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# Digital Twin-based Unmanned Air Traffic Management for Emergency Response

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***1. ABSTRACT:*** The use of drones or UAVs for commercial and civilian purposes has grown steadily in the last years, however the legislature governing their use is very slow to adapt to the new possibilities that the developing technology delivers. The existing regulations are mostly based on commercial flight regulations and do not encompass the whole spectrum that the UAV solutions can provide. While each country follows their own regulations, most are still restrictive for a broader use of UAVs. The use of UAVs for emergency uses, surveillance, and monitoring has been broadly studied. As such UAVs can be used to transport human organs or medical supplies, detect forest fires, monitor flooding, provide or extend communication range in case of outages, etc. The current regulations in most countries with their restrictions currently do not provide a viable solution to fully employ this UAV capabilities without a lot of administrative work. As the use of drones can pose a hazard for the population as well as the environment, solid regulations are necessary to minimize any risk, however too strict regulations can prevent an efficient use of drones. Changing the regulations to provide a broader use of drones would only increase the risks without addressing the main issues. A digital platform for unmanned aerial traffic management proposed in this paper addresses these issues directly and provides grounds for the changing of the regulations to allow a broader use of drones. Designing the platform as a digital twin of the aerial surveillance process allow for detailed overview that not only observes the currently active UAV data but can predict potential hazards and act accordingly to prevent them or minimize their effects, this increasing overall safety of UAVs, the environment, and general populace.

***Keywords:*** *UAV, Flight regulations, Air traffic management, Digital twin.*

## 2. INTRODUCTION

Drones or unmanned aerial vehicles (UAV), are an unmanned aircrafts guided by remote control or on-board computers. The wingspan of unmanned aerial vehicles can be up to 61 meters and there weigh up to 15,000 kilograms. They can be used for commercial, military, and home-use purposes. We can classify them into three main areas of application: civilian, environmental, and defence (Macrina et. al, 2020). The number of drones is increasing and according to the Federal Aviation Administration (FAA) on October 27, 2020 there were 1,726,726 drones registered in the United States alone (FAA, 2020). The demand for drones is increasing, as is their development and use versatility.

Contemporary research confirms that along with classical commercial use, the drones are increasingly more employed in emergency situations where they can provide either necessary equipment or surveillance capabilities.

That there is still a lot of place for development here is shown in the study by Zailani et al. (2020), which notes a significant deficiency in the number of reported studies analysing mode of medical product transportation and adaptation of drones in maternal healthcare. They suggest that a future drone research framework should focus on maternal healthcare-specific drone applications in order to reap benefits in this area. Korent, Smereka, and Szarpak (2019) believe that the use of drones for medical purposes brings many advantages, such as quick help, shortening the time of traveling to the patient, reduction of complications in the injured owing to a short time to wait for rescue, support and improvement of basic operations of medical emergency teams, and the opportunity to reach places inaccessible for basic means of medical transport (e.g., because of floods and blocked roads). One of the areas where drones are and will be very useful are emergency situations for the delivery of automated external defibrillators (AEDs).

