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„Prospects of the European unmanned aircraft systems market and their implications on air navigation service providers "

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Emily Lisa Pfister, B.A.

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I. Abstract

Unmanned aircraft systems, or UASs, are quickly turning into a disruptive technology in areas such as package delivery, agriculture, search and rescue missions, and many more as they change traditional business models. To fully unlock the potential of these new carriers of technology a framework for their operation must be established. This research analyses six areas that have a particular impact on the development of the UAS market. These include a regulatory framework, a traffic management system for unmanned aircraft, economic potential, technological advance, security threats, and public acceptance. As the market is still developing, many stakeholders are faced with a great deal of uncertainty. Particularly the impacts on air navigation service providers regarding these new airspace participants have been relatively unexplored in scientific literature so far. After projecting these factors into the future, this research shows that their development can have a significant impact on the feasibility of integrating UASs into national airspace structures. Further it highlights the unique role of air navigation service providers in this context. *Keywords: UAS, UAV, ANSP, integration, regulation, UTM, economic potential, technology, security, public acceptance*

Unbemannte Luftfahrtsysteme, im englischen UASs, entwickeln sich schnell zu einer disruptiven Technologie in Bereichen wie Paketzustellung, Landwirtschaft, Such- und Rettungseinsätzen und vielen anderen, da sie traditionelle Geschäftsmodelle verändern. Um das Potenzial dieser neuen Technologieträger voll auszuschöpfen, müssen operative Rahmenbedingungen geschaffen werden. In dieser Studie werden sechs Bereiche analysiert, die für die Entwicklung des UAS Marktes von besonderer Bedeutung sind. Dazu gehören rechtliche Grundlagen, ein Verkehrssteuerungssystem für unbemannte Flugzeuge, wirtschaftliches Potenzial, technologischer Fortschritt, Sicherheitsbedrohungen und die öffentliche Akzeptanz. Da sich der Markt noch in der Entwicklung befindet, sind viele Akteure mit einer großen Unsicherheit konfrontiert. Insbesondere die Auswirkungen auf die Flugsicherungsorganisationen im Zusammenhang mit diesen neuen Luftraumteilnehmern sind in der wissenschaftlichen Literatur bisher noch relativ unerforscht. Nachdem die Einflussbereiche in die Zukunft projiziert wurden, zeigt diese Untersuchung, dass ihre Entwicklung einen erheblichen Einfluss auf die Integration von UASs in nationale Luftraumstrukturen haben kann. Zusätzlich wird die einzigartige Rolle der Flugsicherungsdienstleister in diesem Zusammenhang hervorgehoben. *Schlüsselwörter: UAS, UAV, Flugsicherung, Integration, Regulierung, UTM, Wirtschaftlichkeit, Technologie, Sicherheit, öffentliche Akzeptanz*

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V. List of Abbreviations

ADQ	Aeronautical Data Quality
ADS-B	Automatic Dependent Surveillance Broadcast
AIS	Aeronautical Information Services
AMC	Acceptable Means of Compliance
ANSP	Air Navigation Service Provider
ATC	Air Traffic Control
ATM	Air Traffic Management
BIS	Business Internal Services
BMVI	Bundesministerium für Transport und Digitale Infrastruktur (German Ministry of Transport and Digital Infrastructure)
BVLOS	Beyond Visual Line of Sight
C2 Link	Command and Control Link
CAGR	Compounded Annual Growth Rate
CISP	Common Information Service Provider
CNS	Communication, Navigation, Surveillance
ConOps	Concept of Operations
C-UAS	Counter UAS
DFS	Deutsche Flugsicherung (German ANSP)
DII	Drone Industry Insights
DIN	Deutsches Institut für Normung (German Institute for Standardisation)
DPIA	Data Protection Impact Assessment
DLR	Deutsches Zentrum für Luft- und Raumfahrt (German Aerospace Centre)
DSP	Drone-as-a-service Provider
EASA	European Union Aviation Safety Agency
EU	European Union
EUROCAE	European Organisation for Civil Aviation Equipment
eVTOL	Electrical Vertical Take-Off and Landing
FAA	Federal Aviation Administration
GA	General Aviation
GM	Guidance Material
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HFR	High-level Flight Rules

ICAO	International Civil Aviation Organisation
IFR	Instrument Flight Rules
IMU	Inertial Measurement Unit
INS	Inertial Navigation System
ISR	Information, Surveillance, Reconnaissance
JARUS	Joint Authorities for Rulemaking on Unmanned Systems
LBA	Luftfahrt-Bundesamt (German Federal Aviation Authority)
LUC	Light Unmanned Aircraft Operator Certificate
LuftVG	Luftverkehrsgesetz (German Air Traffic Act)
LuftVO	Luftverkehrsordnung (German Air Traffic Regulation)
MSDF	Multi-Sensor-Data-Fusion
MTOM	Maximum Take Off Mass
NASA	National Aeronautics and Space Administration
NFZ	No-Fly Zone
NOTAM	Notice(s) to Airmen
OEM	Original Equipment Manufacturer
OSO	Operational Safety Objectives
PDRA	Pre-Determined Risk Assessment
PEMFC	Polymer Electrolyte Membrane Fuel Cell
RAIM	Receiver Autonomous Integrity Monitoring
RF	Radio Frequency
RoA	Rules of the Air
RPA	Remotely Piloted Aircraft
RPAS	Remotely Piloted Aircraft System
SAIL	Specific Assurance and Integrity Level
SARPS	Standards and Recommended Practices
SBAS	Satellite-Based Augmentation System
SERA	Standardised European Rules of the Air
SESAR	Single European Sky ATM Research
SESAR JU	Single European Sky ATM Research Joint Undertaking
SORA	Specific Operation Risk Assessment
SSR	Secondary Surveillance Radar
sUAS	Small UAS
SWAP	Size, Weight, and Power

TCAS	Traffic Alert and Collision Avoidance System
UA	Unmanned Aircraft
UAM	Urban Air Mobility
UAS	Unmanned Aircraft System
UAV	Unmanned Aerial Vehicle
USSP	U-Space Service Provider
UTM	UAS Traffic Management
VFR	Visual Flight Rules
LFR	Low-level Flight Rules
VLOS	Visual Line of Sight
VTOL	Vertical Take-Off and Landing
VUL	Verband Unbemannte Luftfahrt (German Unmanned Aviation Association)
WAAS	Wide Area Augmentation System

Introduction

1.1. Research objective

Unmanned Aircraft Systems (UASs), commonly known as drones, are quickly evolving to be a disruptive technology in various fields of application (Jenkins et al., 2017). The UAS market has long passed the stage of leisure flights and toy drones for children. It presents substantial opportunities for businesses, society, and sustainability (BMVI, 2020). The overall UAS market, including manufacturing, maintenance, and repair, is estimated to be worth approximately 23.1 billion Euros in 2021. Within the next five years the market is expected to more than double to 49.3 billion Euros (Markets and Markets, 2021). As civil and commercial applications of unmanned aircraft are continuously increasing, there is a need to integrate them into existing national airspace structures and enable their operations across all spheres of airspace. Thus, a regulatory framework is required to utilise the full potential of this technology without compromising the safety standard of the aviation industry. The development of this legislative structure is a prerequisite for a scalable and structured UAS market.

The framework and foundation of the market are still evolving. This exposes stakeholders to a great deal of uncertainty about the potential of the industry as well as their position within it. One such stakeholder are national air navigation service providers (ANSPs). They are in charge of managing traffic volumes in the air and ensuring safe operations. The challenge for them is to integrate these new entrants into existing infrastructure while ensuring the continuous efficient operations of manned aviation (CANSO, 2011). While many contributions to scientific literature focus on economic potential or regulatory barriers, the impact of integrating unmanned aircraft into air traffic management infrastructure from an ANSP perspective is relatively unexplored (Liu et al., 2021).

Thus, this research pursues two main objectives. For one, it aims to clearly outline the current state of the market, identify areas of influences and drivers for the development of the industry, and provide possible projections over the next decade. Additionally, this research intends to examine the particular challenges of enabling this new market from an ANSP perspective and providing this group of stakeholders with strategic recommendations on how to position themselves in the industry. To conduct the analysis and answer the aforementioned research questions, the scenario technique is applied. This method is particularly suitable to derive strategic guidelines in uncertain environments. Traditional projections are often based on quantitative, linear forecasts of historic data (Gausemeier et al., 2017). However, this approach often does not include unique developments in a market and is particularly futile for an emerging market such as the UAS industry. Therefore, the approach of the scenario analysis is more suitable in this context, as it includes qualitative considerations and allows for a more comprehensive overview of possible developments. Its idea is to provide a range of possible trends and to establish contingency plans for several scenarios, instead of just one linear projection. This enables businesses, regulatory authorities, and other stakeholders in a market to detect threats and opportunities early on and steer their organisation in the direction of highest success (von Reibnitz, 1992).

1.2. Structure of the thesis

The first section of this study presents the issue and scientific research gap. Next, a general overview over the UAS industry is given. This includes the different types and configurations of UASs as well as their strengths and weaknesses. Further subsections differentiate between market segments and between the specific use cases that are being explored in each segment, and finally, the individual stakeholders and their roles within the industry. Following that, the methodology is described in more detail in section 3 and the scenario analysis is conducted in section 4, providing a detailed examination of major influences on the UAS market. This includes a breakdown of the most relevant drivers in each area of influence. These drivers are first presented in their current situation and then projected into the future, providing distinct alternatives of how they could develop. Afterwards, two scenarios will be derived from the analysis. Section 5 consists of the transferral of these scenarios on DFS operations, highlighting strengths and weaknesses of DFS' position in the market as well as recommendations on how to prepare for possible developments. Lastly, the results of this research are presented as well as the limitations of the study and an outlook for future research potential.

2. UAS industry

2.1. History and terminology

The origins of aviation lie in humanity's inherent curiosity about conquering the skies. The mythology around Icarus or Da Vinci's drawings of flying machines all indicate a profound interest in surpassing the bounds of gravity (Marshall & Trapnell, 2021). The very first attempts of this endeavour have been made through unmanned vehicles. Meteorologists have floated balloons into the air and used them to test aerodynamics and dispersibility. Subsequently, they have used them for atmospheric and climate research since the 19th century (BMVI, 2020). However, as many modern day civil and commercial technologies, the use of unmanned aerial vehicles (UAV) was fostered through military applications. The early versions of UAVs date back as far as the American Civil War in the 1860s when balloons were loaded with explosives and sent in the direction of the opposing army. When navigational capabilities were added to the vehicle during World War I, the UAV turned into an unmanned aircraft system (UAS) (Babayomi & Makarfi, 2019).

