on tactical and operational level
2.	Automated centralized flight plan processing system
3.	"uAUP"- UAV Airspace Use Plan
4.	Collaborative interface "uANSP" with ANSP
5.	Real-time traffic information service
6.	Advanced Monitoring system for tracking and controlling
7.	Conflict resolution system on the operational level
8.	Airspace violation control measures (for example drone catcher)
9.	Channels for real-time communication with UAV Operators' operations room
10.	UAVs operator with the system to take control over UAV in emergency situations
11.	Advanced DAA solutions compatible with ACAS for manned aircraft
12.	Implemented SMS - Safety Management System by all involved stakeholders
13.	Contingency and Emergency Plan
14.	Real-time occurrence reporting system

Advanced DAA solutions compatible with ACAS (Airborne Collision Avoidance System) for manned aircraft will be required.

Namely, in order to achieve the same level of separation and collision avoidance functionality as exist the case for manned aircraft, UAS should be designed in such a way that it effectively offsets the partial deprivation of situational awareness that is provided by a pilot inside the airframe. This could be done both procedurally and by increasing on-board systems functionality. Since some of the specific procedural actions cannot be performed by UAV directly, i.e. following other air traffic under ATC instruction, this is where UAV's capacity of performing autonomous actions comes into play [12].

The same applies in other instances such as loss of communication between the UAV and the Operations Control Room on the ground. In any case, UAS should have the ability to autonomous operation in secondary mode, which would clear the possibility of mid-air conflict by maneuvering different preprogrammed patterns [12].

Authors [13] research effectiveness of ACAS installation on unmanned aerial vehicles and shows that two of the three most influential factors are actually those within the Detect function. Therefore, more effort is required in the development of UAV system's elements that detect the conflict (sensors).

4.4 Future efforts

Ideally vision will be aviation system that enable airspace users to fly their preferred flight trajectories, delivering passengers and goods on time to their destinations as cost-efficiently as possible [14].

The European ATM system and network will not be able to accommodate the expected traffic growth and the new challenges without embracing digitalization at an accelerated pace. Thus, the further improvement will be delivering a digital European sky.

The digital European sky is an evolution of the European airspace architecture that leverages modern digital technologies to decouple service provision from local infrastructure. At the same time, it progressively increases the levels of collaboration and automation support through a data-rich and cyber-secure connected digital ecosystem. Airspace configuration and design will be optimized and the system should serve a growing number of increasingly diverse aircraft (manned and unmanned) integrated into all environments and classes of airspace, operating safely [14].

It is expected that this work will contribute to mentioned effort from the safety strategy side.

5 Conclusion

It is expected that in the next 15 years, increasing numbers of aircraft (conventional and unmanned aircraft) will be taking to Europe's skies, with the need to operate in all environments and classes of airspace.

Because of the numbers and the diversity of applications involved, adequate infrastructure will be required to support the safe operation of UAVs in smart cities. Needed infrastructure will be evolving from a model of airspace segregations- airspace zones, trough airspace with routes, to free airspace, while the supporting infrastructures will start from droneports to specific "U-ports" with passenger terminals, parking lots, etc.

In order to manage future traffic growth in the following years, safely while mitigating the environmental impact, UAV management systems in smart cities are needed. In the full integration scenario (S3 and beyond), it will be expanded into a UTM concept like ATM is for manned aviation.

Moving towards autonomy, UAVs rely on collision avoidance systems, which are recognized as the most important prerequisite for their safe integration into the airspace with manned aircraft, as they present direct and last system barriers to prevent mid-air collisions.

The safety risk management approaches are needed to be proactive, with developed and implemented SMS, including Emergency and Contingency Plans, within all stakeholders.

To conclude, to enable the safe integration of UAVs in smart cities, it is needed to develop and implement solutions that cover operational, technical, and safety requirements. This paper proposed mentioned solutions as strategies that should be applied in the coming years, considering different levels of UAV integration in smart cities in the next 15 years.

As mentioned, with the presence of a large number of UAVs and manned aircraft that will be expected in the following years, air traffic control services will be under the highest pressure, so the introduction of advanced digital technologies, followed by an appropriate regulatory framework will be needed. Thus, future research will be also expanded to the incorporation of digital transformation principles and changes that it will bring to the concept of UAV management systems for smart cities, as it will have a great impact on achieving a high level of aviation safety.

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