Seding et al. (2020) in their research came to the conclusion that drone-delivered AEDs may be feasible and effective but successful uptake in smaller communities will require a deep understanding of a community's cardiac arrest literacy levels, information needs, and readiness for innovation. They believe that this work will inform a robust community engagement plan that will be scalable to other locations considering a drone AED program. Cheskes et al. (2020) and Zègre-Hemsey et al. (2018), furthermore believe that AED drone delivery is feasible, with improvements in response times during simulated out of hospital cardiac arrest scenarios. Their opinion is that AED drone delivery has the potential to decrease the time to defibrillation in rural and remote communities. Further research is required to optimize the integration of drones into the emergency response system, as well as improve strategies to simplify bystander application of a drone‐delivered AED. Mermiri, Mavrovounis and Pantazopoulos (2020) found out that while drones have the potential to dramatically improve cardiac arrest patient care, further studies are needed to evaluate their effectiveness in real-life clinical scenarios. Yakushiji et al. (2020) in their study examined UAV-assisted transportation in Japan, a natural disaster hotspot, with a focus on the potential uses of UAVs in situations where traffic blockages make ground transportation impossible. Their conclusion is that UAVs can be used during disasters, especially when traffic is blocked in both urban and suburban areas, in affected areas where people's survival is threatened by medicine and medical supply shortages, and in areas where there is a need to secure food after the disaster. A drone that is equipped with a portable AED can fly from a base station to the patient's site where a bystander receives it and starts treatment. In paper written by Wankmüller et al. (2020) were considered such a response system and proposes an integer linear program to determine the optimal allocation of drone base stations in a given geographical region. In detail, the developed model follows the objectives to minimize the number of used drones and to minimize the average travel times of defibrillator drones responding to sudden cardiac arrest patients. In an example of application, under consideration of historical helicopter response times, the authors have tested the developed model and demonstrate the capability of drones to speed up the delivery of AEDs to sudden cardiac arrest patients. Results indicated that time spans between sudden cardiac arrest and early defibrillation can be reduced by the optimal allocation of drone base stations in a given geographical region, thus increasing the survival rate of sudden cardiac arrest patients.

While providing necessary equipment in timely fashion can be one of critical uses of drones in emergency situations, other most commonly used are for providing monitoring capabilities in disastrous events to provide critical information to responders. As such valuable data can assist firefighters through fire monitoring. Sudhakar et. al (2020) research the possibilities of image analysis for detection of fire forests. The drones are used to provide a quick overview of affected areas, while the visual inspection is not their main but instead analyse the images for smoke detection and evaluate them for fire potential. Lindner et. al (2015) researched capabilities of UAVs for landslide monitoring and found that measurements taken by the UAVs provide a cost as well as time-effective way to gather data and allow their further analysis. While immediate emergencies, proper monitoring at regular intervals can trigger alerts and allow to manage such events on time. Along with monitoring UAVs have proven to be a useful tool for search and rescue missions in less accessible areas where fully autonomous UAVs can be employed in search and rescue operation and avalanche events.

Numerous uses of UAV to ensure increase security and provide support in emergency situations exist today, however the governing legislative does not provide full support to employ the full potential of drones. With an increased use of UAVs in the future the requirement of a comprehensive overview system is a necessity. With an ever-increasing traffic and various events that take place in the urban environment the overview of all critical occurrences is a necessity to ensure the safety for all participants. In this regard, much of recent research has been focused on digital twins.

While the origin of the digital twin concept can be found in manufacturing it has since been applied in various areas. A digital twin is a digital representation of a physical product, process, or service as described by Qi et. Al (2019). This representation is based on real-time data acquired by sensors as well as on historical data that can be used to improve the digital model of the physical world. Although there are different views as to what a digital twin is (Schleich et. al (2017), most of the interpretations describe it as an advanced simulation and optimization approach that does not focus solely on modelling a single product or process but can work as a merger of combination of different simulation models. Although digital twins may be mostly researched in manufacturing and product life cycle modelling, the approach has proven to be useful for simulation of any of more complex systems.

Digital twins indicate great opportunities for modelling and managing the processes in cities, supporting the transformation to Smart cities (Farsi et. al, 2020). As a Smart city's functioning is based on collecting and processing data, this may be limited to subsystems governing specific areas such as traffic and transportation, energy management, healthcare, security etc. While each of the subsystems could be modelled by digital twins to provide individual modelling of the said areas, however by linking information provided by sensors to be used by all participants can provide an all-inclusive overview and yield opportunities to optimize the quality of life and increase overall safety.

An increase in UAV use in an urban area will increase potential hazards to property, environment or population. Similarly, as regular traffic can be governed by an information system and incorporated into the Smart city digital twin, the same concept can be arranged for air traffic control. A systematic overview of the UAV activity in urban is necessary in order to ensure safety and avoid accidents or at least minimize their consequences. As such a complete unmanned air traffic management system (UATM) that is incorporated into a digital twin of a Smart city can provide the solution to the presented problem. By accessing the collective data of all Smart city parties, the digital twin can detect or even anticipate increase in traffic, gathering of people, emergency situations, and other events, and react according to them.