In the following years and wars, there was significant interest in developing missiles that could be used without endangering pilots. The early versions of unmanned aircraft were simply flying torpedoes, that could be manipulated to crash and explode at a set location by programming the propeller rotations (Pop et al., 2017). During the Vietnam War, technology had improved enough to use UASs for reconnaissance and missile detection missions. Since then, significant progress in positioning technology, measurement electronics and propulsion methods, has led to a variety of uses for UASs. Today, military UASs are commonly used in warfare missions as well as intelligence, surveillance, and reconnaissance (ISR) operations. They can fly autonomously, automatically locate targets, initiate attacks, and collect high-resolution data of enemy and home territories (Keane & Carr, 2013).

It is difficult to pinpoint exactly when UAV applications started to include civil and commercial fields as well as military operations but the advancement of technology and the continuous need to improve and enhance operations soon fuelled a shift in the industry in the late 1900s. One of the oldest commercial purposes is the use of unmanned aircraft in agriculture as early as the 1990s, when Yamaha Motor Corporation brought their unmanned helicopter Yamaha R-50 to market (Yamaha Motor Corporation, 2019). Since then, UASs have become a topic of intense research and development, which has caused numerous commercial and civil applications to emerge (Babayomi & Makarfi, 2019). With the advancement of flight technologies, multirotor UASs became increasingly easy to operate, even for inexperienced users. This marked the beginning of hobby and toy UASs. Since then, sensors and capabilities have continuously improved to enable a variety of civil and commercial applications (Kyrkou et al., 2019).

With the shift from military to commercial applications, the terminology of these aerial vehicles has also changed. To alter the public image of ‘drones’ and their association with warfare and espionage, more neutral and technological terms were introduced. The terms ‘unmanned aerial vehicle’ and ‘unmanned aircraft’ (UA) describe the airborne component of an ‘unmanned aircraft system’ (UAS). The complete system includes the ground station, the operator of the system as well as payloads and the software necessary to operate it. While these terms encompass all unmanned aircraft structures, the term ‘remotely piloted aircraft’ (RPA) and ‘remotely piloted aircraft system’ (RPAS) only describe unmanned aircraft that require active piloting commands to operate (ICAO, 2020).

2.2. Types of UASs

2.2.1. Classification

There are different ways to classify UASs. They can be categorized according to size, weight, altitude, configuration, endurance, or speed. This research uses a categorization based on size and weight for two reasons. For one, the size and weight of a UAS typically have implications on their technical abilities. For example, larger UASs can carry heavier payloads and are more resilient to atmospheric turbulence than smaller UASs. This also makes them more suitable for operations in higher altitudes. Secondly, the weight and size of a UAS are major factors when assessing the risk of a UAS mission (Badea et al., 2020).

Size	*Dimensions*	*Endurance*	*Range/time*
Nano	Leaf-sized	*Very close-range*	5 km/ <60 min
Micro	<50 cm	*Close-range*	50 km/ 1-6 hrs
Small	50 cm - 2 m	*Short-range*	~150 km/ 8-12 hrs
Medium	2 m - 5 m; wingspan up to 10 m	*Mid-range*	300 km/ >24 hrs
Large	~ manned aircraft-sized	*Endurance*	unlimited

Table 1: UAS classification (created by author)

Typically, UASs are categorized into nano/micro UASs, small UASs, medium UASs, and large UASs. Nano UASs can be as little as a small leaf and are often used in swarms (Austin, 2010). As they are rarely used in commercial operations, they can be dismissed in the context of this research. Micro UASs can have a wingspan of up to 50 cm and are commonly used as recreational drones. Small UASs (sUAS) currently make up the majority of all UASs with approximately 54% falling in this category (DTI & AUVSI, 2019). They have at least one dimension (width, breadth, height) that is between 50 cm and 2 metres and are typically light enough to be launched into the air by hand. Medium UASs range between 2 and 5 metres with a wingspan of up to 10 metres. They are typically too heavy to be carried by one person and can bear payloads of up to 200 kg. Large UASs resemble manned aircraft and are mainly used for military operations (Babayomi & Makarfi, 2019).

The size of a UAS usually correlates to its endurance. While larger UASs require more energy to fly, they are also able to carry heavier payloads and more complex propulsion systems. Literature distinguishes between very close-range, close-range, short-range, mid-range, and endurance UASs. The very close-range category describes UASs that have a range of up to 5 km and can stay in the air for less than an hour. Close-range UASs already have a range of up to 50 km and can stay in the air for 1-6 hours. Short-range UASs are able to fly for 8-12 hours and have a range of approximately 150 km. Mid-range UASs are mostly used in military missions with a high-speed radius of up to 300 km and an endurance that exceeds one day. Endurance UASs can technically stay in the air indefinitely, provided the energy source is self-sufficient (DTI & AUVSI, 2019).

2.2.2. Configuration

The exact configuration of a UAS is strongly dependent on its specific use. Different applications require different specifications. For example, a UAS used for power line infrastructure inspection needs to travel longer distances than a UAS that is used for aerial photography, while a photographic mission may need a higher degree of steadiness than an inspection mission. Although there are numerous UAS designs and configurations, scientific literature generally distinguishes between four different types. The UAS operator Australian UAV (Australian UAV, 2016) defines these four categories as follows:

- Multi-rotor: This includes all UASs that are powered by more than one rotor (Figure 1). While the so-called ‘quadcopter’ with four rotors is the most frequently used design, the number of rotors can be increased or decreased, as necessary. These UASs are commonly used in the recreational sector. But they also provide significant benefits for some commercial applications. Their high stability and precise positioning and framing provide the ideal basis for aerial photography and high-precision scans. Furthermore, they are typically the cheapest option in the market and are easy to operate. The downside of this type of UAS is their limited endurance. Their design makes them unsuitable for gas-engine propulsion and the operation of the rotors take up a lot of energy. Additionally, they do not reach the same levels of speed as for example fixed-wing aircraft, which makes them less apt for longer distances.

- Single-rotor helicopter: This UAS type, like the multi-rotor UASs, is powered by rotating blades (Figure 2). However, it only has one set of rotors. As a general rule in aerodynamics, a larger, slower spinning blade is more energy efficient than a smaller and faster one. A single rotor can carry larger blades that almost serve as wings to keep the aircraft aloft. This enables the single-rotor helicopter to move heavier payloads or conduct missions that require both hovering and high-speed forward flight. However, these types also have downsides. In addition to the increased risk of injury, single-rotor UASs are considerably harder to operate than multi-rotor UASs. While they do offer the possibility of hovering and easing into the process of operating a UAS, they are less stable than a multi-rotor and more likely to get damaged during a bad landing. Their mechanical complexity also drives up cost of maintenance.

- Fixed-wing: This type of UAS resembles the typical aircraft shape that is used in manned aviation (Figure 3). They are considerably more energy efficient as they only need forward thrust and do not need to expend energy on staying aloft. Thus, they work well for long distance and endurance missions. Typical examples are inspections of pipelines and power lines or aerial mapping. Their main disadvantage is the complexity of take-off and landing. While rotor UASs are able to vertically take-off and land (VTOL), fixed-wing aircraft have to be launched into the air or use a runway system. A runway system is also necessary for landing unless they can be caught in a net or other receiving stations. Only very small UASs can be hand-launched and then belly-land in a field. Additionally, fixed-wing aircraft typically cost more than rotor UASs and are significantly more difficult to operate. As they cannot hover in one spot, the operator cannot ‘pause’ operations in order to figure out their next steps. Once the aircraft is launched, it will move forward constantly and at high speed.

- Fixed-wing hybrid VTOL: This type of UAS can vertically take-off and land and thus combines the benefits of multi-rotors and fixed-wing aircraft without posing the operational complexity or safety hazards of a single-rotor aircraft (Figure 4). They can VTOL and hover, while also being equipped for high-speed, long-distance missions. One idea is to have a vectored thrust system, where the propulsion units first provide the lift and then swivel to create thrust in cruise flight. Another option is to have separate propulsion units for lifting and forward thrust. This system is less complex than vectored thrust, but also less efficient (EASA, 2021b).

Figure 1: Multi-rotor UAS (Alhawi et al., 2019)

Figure 2: Single-rotor UAS (Alhawi et al., 2019)

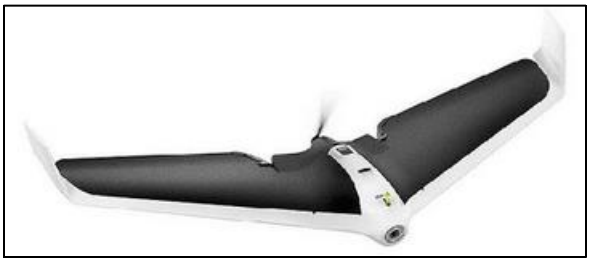


Figure 3: Fixed-wing UAS (Alhawi et al., 2019)

Figure 4: VTOL UAS (Wingcopter, 2021)

2.3. Market segments

A. Military segment

As presented, the military is a major driving force for the UAS market. The deployment of unmanned aircraft in warzones and foreign environments provides a unique opportunity to conduct ISR missions without the threat of endangering troops. More controversially, armed UASs are also used in combat scenarios to conduct targeted killings of opposing forces (Ayamga et al., 2021). According to industry expert Giancarlo Crivellaro, the technological advancements in the UAS market are largely driven by military research and development, especially with regards to automation and artificial intelligence (Crivellaro, 2021). Although there are interfaces and synergies between the military market and commercial and civil applications of UASs, this market segment will not be the focus of this thesis.

B. Civil segment

Generally, the term ‘civil’ is used as a counterpart to ‘military’ and encompasses all non-military markets. In this research, the term ‘civil’ is used to describe state or government operations without military affiliations. Thus, this segment includes public operations that do not serve a commercial purpose. These types of use cases mostly deal with protecting and aiding the public. For example, UASs can be used in search and rescue missions to locate missing persons. Police and other first responders use UASs to assess crisis situations, such as fires, flooding, or accident sites. Furthermore, they can be used for time-sensitive deliveries of medical goods, such as defibrillators, or even medical personnel (BMVI, 2020).

C. Commercial segment

The commercial deployment of UASs is the fastest growing segment of the market. The number of commercially operated UASs in Germany has more than doubled in the past two years, from approximately 19.000 UASs in 2019 to 45.200 UASs in 2021 (VUL, 2021a). Market growth is driven by use cases, which are being developed continuously to utilize the full potential of this technology. There are different ways in which businesses and organisations can benefit from employing UASs. For one, UASs can help save personnel costs on time-consuming and low-energy tasks. This is particularly helpful for the inspection of extensive infrastructure such as pipelines, or the mapping and surveying of landscapes, wildlife stock, or coastal erosion. In addition, UASs are significantly more cost-effective than helicopters and can provide a far more detailed birds-eye view to the operator due to their size and flexible steering mechanisms (Page et al., 2021). Another benefit is the reduction of safety hazards by eliminating the human factor from an operation. The energy sector in particular can profit from this. Many energy-generating infrastructures, such as wind parks, high voltage power lines, refineries, or hydroelectric power plants need to be inspected regularly. This is often linked to a significant safety risk to the inspection crew and long down-times of the plant, which can be reduced by using UASs (McHann, 2021).

A major field of possible use cases for UASs is developing in the transport and logistics industry. In the medical sector, UASs are being used to deliver time-sensitive goods, such as blood or tissue samples, to remote locations, or across highly congested urban environments. Furthermore, the e-commerce sector is exploring the use of UASs for the last-mile delivery of good. In the long run, UASs are expected to carry larger volumes of cargo as well as passengers (Kellermann et al., 2019). In agriculture, UASs are often used to optimise resources through precision farming, which describes the process of using scanners and sensors to locate areas of draught or disease in a field of crops and allocating resources such as water and pesticides accordingly (Hassler & Baysal-Gurel, 2019). UASs are being used in the entertainment sector and media production, maritime operations, construction and real estate development, as well as to improve connectivity in rural areas by transmitting mobile signals (McKinsey & Company, 2017). One key area of commercial operations is consolidated under the term Urban Air Mobility (UAM). This encompasses all air operations in urban environments with a focus on the transport of passengers and goods. According to market studies, the European UAM market will be worth approximately 4.2 billion Euros by 2030 and sustain around 90.000 jobs. This would account for one third of the global UAM market (EASA, 2021b).

D. Leisure segment

The leisure segment refers to the private use of UASs and hobby drone pilots. Currently, this is still the largest segment in Germany making up for 90% of the market. However, the number of UASs has decreased from approximately 455.000 in 2019 to 385.500 in 2021 and is predicted to decrease further until 2025 (VUL, 2021a). Industry expert Ronald Liebsch from the German Institute for Standardisation estimates that the private consumer segment is responsible for a significant share of the market's potential. He stresses the importance of maintaining easy access to the market for private UAS users and enthusiasts, as many of them drive the innovative progress and societal acceptance in this area (Liebsch, 2021).

E. Secondary markets

The previously described segments are all directly based on the operation of UASs. They form the primary market. However, these activities also affect a number of markets which are not involved in the actual operation of UASs, the secondary markets. Jan Dirks from the German Ministry of Transport estimates that besides the UAS manufacturing market, the Original Equipment Manufacturers (OEM) and suppliers will significantly benefit from an increase in UAS operations. He further stresses the importance of research activities. The dynamic UAS market has increased the funding of research centres and development facilities (Dirks, 2021). Heidger suggests that the potential of this new market can provide sufficient incentive for the telecommunications sector to expand and adapt their network to support UAS operations (Heidger, 2021). Kies adds that the insurance market will see an increase in insurance policies taken out by UAS operators for third-party damage liability insurance as well as insurance policies against damages to their own vehicles. Additionally, she predicts a trend in the legal sector towards specialisation in UAS specific law and a visible influence in the capital investment sector, with trust companies purchasing shares of UAS related businesses. In the long run, she assumes that the focus on automation in the UAS sector will also impact the traditional aviation sector, first by reducing the number of pilots to a single cockpit operation, and then possibly to fully autonomous flights (Kies, 2021).

Thus, the ramifications of UAS growth have led to a number of new markets, ranging from UAS rental companies to maintenance and repair businesses (Rao et al., 2016). However, possibly the largest emerging market in this area is the Counter UAS (C-UAS) market aimed at the defence against UAS operations. Technically, C-UAS technologies are evolving alongside the military segment of the UAS market. However, with the shift of UASs from military to commercial applications, the concern about malicious abuse in domestic scenarios has increased. The growth of the C-UAS market is directly related to these rising apprehensions (Michel, 2018). Studies estimate that the global C-UAS market will be valued at approximately 4.7 billion USD by 2027 at a compounded annual growth rate (CAGR) of 26.8% (Emergen Research, 2020).

<table>
<tr><td>Segment</td><td>Applications</td><td rowspan="5">Secondary markets:
OEM
Insurance
Capital Finance
Manned aviation
C-UAS</td></tr>
<tr><td>Military</td><td>ISR; combat</td></tr>
<tr><td>Civil</td><td>Search and rescue, police, firefighting, emergency services</td></tr>
<tr><td>Commercial</td><td>Inspection, mapping, surveying, transport, agriculture, construction, (…)</td></tr>
<tr><td>Leisure</td><td>Photography, hobby flights</td></tr>
</table>

Table 2: UAS market segments (created by author)

2.4. Stakeholders

A. Regulators and government agencies

Germany:

The integration of UASs into national and transnational airspace systems requires a new legislative framework. In Germany, this process started with the amendment of the Air Traffic Act, Luftverkehrsgesetz (LuftVG) in 2012 to include UASs in the catalogue of aircraft (BMVI, 2020). In March 2021, the European legislation was translated into national law through the Air Traffic Regulation (Luftverkehrsordnung – LuftVO). The German ministry for transport and digital infrastructure (Bundesministerium für Verkehr und digitale Infrastruktur – BMVI) and the German Federal Aviation Authority (Luftfahrt-Bundesamt – LBA) are the relevant authorities regarding the implementation of UAS law into national legislature and the governance of the market. Some tasks, such as the governance of geozones, are tasked to the federal state aviation authorities. The German Institute for Standardisation (Deutsches Institut für Normung – DIN) is in charge of developing a harmonised and uniform framework across all German authorities. This includes the standardisation of geo data collection, authorisation processes and UAS detection and interception procedures (DIN, 2021a).

Europe:

On a European level, the European Union Aviation Safety Agency EASA is working together with the European Council, the European Commission, and the European Parliament to develop the legislative framework underpinning the UAS market. The following regulations are the primarily relevant laws for this research and will be explained in more detail in subsection 4.2.1.:

- Regulation (EU) 2019/945
- Regulation (EU) 2019/947
- Regulation (EU) 2021/664

Another noteworthy organisation in the context of European air traffic is Eurocontrol, who is in charge of safe air traffic management and contributes to a safe integration of UASs into existing airspace systems by assessing the interface to current air traffic management (ATM) standards (Eurocontrol, n.d.). Similar to the German DIN, the European Organisation for Civil Aviation Equipment (EUROCAE) is developing standardised norms and procedures on a European level (Eurocae, n.d.).

Global:

Globally, there is no comprehensive set of binding regulations. Nonetheless, organisations such as the International Civil Aviation Organisation (ICAO) and the Joint Authorities on Rulemaking for Unmanned Systems (JARUS) are working on providing guidelines and standards that can be implemented into national or transnational regulations (Alamouri et al., 2021). Jörg Dittrich, who is involved in the JARUS working group for Safety Risk Management, explains that regulation 2019/947 is largely based on a concept that was initially developed by JARUS and is now adapted and modified in regulations all over the world (Dittrich, 2021).

B. Air navigation service providers

ANSPs coordinate the traffic flow in controlled airspace. They are responsible for the ATM of civil and sometimes military flights. This includes providing take-off and landing permits as well as the provision of navigation services within controlled upper and lower airspace. The emergence of UAS operations has significant implications for ANSPs. For one, UAS regularly disrupt or endanger manned aviation, by entering the controlled airspace around airports, which subsequently also disrupts ANSP operations. Managing the issues revolving around the detection and interception of UASs is one of the major tasks for ANSPs in this context. Secondly, the integration of UAS into national airspace structures requires an interface with ATM systems. Particularly in the long run, manned and unmanned aviation are expected to become more and more integrated, and it is crucial that ANSPs are involved in the development of the UAS market to ensure compatibility of UAS systems with standard aviation procedures and the integration of this new airspace entrant without compromising the safety record of the current infrastructure (CANSO, 2011).

C. Operators

As opposed to manned aviation, the UAS market is not restricted to aviation-savvy operators. From inexperienced hobby pilots to model aircraft experts to trained commercial pilots, there is a broad range of skill level to be found. This group of stakeholders is crucial in ensuring a safe development of UAS use cases as they are the ones actually steering and controlling the aircraft. They are impacted mostly by regulatory stipulations and technological development. Depending on the weight and operating class of the UAS, the remote pilots are required to have a Certificate of Competence, a Remote Pilot Certificate (European Commission, 2019b).

D. Suppliers

This category of stakeholders encompasses any commercial institution that provides 'background' services to the market. This includes hardware and software providers, maintenance and repair services, original equipment manufacturers and suppliers, and technical solutions providers. These stakeholders are affected by the regulatory performance requirements of UASs, as stipulated in EU regulation 2019/945. Additionally, they depend on the progressing technological advancement, particularly when it comes to certification processes and automated solutions. Economic developments and changes in demand also have a significant impact on this group of shareholders as they have to adapt to serve their customers' needs (Justin et al., 2018).

E. Research institutes

Research institutes play a crucial role in the UAS market. As the technology is still evolving, research institutes are essential players in the market. On a European level, the European Union and Eurocontrol have founded the organisation for Single European Sky ATM Research (SESAR) and SESAR Joint Undertaking (SESAR JU). These institutes are driving the research and development efforts within the European Union and focus on updating and expanding ATM procedures. With the emergence of UASs and their implications on ATM, SESAR JU is also heavily involved in developing a procedural framework for this new market (SESAR JU, n.d.). Dittrich from the German Aerospace Centre DLR explains that they are committed to expedite technological advancement and sharing new findings with industry stakeholders. Similar to SESAR, they also support the development of the regulatory framework by pushing the boundaries of what is currently possible and uncovering potential gaps or missed potential (Dittrich, 2021).

F. General aviation

General aviation, or GA traffic, includes all air traffic that is not a commercial air transport operation. This generally encompasses private pilots and recreational pilots such as glider pilots, paragliders, and parachutists. As this group of airspace participants often operates in low levels of airspace, they are more likely to encounter a UAS than aircraft in controlled airspace. Thus, they also have a stake in the development of the UAS market. The operation of UASs either requires interaction protocol with manned aviation to co-exist within the same airspace, or it requires segregated airspace to avoid conflict between the two groups. Either way, GA traffic will be impacted by the increase of UAS operations and their integration into airspace systems (Kabo et al., 2020).