According to this the UATM system should not only provide surveillance of the airways and UAV activity, but must also incorporate any crucial events provided by the Smart city digital twin. As a participant the system must also provide the data to the twin for instance by informing proper authorities about accidents or other events to guarantee timely action. The application of drones in Smart cities has been researched by Mohammed et. al (2014), where opportunities included remote surveying, surveillance for security purpose, traffic management, disaster control and monitoring among others.

Either incorporated into a Smart city solution or an autonomous UATM system implemented properly is necessary to ensure safety, which one of main reasons for the slow progress of regulations covering unmanned flight. A solid technological solution that prevents accidents and enables a rapid warning system support would set the foundation for changing the regulation in order to provide new opportunities. As such Yun et. al (2022). propose reinforce learning for managing multiple drones for surveillance purposes.

While much research is done in this area, there appear to be diverse approaches that ignore the regulative branch of the problem. This paper explores a solution that follows the European U-space framework guidelines and thus adheres to the regulations while providing advanced features to ensure automation on a higher level.

## 3. UAV REGULATION OVERVIEW

The lack of regulations hinders the use of UAVs for emergency as well as commercial use. While the past restrictions applied to the use UAVs have been the result of slow legislative development, the direct result this is slow progress in the commercial and civilian use of UAVs. As such it depends on local regulations of each country to set the requirements. Providing a complete set of regulations for can ensure a safe and responsible use of UAVs that allows new business opportunities as well as increase safety by providing new approaches such as transporting medical supplies or monitor hazardous conditions.

### *3.1.EU Regulations*

In Europe, drone regulations are handled by the European Union Aviation Safety Agency (EASA). EASA is the centrepiece of the European Union's strategy for aviation safety. They ensure that flights are safe in all phases: beginning with the rules the airlines and crew need to follow through to the certification of the aircraft. The latest European regulation dictate drone users will be legally obliged to register as users of their drones with their national aviation authorities from December 31, 2020, when the European regulation on drones (EU) 2019/947 takes effect. Most important EU Regulations for operations in open and specific category are Commission Delegated Regulation (EU) 2019/945 and Commission Implementing Regulation (EU) 2019/947. First one is about technical requirements and third country operations, entered into force and became applicable on 1st July 2019. The second one is operational requirements and registration which also entered into force on 1st July 2019 and became applicable on 1st July 2020. Some of those most important regulations for all kind of drones' category define that the during flight, the unmanned aircraft is maintained within 120 metres from the closest point of the surface of the earth, except when overflying an obstacle, the remote pilot ensures that the unmanned aircraft is kept at a safe distance from people and that it is not flown over assemblies of people. The maximum take-off mass of unmanned aircraft has a less than 25 kg. During flight is for the unmanned aircraft prohibit carry dangerous goods and drop any material. Operations in subcategory A1 must comply with the conditions carried out in such a way that a remote pilot of the unmanned aircraft does not overfly assemblies of people and reasonably expects that no uninvolved person will be overflown. In the event of unexpected overflight of uninvolved persons, the remote pilot shall reduce as much as possible the time during which the unmanned aircraft overflies those persons in some cases flying over people also is not allowed. For subcategory A2 applies if the unmanned aircraft does not overfly uninvolved persons and the UAS operations take place at a safe horizontal distance of at least 30 metres from them; the remote pilot may reduce the horizontal safety distance down to a minimum of 5 metres from uninvolved persons when operating an unmanned aircraft with an active low speed mode function and after evaluation of the situation regarding: weather conditions, performance of the unmanned aircraft and segregation of the overflown area. For some category applies that safety distance is keeping a minimum horizontal distance of 50 meters from people. Operations in subcategory A3 shall be carried out at a safe horizontal distance of at least 150 meters from residential, commercial, industrial or recreational areas (Commission Implementing Regulation (EU) 2019/947).