3. Methodology

This research is conducted using a scenario technique. This method follows two principles: connected thinking and multiple futures. Connected thinking describes the concept of acknowledging that every business, market, or industry is part of a complex construct of influences and interconnectedness. Thus, it takes into consideration the interrelation of different factors. In the case of this research, the impact of each factor is analysed both in regard to the whole market and in regard to the other factors. The concept of multiple futures describes the idea that instead of focusing on one linear trend, stakeholders should prepare for a variety of possible futures, as projections become less predictable the further they are cast into the future (Gausemeier et al., 2017). There are different opinions on how many different scenarios are appropriate for such an analysis. Depending on the time frame and the factors under examination, an infinite number of scenarios can be derived from the analysis. Following the approach of Von Reibnitz (1992), only two scenarios are necessary to allow for a comprehensive set of strategic recommendations. These scenarios typically describe the range between the best-case and the worst-case developments, as depicted in Figure 5. However, the valuation of ‘best’ and ‘worst’ strongly depends on the point of view of any given stakeholder. Thus, this assessment is usually measured by the goals set out at the beginning of the analysis (Millett, 2011).

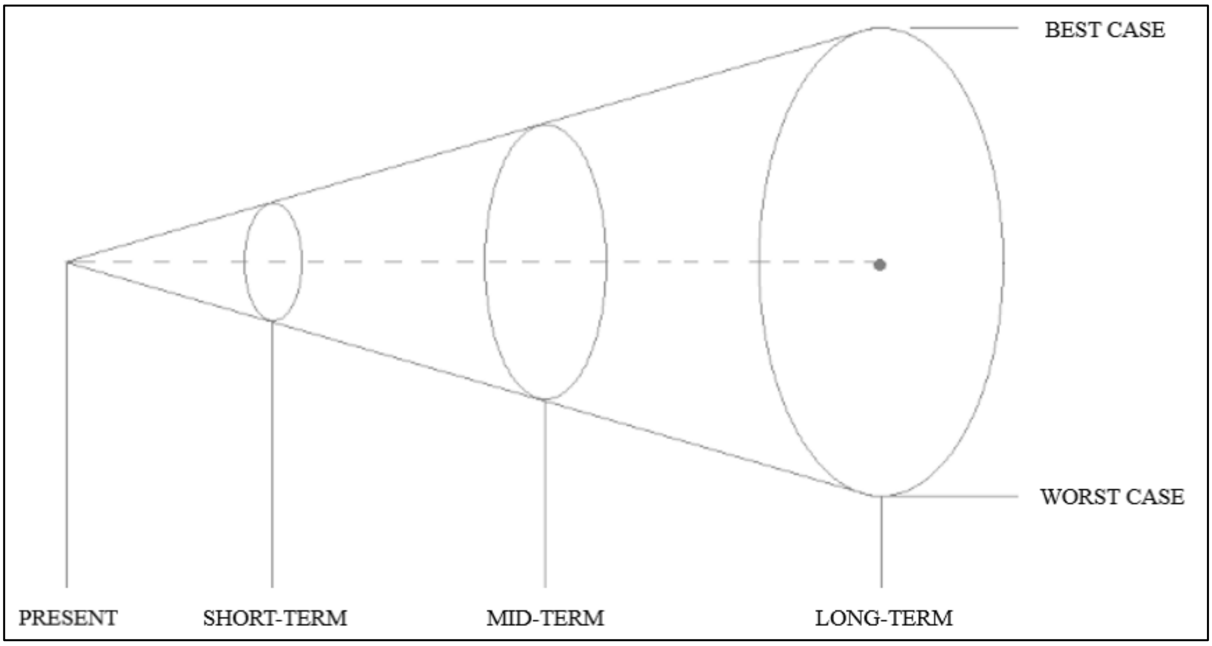


Figure 5: Scenario cone (created by author)

A scenario analysis is conducted in steps. The exact number and definition of the steps differs between different scientific contributions. For example, Von Reibnitz (1992) applies and 8-step model, whereas Gausemeier (2017) uses a reduced 5-step approach. This study generally follows the Von Reibnitz model, albeit with some modifications due to the nature and scope of the research. First of all, one step in Von Reibnitz' analysis was excluded as it is directed at a scenario analysis from a business point of view, while this paper examines the development of a market. Similarly, the analysis of the impact of catastrophic events was excluded as this also strongly varies between different stakeholders and cannot be generalised for an entire market. Thus, the following six steps were defined for this research (Figure 6):

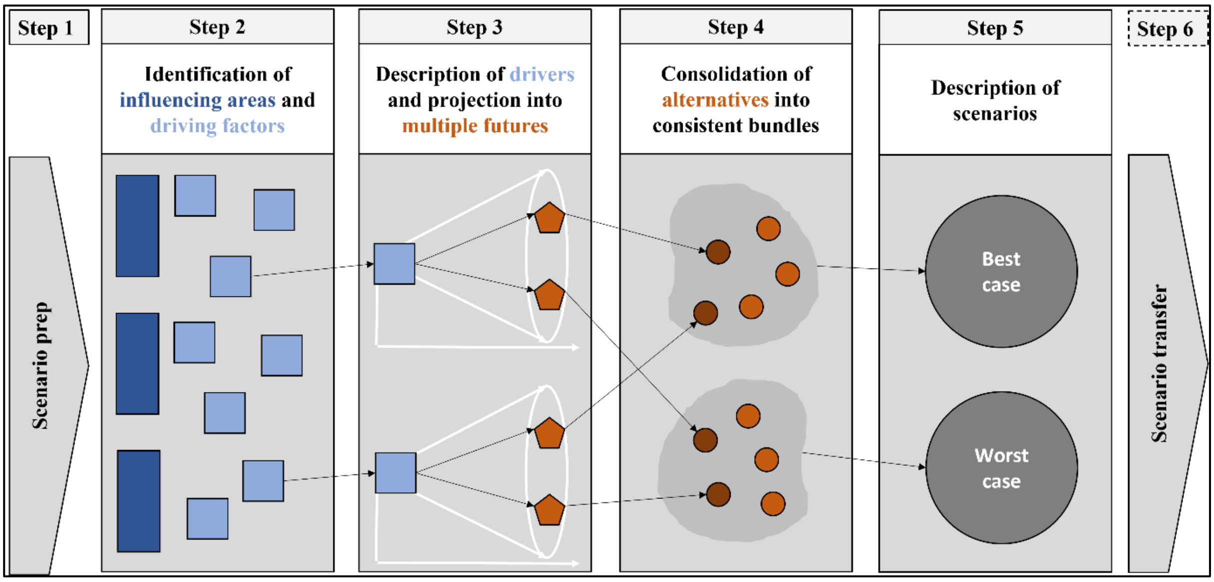


Figure 6: Scenario analysis process (created by author)

1. Scenario preparation: The task of the analysis is defined. Within the context of the study, the goal of the analysis is identical to the research objectives set out in the introduction of this paper. In other words, the task is to identify and illustrate trends and developments in the UAS market and translating the resulting challenges and opportunities to ANSP operations. Additionally, the current strengths and weaknesses of the market are presented as well as a timeline for the projection.
2. Analysis of influences: The second step is divided into two parts. First, the major influences on the market's development are identified. Usually, these include political, economic, or legal factors, but they can differ significantly depending on the subject of the analysis, in this case the UAS market. Within these areas of influence, individual drivers are defined that are the most impactful on the development of the respective area. For example, one driver that influences legal aspects could be a new regulation. Afterwards, the hierarchy of these areas is defined by analysing the interconnectedness of the factors. Thus, areas that exert more active influence are prioritised over areas with a high degree of passive influence.
3. Trend projection: Once the order of the influencing areas is specified, the individual drivers within them are projected into the future. In a first step, the current state of each driver is presented and put into the context of potential threats and opportunities. Subsequently, different alternatives are derived to describe how various developments might impact the market. While the number of alternatives is not inherently restricted, this study is limited to two alternatives for each driver that generally depict progressive and conservative outcomes respectively.
4. Consistency check: Before deriving scenarios from the list of alternatives, the consistency of these projections must be ensured. This means that no two alternatives can be bundled into the same scenario that are fundamentally contradictory. This is either done by pitching each alternative against all others in the context of a working group, or for more complex matters, a consistency matrix is used. After excluding all contradictory alternatives from consolidation, the alternatives that are logically connected are sorted into the same scenario. For example, a high level of safety will plausibly increase the level of public acceptance for new technologies.
5. Scenario creation: The bundles of alternatives derived from the consistency check are presented as distinct scenarios and are put into the context of the goals presented in the scenario preparation. Generally, these scenarios are provided with a caption that

describes their most notable feature. The scenarios are presented as facts rather than hypothetical events.

6. Scenario transfer: As this particular scenario analysis does not examine developments within a specific business or a group of businesses, but the developments of a whole market, the transfer of these scenarios is conducted in an additional step and presented as its own section (section 5). To translate the scenarios on European ANSPs, the German ANSP DFS – Deutsche Flugsicherung GmbH is used as an example. The transfer highlights the risks and opportunities related to the scenarios as well as strategic recommendations for ANSPs in regard to their position in this market.

The analysis is based on a collection of primary and secondary data. In a first step, a scientific literature research regarding the UAS market and its developments was conducted to define the market and outline areas of particular influence. These findings were then confirmed and expanded through a number of interviews with experts in the industry. To establish a thorough and complete picture, the interview partners were chosen to cover a majority of the stakeholders in the market. Global, European, and German regulatory viewpoints were included through interviews with JARUS, the European Commission, the German Ministry of Transport, and the German Federal Aviation Authority. This perspective was expanded through an interview with Austro Control, who serves as both the Federal Aviation Authority and the ANSP in Austria. The German ANSP was represented by two experts who provided insights about the unique challenges this particular group of stakeholders is faced with. Interviews with representatives from Wingcopter and DJI provided the perspective of UAS manufacturers and operators. Additionally, a Fraport representative also contributed some insights as UAS operator as well as on the implications of UASs on airports. Research facilities were represented by the German Aerospace Center DLR, the German Institute for Standardisation DIN, as well as the European research program SESAR JU. Various European suppliers of software and necessary infrastructure were also included through interviews with Droniq based in Germany, Unifly based in Belgium, and Frequentis based in Austria. Finally, a representative of the German Unmanned Aviation Association provided the perspective of the industry as a whole in a written questionnaire. The list of experts that were interviewed for this study is as follows:

- Richard Boden from Wingcopter
- Giancarlo Crivellaro from the European Commission,
- Dr. Jan Dirks from BMVI
- Jörg Dittrich from DLR and JARUS

- Robin Garrity from SESAR JU
- Tamara Hartwich from BDL/VUL (written feedback)
- Ralf Heidger from DFS
- Berkay Inan from Austro Control
- Angela Kies from DFS
- Carsten Konzock from LBA
- Ronald Liebsch from DIN, who is a former employee of DJI
- Dr.-Ing. Nora Metzner from Droniq
- Koen Meuleman from Unifly
- Ansgar Sickert from Fraport
- Jan Ziegler from Frequentis

Further information on the experts and their respective organisations can be found in appendix A.

4. Scenario analysis

4.1. Scenario preparation

Although hobby UASs have been in operation for several years now, the commercial UAS market is still in its very early stages. In recent years, an increasing number of UAS operations and an even higher number of proposed use cases for UASs, have amplified the need for a comprehensive regulatory framework to govern UAS flight. The goal of this framework is to enable the safe, secure, and fair integration of UASs into national airspace systems without hindering innovative growth (Eurocontrol, 2018c). With the right legislative guidelines at the right time, regulating authorities could provide the framework for this new industry to grow (Jenkins et al., 2017). However, regulation only provides the foundation on which integration is possible. Other areas that significantly shape the development of the market are the implementation of EU legislature into national law, the economic viability of UAS operations, the technological capabilities of UASs, the security measures to protect against unwanted UAS flight, and finally the public's acceptance. The objective of this analysis is to illustrate possible developments within these areas and to evaluate their impact on European ANSPs.

The next ten years will be fundamental in the development of the UAS market as they mark the period in which all legislative framework is expected be finished and effective and the integration of UASs into national airspace systems complete (EASA, 2021b). Thus, the next ten years are the timeline under examination in this analysis.

4.2. Analysis of influences

4.2.1. Areas of influence

A. Regulation

Regulation is a core element in establishing a commercial UAS market. It is what provides guidance to the stakeholders on how the market will operate. Regulation 2019/947, which is applicable since December 31, 2020, on the rules and procedures of unmanned aircraft marked a revolutionary step in this context as it is the first harmonised legislation on UASs across the Member States of the European Union (EU) (Liebsch, 2021). It provides a comprehensive classification scheme of UASs and their operators as well as the distinct requirements that need to be fulfilled to operate any given UAS. While UAS operations will generally be distinguished into three categories, open, specific, and certified, the regulation presently only covers the open and specific category, with stipulations for the certified still under development. Complementary, regulation 2019/945 provides stipulations on the design and manufacturing specifications of UASs, particularly with regards to certification requirements. A third regulation, 2021/664, provides a regulatory framework for U-Space, a traffic management infrastructure specifically for UASs. This regulation will go into effect in January of 2023 (Dittrich, 2021). These regulations provide the hard law, but the European Commission and EASA also work closely with different stakeholders from the industry to provide soft law regulating the market. This includes Acceptable Means of Compliance (AMC) and Guidance Materials (GM) which are intended to facilitate the process of applying the law (Crivellaro, 2021). However, in order to enable UAS operations in the first place, the fundamental flight rules underpinning all aviation must be amended. They establish interaction protocols between different airspace participants, manned or unmanned (Garrity, 2021).

Drivers:

- Regulation 923/2012: Flight rules
- Regulation 2019/947: Flight authorisations
- Regulation 2019/945: Certified UASs
- Regulation 2021/664: U-Space

B. U-Space infrastructure

U-Space is the European counterpart to the United States' UAS traffic infrastructure. The National Aeronautics and Space Administration (NASA) has coined this infrastructure as Unmanned Aircraft Systems Traffic Management, or UAS Traffic Management (UTM)

(NASA, 2020). Both refer to the traffic management framework in which UAS operations will be conducted and represent the equivalent to manned aviation's Air Traffic Management (ATM) (SESAR JU, 2020). While 'U-Space' is the official European denomination, 'UTM' illustrates the parallels to ATM. Thus, both terms will be used synonymously. The regulatory framework provides the basis for the actors that will be involved in managing UAS traffic as well as the conditions under which UASs can be operated. It defines the roles of the Common Information Service Provider (CISP) and the U-Space Service Provider (USSP). Additionally, it provides a framework of the geographical zones in which U-Space airspaces will be established (European Commission, 2021). However, it leaves significant room for interpretation for the Member States and their implementation into national law.

Drivers:

- Common Information Service Provider
- U-Space Service Provider
- U-Space airspace

C. Economic impact

The business potential of UASs is particularly interesting as it is the main driver for commercial UAS operations. As a disruptive technology, UASs impact wide areas of the economy. They not only create a new means of transport which can deliver people and goods faster, cheaper, and more sustainably, but they also create new applications in terms of remote sensing, which were previously impossible or significantly more complex. However, the extent of the economic impact depends on the viability of the use cases both legally and technologically (Meuleman, 2021). This strongly depends on whether the operations happen in urban or in rural airspace. Additionally, the decision of in-house vs. outsourced UAS operations can shape the development of the market, particularly in the short run (Drone Industry Insights, 2020).

Drivers:

- Urban vs. rural operations
- Internal vs. external services

D. Technology

Technological advancement is the basis on which the development of a commercial UAS market is possible in the first place. Enhanced simplicity of use, sensors that enable safe and stable operations, and improved duration of batteries have created new market potential and continue to do so (Kyrkou et al., 2019). Particularly for operations within the pilot's visual line of sight (VLOS), UASs already show significant capabilities and reliability. However, the true value of this new mode of transport lies in operations beyond the visual line of sight (BVLOS) and autonomous operations (Jenkins et al., 2017). These missions have different technological requirements, some of which are still under development. The main goal is to provide the UAS with its own situational awareness, meaning to substitute the pilot's eyes and perception through technological solutions, thus moving from 'see-and-avoid' to 'sense-and-avoid'. The most important drivers in this area are dependable communications and surveillance systems, reliable separation mechanisms between the UAS and mobile or stationary objects in its flight path, as well as efficient propulsion systems to increase the endurance of UASs for BVLOS missions (SESAR JU, 2020).

Drivers:

- Communications, navigation, and surveillance link
- Separation and conflict management
- Propulsion systems

E. Security

Safety and security are two of the main principles in aviation. Every aspect of manned air traffic is derived from high safety standards to prevent accidents. In terms of security, the industry reacted to hijackings such as the 9/11 terror attack by significantly tightening preventive measures. For UASs, safety is a core element of both regulation and technology (EASA, 2021). However, security issues are amplified by the distance between the operator and the UAS itself. This distance has a twofold impact. For one, it decreases the sense of responsibility within the pilot and may lead to negligent or inconsiderate abuse of a UAS. Secondly, the remote steering of a UAS moves hijacking efforts from physical capture of the aircraft to a technological level, which drastically changes the prevention mechanisms that are required (Michel, 2018). Another issue are the unique challenges of detecting and identifying UASs which are linked to the size and speed of the aircraft. Subsequently, protection mechanisms are also faced with the challenge of reliably disabling unauthorised UASs without endangering people on the ground (Dirks, 2021).

Drivers:

- UAS detection
- Counter measures
- Hacking prevention

F. Public acceptance

As with any new and disruptive technology, public acceptance plays a vital role for its adoption. Since the number of professional UASs is still limited, public acceptance can only be measured on expectations. One factor that is expected to have an impact is the area of operations. For one, this refers to the geographic area, where the acceptance of UASs may differ between urban and rural operations. But additionally, public acceptance is expected to differ in regard to the use cases. Other factors are the implication on privacy and data protection of citizens as well as the perceived safety and security of UASs. Lastly, the subject of environmental protection is particularly relevant for all modes of transport, including UASs (EASA, 2021).

Drivers:

- Area of operations
- Privacy and data protection
- Safety and security
- Environmental factors

	Regulation	*UTM*	*Econ.*	*Tech.*	*Security*	*Public Acc.*
Drivers	Flight rules	CISP	Urban vs. rural	CNS link	Detection	Area of operation
	Flight authorisation	USSP	Internal vs. external	Separation management	Counter measures	Privacy and data protection
	Certified UASs	U-Space airspaces		Propulsion methods	Hacking prevention	Safety and security
	U-Space					Environmental factors

Table 3: Overview of influencing areas and drivers (created by author)

4.2.2. Analysis of interconnectedness

As part of the analysis of influences, the different areas must be ranked according to their level of impact on the market. To do this, the interconnectedness of the areas is analysed. Thus, each area of influence is assessed in regard to its impact on the other factors. The impact is codified according to a three-point scale from 0-2. 0 describes ‘no impact’ on the respective area, 1 describes 'indirect or weak impact', and 2 describes 'strong impact'. The resulting sum of each area is labelled as 'active sum', and the sum of the influence that is exerted on any one area is labelled as 'passive sum'. Typically, this assessment is conducted in a group setting, through brainstorming and discussions. Within the scope of this study, the interrelation was evaluated based on the data collected from scientific publications and the expert interviews. The interconnectedness matrix is depicted in Table 4. The results of the matrix are transferred to a system grid as seen in Figure 7. The boundaries of the grid are derived through the mathematical mean of active or passive sums across all areas. Subsequently, the four resulting domains describe active, ambivalent, buffer, and passive influences.

	Tech.	Reg.	UTM	Security	Econ.	PA	Active sum
Technology		0	1	1	1	1	4
Regulation	0		2	1	2	2	7
UTM	2	0		1	2	1	6
Security	1	1	0		1	1	4
Economic	0	2	1	1		2	6
Public Acceptance	0	1	0	0	1		2
Passive sum	3	4	4	4	7	7	4,833333

Table 4: Interconnectedness matrix (created by author)

Regulation is the area that exerts most influence over the other areas. It sets the framework for a UTM system and the viability of economic use cases. Furthermore, it indirectly impacts security protocols and public acceptance. UTM infrastructure has a similar impact on the other factors (McKinsey & Company, 2017). The economic area is particularly interesting as it exerts considerable influence on other factors while being strongly impacted itself. Economic interests are the driver of the market, with businesses pursuing the reduction of cost and the utilisation of new potentials. However, the degree of this economic impact is highly dependent on other developments in the market. Regulation may restrict certain use cases to the point of infeasibility, as may technological advancements. Indirectly, public acceptance may hinder large-scale UAS operations (BMVI, 2020). Technology and security both present buffer areas in the market. While they should not be neglected, the fundamental market structures are not dependent on any significant changes in these areas (Liebsch, 2021). Finally, public acceptance is a passive area of influence. It indirectly impacts the areas of regulation and the economic viability of certain use cases, but not strongly enough to constitute an ambivalent influence. On the other hand, public acceptance may vary significantly depending on developments in the other areas (EASA, 2021).