As of 2016 the U-space framework has been established in order to address both future regulation development as well as technologically required adherence to the regulations (Huttunen, 2019).

### *3.2. U.S.A. Regulations*

In the USA the regulations about Unmanned Aircraft are under Federal Aviation Administration (FAA). The responsibilities of FAA are regulating civil aviation to promote safety within the U.S. and abroad. In U.S. Unmanned Aircraft need to be register if it weighs more than 0.55 lbs. (250 grams) and less than 55 lbs. (25 kg). For commercial flights is required a commercial pilot's certificate issued by the FAA. Some operational limitations by rule 107 are that flying is permitted only in Class G unmonitored airspace. Regulations also determine that the maximum flying altitude is 400 feet (120 m). The UAS must always be able to be seen by its operator without using binoculars. Flying is permitted only in daylight for a UAS without lighting. Flying is allowed in civil twilight if the UAS has lighting. Flight speed is limited to 100 mph (160 km/h) or less. Preference is given to manned aircraft and flying directly over people it is not allowed ("Summary of Small Unmanned Aircraft Rule" (Part 107) [FAA News], 2016).

## 4. UNMANNED AIR TRAFFIC MANAGEMENT (UATM)

The current procedure to perform UAV flight mission for personal, or commercial use requires applying for a flight permit in advance, which can be time consuming and requires a lot of manual work. As such, this approach also does not provide any real capabilities for monitoring the flight missions or detect potential hazards to the UAVs themselves or more importantly, hazards to the civilian population or the environment. To provide a systemic approach to handle both approval as well as detect hazards while on mission we propose an IT platform that will manage all aspects required by the regulations and provide a solid foundation to monitoring of ongoing UAV flights. The proposed platform follows the U-Space guidelines.

### *4.1.UAV flight registration*

The UATM platform will require the UAV operators to register online by providing a valid license. Along with operators, any UAV that is intended for use must also be registered, providing data such as manufacturer, model, battery type/capacity, battery status, maintenance log, acceleration, top speed, etc.

An operator must log on to the platform in order to apply for a flight mission where he needs to upload the following data:

- UAV ID
- UAV operator ID
- Starting location
- Destination location
- Cargo type
- Requested sensor use
- Mission purpose

Depending on the provided data the system checks the provided data in order to either approve or deny the flight mission request. For the system to approve the flight application the license validity check for the operator is performed as well as battery status for the UAV. While the operator uses a mobile application for communication and flight requests, the UAV must also maintain a constant uplink with the platform in order to send its main information for flight approval, and later for flight control. With a valid operator and UAV status (proper battery voltage, error checking, etc.) the next check is on the start and destination locations and whether a safe route between both points can be generated – the route must not cross no-fly zones, protected environments in case of hazardous cargo, avoid watery areas, populated areas etc. Another issue that needs to be addressed is the use of sensors and privacy concerns. While the system automatically analyses the data for a requested UAV flight and proposes an approval or denial based on hazard checks it can automatically confirm the flight, or provide the suggestion to an UATM administrator for further study.

Once a UAV flight mission is approved the flight must take place under strict supervision by the UATM system. For this purpose, the UAV operator must be provided by restrictions, which he must comply with at any time while the mission is on. The requested flight mission data that is processed by the platform service generates the complete mission description that needs the actual UAV flight is required to follow strictly. The approved mission includes:

- UAV flight mission ID
- Emergency landing locations
- Hazard assessment
- Allowed sensor use
- Mission start time
- Flight route
- Flight time window

The flight route or corridor is generated depending on the requested starting and landing location. While a straightforward approach would be to generate the route by elevating vertically from the starting location to a maximal allowed altitude, then translating to the destination location and lowering to the ground, terrain or surface features may provide obstacles. Furthermore, depending on the cargo type, certain areas above the terrain may need to be avoided. For this purpose, the platform generates the flight route over a 3D terrain hazard map, avoiding areas which could pose an environmental or safety hazard. Along with the flight route a time window for the UAV mission is generated, requiring during the active mission that the UAV passes certain areas of the flight route at a predefined time. The generated flight route and its complementary time window is checked for intersections with any other approved or active flight routes by other UAV missions. If there is a possibility that two (or more) UAVs might cross each other paths within a reasonable time frame the mission request is either declined or the start (and the whole time flight window) is postponed to such a time where no critical intersection is expected. The allowed sensor use may be overridden from the requested one in order to comply to privacy requirements. For instance, a requested camera use or recording may be declined near a populated area.