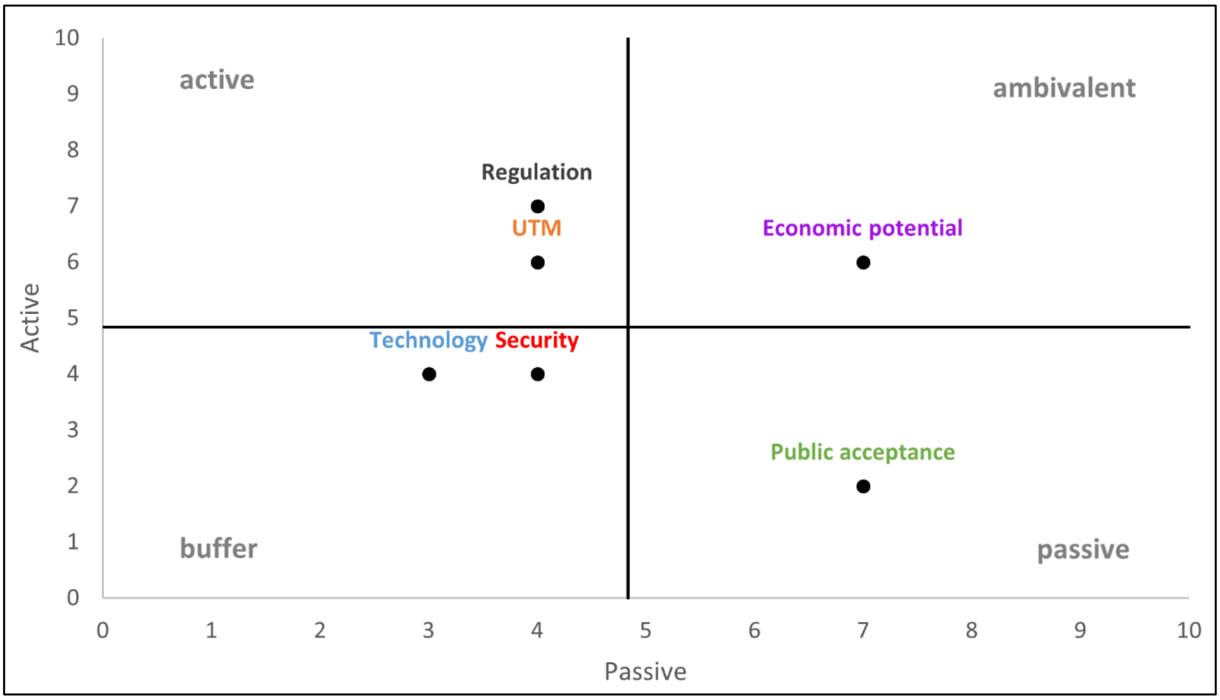


Figure 7: System grid derived from interconnectedness matrix (created by author)

4.3. Trend projections

4.3.1. Area A: Regulation

4.3.1.1. Driver: Regulation (EU) 923/2012 – Flight rules

In accordance with ICAO's Standards and Recommended Practices (SARPS), all flights are subject to the Rules of the Air (RoA). In Europe this was translated into regulation 923/2012 on the Standardised European Rules of the Air, or SERA. Currently, these so-called flight rules are distinguished into Visual Flight Rules (VFR) and Instrumental Flight Rules (IFR). Additionally, General Rules describe universal stipulations for all flights (Eurocontrol, 2018b). Flight rules determine visibility, altitude ranges, speeds, conditions for night flying, flying over populated areas, equipage and reporting (SESAR JU, 2019). Robin Garrity from SESAR JU is heavily involved with these integration mechanisms and states that currently, UAS cannot operate in either category. Especially smaller UASs are unable to support the equipment that is needed to participate in IFR traffic, and VFR traffic requires the UAS to perceive its environment as if it had eyes. Garrity states that even if technological solutions were sufficient to mimic human eyesight, the regulations currently do not allow for it. Thus, the flight rules that are underpinning aviation need to be amended to enable integration of manned and unmanned air traffic operations in the long run (Garrity, 2021).

Visual Flight Rules	Instrument Flight Rules	Low-level Flight Rules	High-level Flight Rules
VFR	IFR	LFR	HFR
ICAO Annex 2 Chapter 4	ICAO Annex 2 Chapter 5	To be developed	To be developed
SERA 5001-5010	SERA 5015-5025		
General Flight Rules			
ICAO Annex 2 Chapter 3			
SERA Section 3			

Figure 8: Proposed amendments to flight rules (Eurocontrol, 2018b)

Generally, UASs are supposed to fly in Very Low-Level (VLL) airspace, which has a maximum altitude of 500 feet or 150 metres. In urban environment this limit is extended to 1,000 feet or 300 metres. Although VFR traffic is supposed to stay above VLL airspace, this is not a fixed barrier. Especially in urban environments, many helicopters carrying out medical, police, or firefighting missions fly within that airspace. And even in rural areas, hang-gliders, or ultralight aircraft commonly cross into VLL airspace. Boden explains that there are many occurrences in which VFR and GA traffic passes below the 500 ft mark, even if it is just for a short period of time (Boden, 2021). Inan from Austro Control points out that the integration of unmanned aircraft into a system that was designed purely for manned aviation requires additional provisions on the interaction between those players, such as right of way protocols (Inan, 2021). Eurocontrol proposes the definition of two more classes of flight rules as presented in Figure 8. The airspace below VFR traffic would then be governed by Low-level Flight Rules (LFR), and the airspace above IFR would be governed under High-level Flight Rules (HFR). Figure 9 illustrates the flexible boundary between LFR and VFR airspace, which further drives up complexity. These flight rules need to determine how different stakeholders interact in any given airspace. This includes, for example, defining a right of way concept, separation minima, and the communication between different aircraft (Eurocontrol, 2018b).

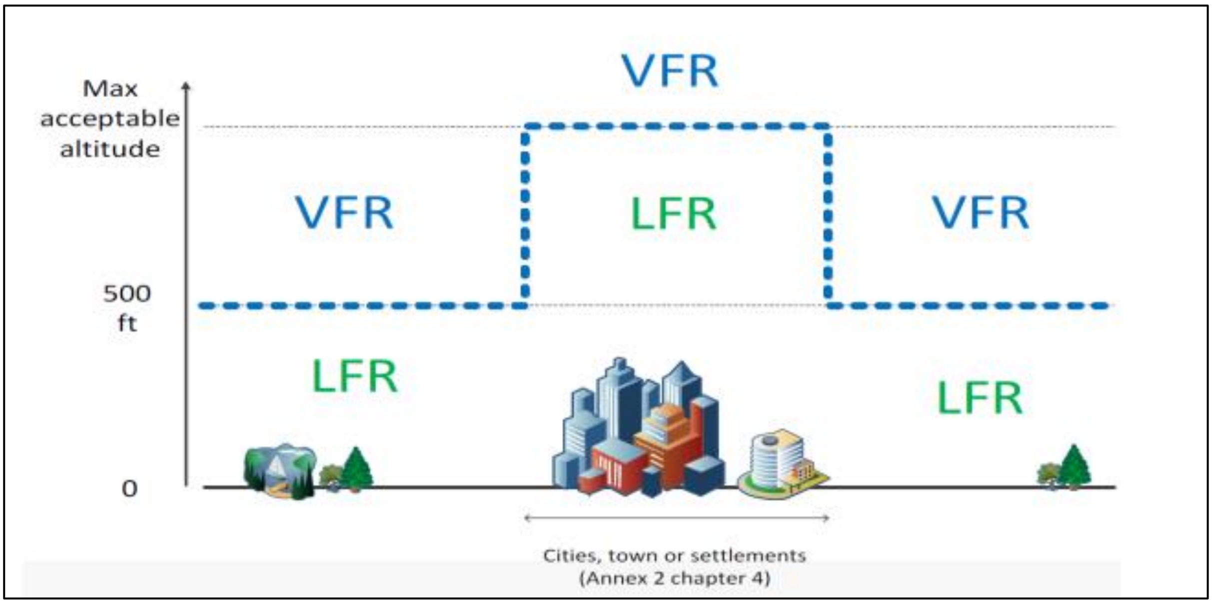


Figure 9: VFR/LFR boundary (Eurocontrol, 2018b)

One option of ensuring safe coexistence of GA and UAS traffic is to make all airspace participants visible in the UASs' operating systems. This is referred to as electronic conspicuity. However, it requires the aircraft to carry an electronic device that transmits their position, altitude, orientation, and velocity. Garrity remembers a sports aviation conference in which he proposed this idea to a GA crowd and the intense negative feedback he received. He explains that, at today's prices, putting these electronic devices on GA aircraft, could often cost more than the aircraft itself. Thus, although prices are reducing, forcing this group of airspace participants to become electronically conspicuous could easily price them out of their hobby. Garrity adds that this is precisely the opposite of what flight rules were created to do in the first place, which is to enable all aviation (Garrity, 2021). Boden had a similar experience at a rotorcraft workshop when EASA presented the idea. He agrees that imposing these requirements on GA traffic noticeable reduces their privileges and flexibility in the air. He expresses doubts of this happening in the foreseeable future (Boden, 2021). Additionally, Kies points out that some public service aircraft, such as police or authorities with security tasks may not want to become electronically conspicuous because they want to stay under the radar (Kies, 2021). On the other hand, Boden explains that it is incredibly difficult for UAS operators to ensure separation to manned aircraft that are neither electronically visible, nor flying according to a filed flight plan (Boden, 2021). Inan describes trial runs in which UAS operations are announced to the responsible or to affected airspace participants as a means of situational awareness. However, this requires individual agreements between the relevant parties in a very case specific manner (Inan, 2021). If safe separation cannot be ensured, unmanned traffic and manned traffic have to be completely segregated.

Alternative A: The flight rules are amended to allow for coordination of GA and UAS traffic. Electronic conspicuity is established in a universal, cost-effective, and mandatory manner. UASs can give way to VFR traffic and GA aircraft in those instances where the two parties interact. In the long run, a comprehensive overview over all airspace participants paves the way for a comprehensive integrative approach for national airspace systems.

Alternative B: The pushback from the GA industry excludes electronic conspicuity from consideration. A lack of safe and reliable separation mechanisms between manned and unmanned traffic forces the complete segregation of the two parties. Subsequently, airspaces must be distinctly divided and crossovers into other airspace segments must be communicated to all impacted parties.

4.3.1.2. Driver: Regulation (EU) 2019/947 – Flight authorisation

Regulation 2019/947 has been in effect since December 2020 and provides a framework for the operation of commercial and recreational UASs. In broad strokes it divides UAS operations into three distinct categories – open, specific, and certified – and provides stipulations for each category. The open category includes UASs with a maximum take-off mass (MTOM) of less than 25 kg. UASs in this category cannot fly over assemblies of people and must be operated within the pilot’s line of sight or a designated observer’s line of sight. This category is also limited to flights of up to 120 m unless the UAS is passing over an obstacle. No dangerous good can be carried or dropped by UASs in this category. No flight authorisation is needed for operations within this category (European Commission, 2019b). Further subcategories of the open category are described in appendix B.

If the requirements for an open category operation cannot be satisfied, the operation falls under the specific category. This category requires an operational authorization for each flight, which is based on a risk assessment. The AMCs for this regulation propose the specific operation risk assessment (SORA) process, which was developed by JARUS. The SORA process is based on the operator’s proposed concept of operations (ConOps), which describes the planned operation and its environment, the technical specifications of the UAS, contingency measures, as well as information about the operator and the remote pilot. This principle not only factors in the air collision risk based on airspace density and operational flight altitude, but also the ground risk regarding to population density, UAV dimensions, and BVLOS/VLOS characteristics. As a result, SORA categorizes each operation into one of six Specific Assurance and Integrity Levels (SAIL). Lower SAIL classification leads to lower Operational Safety

Objectives (OSOs) that the operator has to fulfil. Thus, risk mitigation measures can be employed to reduce SAIL and subsequently reduce the required OSOs (Torens et al., 2020). The risk assessment, the risk mitigation methods and the resulting OSOs are evaluated by a designated competent authority and if deemed satisfactory, a flight authorization is granted (European Commission, 2019b). The process of attaining this authorisation is depicted in Figure 10.

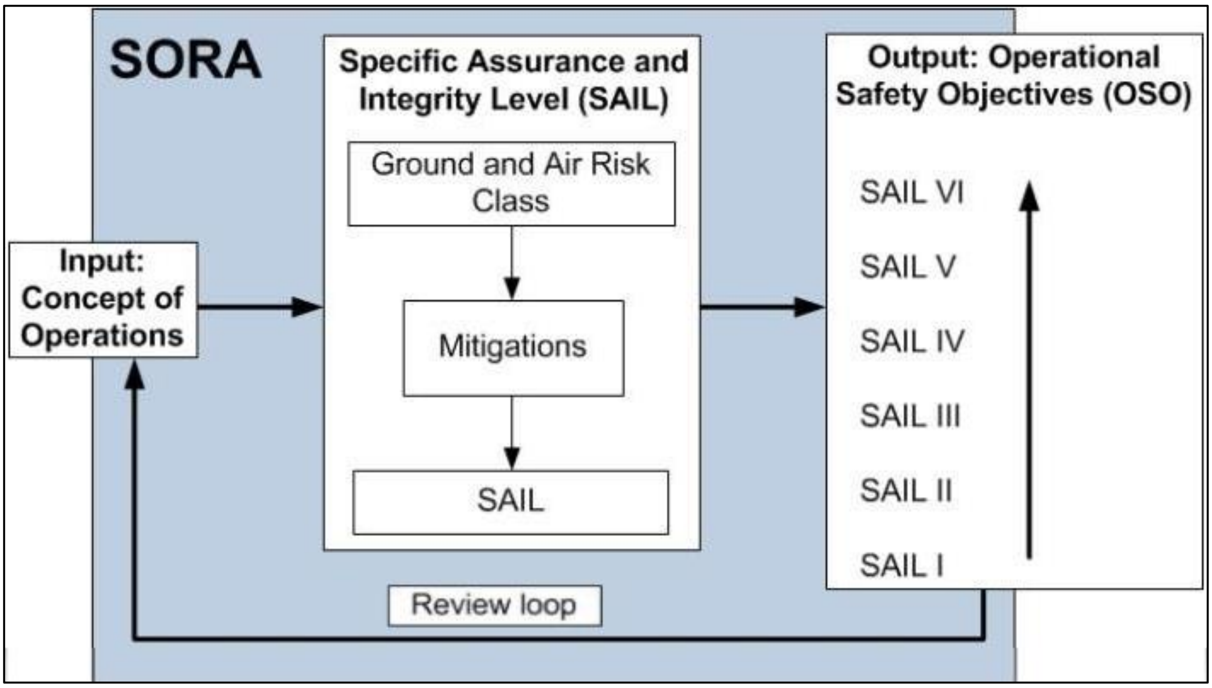


Figure 10: SORA process (Nikodem et al., 2018)

There are three supportive options for operators to navigate the SORA process, a LUC, a PDRA, and a standard scenario. The first option is for operators to obtain a Light UAS operator Certificate (LUC). This encompasses establishing an independent unit which has the authority to clear UAS operations. A LUC also requires them to provide a description of the operational structure and safety management system and guarantee their compliance with all responsibilities of a specific category operator and pilot (European Commission, 2019b). Dittrich describes this option as establishing a smaller in-house version of the competent authority within your organisation. It enables the operators to process short-term changes in their operational concept or their risk assessment without the long waiting periods at the official competent authority. Thus, while it allows the operators to be prioritised by their LUC unit, it does not provide a shortcut around the SORA process. The LUC unit must be independent and free and provide the same processes and receipts as the regular authorisation agency would (Dittrich, 2021). Konzock adds that the requirements to attain a LUC are quite high so only companies with large-scale operations may consider this (Konzock, 2021).

A second option is to apply for authorisation based on a Pre-Defined Risk Assessment (PDRA). These are covered as AMC in the regulation and have already passed through SORA. Konzock describes a PDRA as a framework of requirements for the operator, and once these requirements are fulfilled, an authorization is granted (Konzock, 2021). However, Dittrich clarifies that the workload relief of applying a PDRA is not as high as one may expect. While it does save the operator the time and effort of conducting a SORA, they still have to submit a ConOps that fulfils all the OSO requirements. According to him, the time effort of writing a ConOps and conducting a SORA is 90:10, so the PDRA only superficially simplifies the authorisation process (Dittrich, 2021).

The most convenient way to conduct a flight in the specific category is to use a so-called standard scenario. Unlike a PDRA, a standard scenario is part of the hard-law regulation and defined in the annex, according to Crivellaro, who is actively involved in developing the regulation with the European Commission (Crivellaro, 2021). It provides the operator with the opportunity to submit an operational declaration instead of applying for an authorisation. So far however, EASA has only defined two standard scenarios. One allows for urban VLOS operations and the other for rural BVLOS missions (EASA, 2019). Crivellaro estimates that the PDRAs that are currently part of the AMC of 2019/947 will gradually transform into standard scenarios and get added into the annex of the regulation (Crivellaro, 2021).

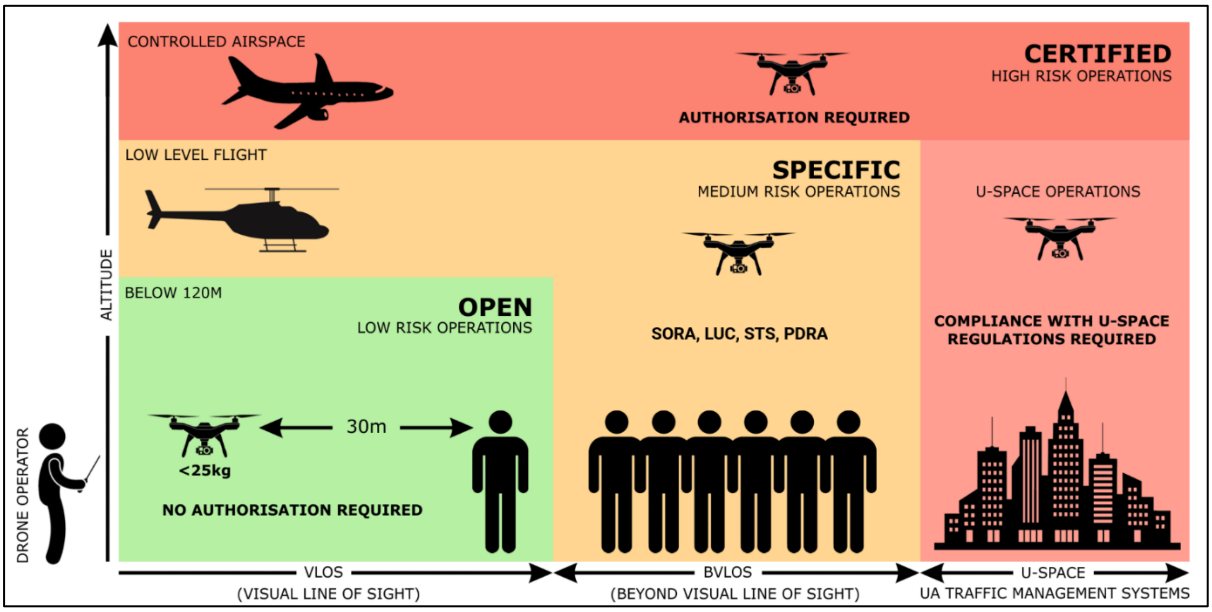


Figure 11: EASA UAS categories (geo-konzept, 2021)

The three categories of regulation 2019/947 are depicted in Figure 11 to illustrate the different requirements associated with them. Dittrich states that this risk-based approach enables a vast range of possible operations already. According to him, even large and heavy UASs can be operated within certain environments, such as rural areas or between island and mainland. He expressed his surprise at the limited utilisation of this framework, claiming that out of 100% of possible UAS application, the market is currently only using 5%. He further estimates that the reluctance of the industry to delve into this new market is due to the complete overhaul of regulatory tenets in the aviation environment. While traditional aviation has been developed and evolved over nearly 100 years, UAS regulation follows a revolutionary new approach (Dittrich, 2021). Other experts agree that the slow adaption of the regulation by the industry is due to its complexity and novelty. Dirks from the German Ministry of Transport says that both businesses and regulatory bodies are still familiarising themselves with the new reality of UAS operations. He adds that the bureaucratic procedures must be simplified to enable smaller companies to utilise UAS potential in their business as well (Dirks, 2021). Inan states that while the process may seem overbearing to the operators, this barrier should be resolved by guiding the operators through the process, instead of facilitating it at potential cost of safety (Inan, 2021).

However, Dittrich warns that the market should not be overregulated before it has had a chance to develop. He points out that some parts of the regulation, such as the requirements to operate under SAIL III, are already being reviewed and tightened without any empirical basis (Dittrich, 2021). Thus, the SORA process is currently used for fairly simple operations with low risks, for example in sparsely populated areas or within line of sight. It requires extensive knowledge about the operation and the technological performance of each individual UAS. This complicates the authorisation process for large-scale operations in complex environments with high predicted traffic volumes (SESAR JU, 2020).

Alternative A: The complexity of SORA is continuously reduced through a growing number of standard scenarios and PDRAs. Operators who intend to conduct large-scale UAS business become LUC holders to reduce the workload of the competent authorities caused by SORA processes. Businesses and research centres lose their inhibitions of entering new ground and utilise the potential of the specific category under current regulations. Simultaneously, regulatory bodies give the market the opportunity to develop and subsequently adapt the legislative framework based on recorded data instead of in advance. Gradually, the flight authorisation process is continuously assessed and evolves along with technological advance in order to utilise the full potential of the market.