### *4.2. Active UAV flight mission monitoring*

During a flight mission the UAV must keep a constant connection with the UATM system, and send telemetry data at regular intervals that among other includes:

- UAV flight mission ID
- GPS location
- GPS time
- Battery voltage
- Active sensor status
- Accelerometer data
- Vibration measurements data
- Events

At any time, the system must provide capabilities to collect data from all active UAVs and detect any hazards that appear. This includes checking whether each drone is at the expected place at the expected time – following its predefined flight route and flight time window. Although the system should not allow crossing of different flight routes, additional checks are made to detect if GPS positions of UAVs are entering the safety area of other drones, in which case the operators are prompted to pay attention to the activities, to alter their course, or to perform an emergency landing.

Similar measurements can be taken at other events, such as a sudden drop in battery voltage, spikes in accelerometer data, which indicated unexpected events such as high winds, performance issues, or any other events that can be detected by UAVs on-board sensors.

With all telemetry data being sent and stored at the platform, the system provides an external black box with any events stored in the database for all active flights providing an audit trail to check for any inconsistency. The proposed UATM system can provide grounds for the changing of existing regulations to allow a broader use of UAVs for commercial and civilian use, while maintaining a high security level and minimizing exploitations. All UAV use would need to register on the proposed system, which would provide a strict overview of the UAVs, their condition, maintenance records, batteries status, which can provide an environmental as well as safety hazard.

As any UAV in use as well as the operator need to be registered determining the responsible parties in case of accidents can be backtracked by analysing the logged data. All flight data uploaded to the UATM database can be used for later analysis of any incidents.

Regulations should require that only registered operators and UAVs be allowed UAV activities as any other, including for recreational use may pose a collision threat. By tracking the GPS position of any active UAV, the system can be used to provide data to other parties of interest such civil flight institutions, in order to prevent collision for instance with helicopters active in the same area, although generally the system should avoid such occurrences by force landing or redirecting active drones. In case of the operators not complying with the instructions by the UATM, either engaging in not allowed recording or straying off the designated route the system sends warning message. Continued ignoring of the warning should be penalised by paying fines according to the transgression or even by revoking the license or confiscating the UAV.

While the proposed system produces the directions that need to be followed by the operator, a possible solution to prevent abuse is by programming the drones to adhere to the UATM override signal. In this case the system would check against recurring irregularities in the flight plan (position, active camera/recording, etc.) and send the signal to force a landing at one of the generated emergency landing sites, while notifying the authorities about the incident. Any airborne drones not managed by the system should be considered as intruders in the airspace that pose a threat to population and legally operated UAVs.

As drones can share the airspace with other members such as gliders paragliders, balloons, a valid consideration is to require all participants apart from civil aviation to use UATM system. While the UAVs can communicate via the ground station or other participants can use mobile devices for communication with the UATM. Any airborne participant could receive proximity warnings and as such provide a complete control over the airways.

## 4.3.Digital twin UATM solution

As stated previously a digital twin is a digital representation of the physical processes that take place in the real world. Modelling those processes and analysing their outcome digitally can provide a safe and reliable alternative compared to observing actual processes that may have a negative impact. Foreseeing unfavourable events with a digital can be used to avoid them or find better alternatives.

In the case of the presented UATM solution, the system oversees the active UAVs and triggers alerts in case of detected hazards. Technically, this description alone could classify the UATM system as a digital twin as it provides a digital footprint of actual drone positions as well as their properties, thus allowing a digital overview of the current situation. The added value of the digital twin solution lies in the anticipation of future flight mission along with observing currently airborne drones. As the generated flight routes, either active or upcoming are all supplied with time windows, the digital twin can predict the risk of drone collisions, identify increased risks due to impending weather changes by observing weather station data, or as a consequence of such data re-evaluate risks to the environment or civilian population. As such the digital twin both depicts the current events as well as performs regular checks for any events and their consequences, thus providing a systemic solution to avoid preventable accidents or minimize their outcomes.

An important issue with the proposed surveillance method presents the level of automation. Ideally any transport flight mission should be completely automated, with the operator only defining the mission, while all the flight instructions should be uploaded to and handled by the drone, with the operator overseeing the mission. While fully automated drone use is possible the regulations generally do not allow fully autonomous operations. And drones must be controlled by flight on vision. A fully autonomous UAV that conforms to the proposed UATM system would minimize the human factor and eliminate the possibility of human error. The automation of UAV mission would require the development of standards that the UAV manufacturers would need to comply to. While the current regulations require the operators to control their drones manually, the communication must involve the UATM system, the UAV as well as the operator. As such the responsibility for the flight mission lies with the latter.

## 4.4.UATM response in emergency situations

Drones can be employed in various emergency response scenarios. They can be used to provide necessary medical supplies to unreachable sits due to terrain features or heavy traffic, provide monitoring of forest fires, support in search and rescue or other situations where it is important to provide critical information on time.

Appropriate institutions must be able to employ their drones safely to offer the best possible support for the emergency response. As such the UATM system must provide them with a priority status, in which case any pending requests within the emergency locality are cancelled or delayed to a time where the emergency is expected to be over. The UATM identifies any active UAVs in the locality and analyses any potential interference with the emergency UAV mission. All active drones that could pose a hazard for the emergency operations are signalled to perform an emergency landing at a predefined emergency landing site, unless a safe route without interference risk can be generated and for the drone to evacuate the area safely. While today's use of drones may not present a heavy traffic burned, let us consider a possible future with a broad use of drones for packet deliveries or other commercial use with numerous active drones at any time. The UATM must be able to track all drones and in emergency cases force them to land or evacuate in order to provide clear airways for emergency UAV missions.

### *4.5. UATM in Smart cities*

Ever increasing population in cities requires adapting to increased traffic, service needs, emergency management, and safety and security requirements. With recent development in UAV use for last mile delivery a future with continually present UAV activity is quite probable. Whether these drones will be operated manually or completely automated, a control system will be necessary to ensure a safe inclusion of the drones into the everyday life, with minimal risk to the population, the environment, or public and private property. Integrating the UATM into the Smart city solution allows the access to the data is not limited to the UAVs and air traffic, but also provides an overview to other events in the city. As such the UATM can quickly adapt to various hazard situations, clear the airways in case of priority emergency requirements, schedule the UAV missions in order to prevent or reduce aerial overcrowding or to reduce the noise. Integrating the UATM with the Smart city would also mean that other institutions would be instantly notified about any incidents taking place, which would allow them to respond appropriately in time.

## 5. CONCLUSION

The current and expected future growth of UAV use will require an efficient approach for unmanned air traffic management that will ensure maximal safety for the civilian population, the environment, as well as public or private property. While the current limitations set by the active legislature are bound to be altered in favour of UAV use, it is imperative that a solution for active monitoring of UAV activities is employed. This approach provides a foundation based on which the legislature can be adapted to allow a broader use of drones, while at the same time it provides a safe environment for all participants. The digital twin approach for the development of the UATM system enables for a complete overview of the aerial activities and allows anticipation of future events, reaching a high level of surveillance and thus maximizing the safety and security. The digital twin approach enables a foundation of integration of civilian services that increases both safety as well as security in aerial and terrestrial environment. Further development should oversee optimization using smart path generation and flight scheduling for UAV fleets and integrated communication with the civil aviation agencies to minimize any hazards.

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