Alternative B: The prospect of cumbersome flight authorisation processes impedes the industries willingness to explore UAS applications within their field of business. Additionally, regulatory bodies undermine the potential of a risk-based operations assessment by relapsing into traditional safety perspectives in aviation and imposing high regulatory criteria on the market. The economic viability of deploying UASs is reduced and the development and testing of new UAS use cases is hindered.

4.3.1.3. Driver: Regulation (EU) 2019/945 – Certified UASs

All operations for which the risk mitigation measures are insufficient to reach acceptable safety levels fall under the certified category. In addition to the operations exceeding the safety profile of the specific category, operations that fulfil at least one of the following conditions automatically belong to the certified category: (a) the dimensions of the aircraft exceed three metres and it is designed to be operated above assemblies of people, (b) the aircraft is designed for the transport of people, or (c) the aircraft is designed to transport dangerous goods (Alamouri et al, 2021). Dittrich explains that the certified category can be compared to a SAIL VII classification, following the principle of the specific category (Dittrich, 2021). The requirements in this category resemble the requirements for traditional aviation operations. For example, the UAS will need a type certificate as well as a certificate of airworthiness, and the remote pilot will need to have a remote pilot's license. However, the regulatory framework for this category is still under development and is expected to be published in 2024, according to Konzock (2021). EASA predicts three types of operation for this category: (1) unmanned cargo aircraft flying under Instrumental Flight Rules (IFR) along with manned aviation, (2) UAS operation in urban environments, such as UAM and drone delivery, (3) initial air taxi operations with a pilot on-board (EASA, 2021a). Because there currently are no certified UASs available on the market, operations in the certified category are not yet feasible. Additionally, operations in the specific category with SAIL IV-VI classifications also require certified UASs and are thus not feasible yet either. Konzock estimates that one of the largest obstacles in the market at the moment is the lack of certified UASs (Konzock, 2021).

Richard Boden, head of certification at UAS manufacturer and operator Wingcopter, explains some of the difficulties of developing a certified UAS. For one, the regulatory requirements are not finalised yet and leave significant room for interpretation. Boden states that the basic requirements are copied from manned aviation but that there is significant need for amendments and optimisation. He states that the next step should be to pass through EASA's design verification process, to obtaining an initial registration for a certified UAS. However, this is challenging as it requires time, manpower, and proof of compliance. This proof of compliance is typically linked to an AMC and GM framework that provide manufacturers with guidelines for the technical implementation of regulatory design specifications. Typically, they include specifications for tests, simulations, and calculations. He adds that other aspects of the regulation need to be developed and updated as well, but that they will be published later as the certified category is not operable without certified UASs anyway. According to his estimation, it will take several years before the first certified UASs are marketed, and the certified category becomes operable, and even longer until a sufficient number of certified UASs becomes available to make the market scalable (Boden, 2021).

Dittrich points out that operations in the specific category under SAIL IV-VI also require a certified UAS. While they may not need to be certified to the same extent as UASs in the certified category, the require the same regulatory and technical framework in order to be developed and manufactured. Thus, until this is finalised, these SAIL levels cannot be operated in (Dittrich, 2021). Although the lower SAIL classes and the open category already enable vast use cases in rural areas, Boden, Dittrich and Konzock all agree that urban operations quickly enter higher SAIL requirements or even the certified category (Boden, 2021; Dittrich, 2021; Konzock, 2021). This limitation could further increase the industry's reluctance to utilize to operational potential that is currently available.

Alternative A: AMC and GM documents enable timely development and construction of certified UASs. Manufacturers are able to specialise in different SAIL categories and produce certified UASs in the specific category in accordance with these AMC and GM. Once the regulation on the certified category is finalised and published, certified UASs are ready and operable. Subsequently, new market potential will open up in urban areas, in particular with regards to the transport of passengers. Based on a learning curve and collected performance data, certification processes are slimmed down to reduce complexities and avoid unnecessary bureaucratic red tape.

Alternative B: The publication of AMCs and GMs drags on and hinders the market's development and growth. UAS operations will be restricted to the open category and lower SAIL classes for the next 5-10 years.

4.3.1.4. Driver: Regulation (EU) 2021/664 – U-Space

EU regulation 2021/664 will enter into force on 26th of January 2023 and provide a framework for a UAS traffic management system, or U-Space. This framework is the foundation on which large-scale UAS operations will be coordinated and managed. Dittrich explains that through regulation 2019/947, UAS operations outside of an experimental context are possible in the first place, but that regulation 2021/664 on U-Space is the regulatory framework that will make these operations scalable, particularly in urban environments (Dittrich, 2021). U-Space is supposed to provide a flexible and adaptable system that can respond to changes in demand, volume, use cases, and technology (SESAR JU, 2019). The regulation defines different roles in the U-Space system such as the Common Information Service Provider (CISP), the U-Space Service Provider (USSP) and the operators of UASs and provides requirements and stipulations relating to these roles. Furthermore, the regulation maps out specific services that must be offered within U-Space airspaces. As the technological capabilities of UAVs and their associated systems are constantly improving, the regulation around them needs to be re-evaluated and harmonized to unlock the full potential of the market (Alamouri et al., 2021).

In order to achieve a high degree of safety, efficiency, and sustainability, U-Space is dependent on available technologies as well as the maturity of U-Space services. Various research projects are being conducted across European nations. Kies describes a U-Space test site in Hamburg, Germany that is supposed to uncover missing specifications in the regulation and provide a better understanding of the roles and responsibilities within the U-Space system. In addition, some questions regarding the economic set-up of U-Space and the associated liabilities are examined (Kies, 2021). Similarly, Inan talks about projects in Austria that deal with the integration of unmanned aircraft into manned air traffic (Inan, 2021) and Meuleman describes a project in the port of Antwerp where UAS operations are coordinated under a geozone manager (Meuleman, 2021). However, the research projects also exceed national borders. It is essential that legislative bodies such as EASA and the European Commission engage in research and development efforts and monitor the various trial phases and projects that are being conducted to advance the regulatory landscape alongside technological progress (SESAR JU, 2020).

For this purpose, EASA and Eurocontrol have founded SESAR and SESAR JU, to foster the research, development, and testing of new technologies, protocols, and mechanisms. SESAR JU has created a blueprint to establish a full set of U-Space services in four stages (see Figure 12). The first stage, U1, deals with the foundation services of U-Space. These are, for example, the e-registration and e-identification of UASs and their operators as well as the designation of U-Space airspaces through geo-fences. The U2 stage builds on that to provide initial services to support the management of UAS operations. These services include the flight and mission planning of UAS operators and the provision of flight authorizations, tracking services, airspace dynamic information, and where necessary, procedural interfaces with ATM. U3 services include advanced services that already provide a high degree of automation and support complex operations in dense airspace. These services require further technological development with regards to automated detect-and-avoid systems and communication systems to enable enhanced capacity management and conflict detection assistance. The final stage of U-Space services. U4, provides full U-Space services and supports the complete integration of UTM and ATM in order to utilize the full operational capability of U-Space. These services require a high degree of automation, connectivity, and digitalisation (SESAR JU, 2019).

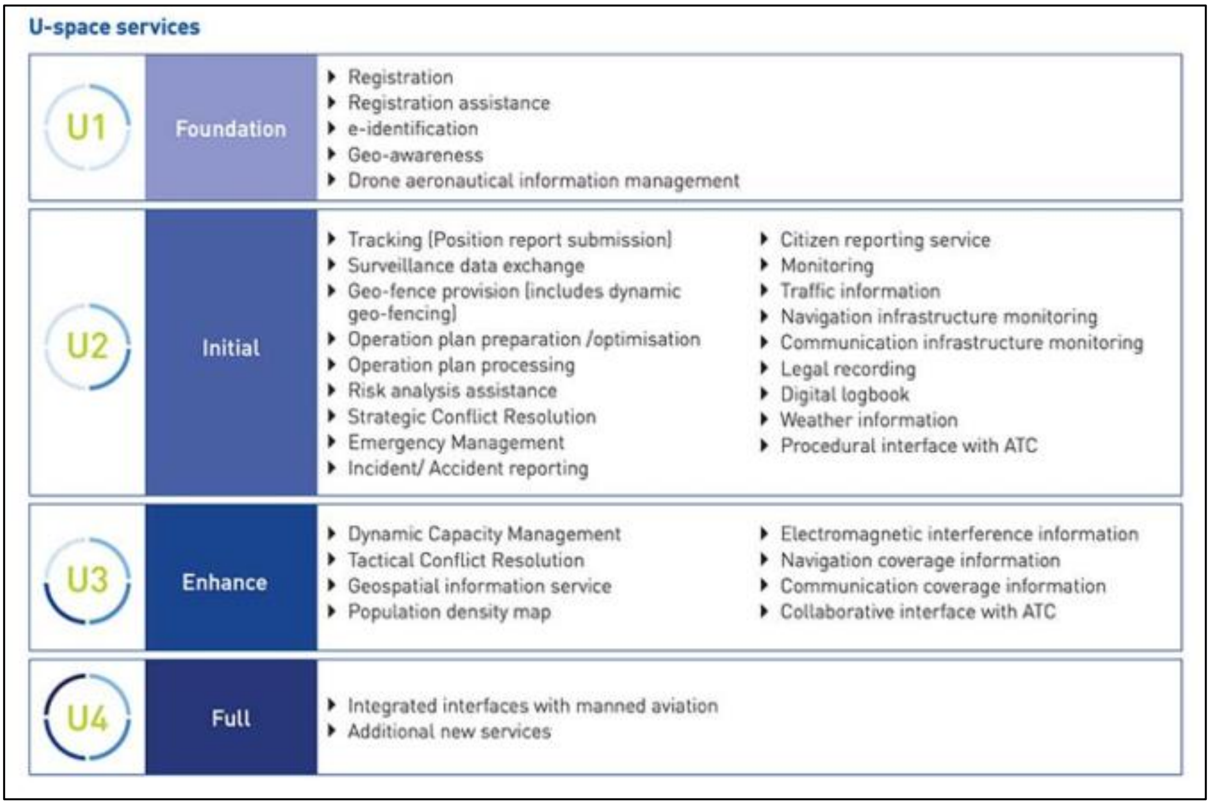


Figure 12: SESAR JU U-Space blueprint (SESAR JU, 2020)

SESAR JU states that the services for stages U1 and U2 are tested and operable, though Garrity points out, that the U2 services are still quite static and provide a limited system in terms of capacity. The actual automation that allows for more densely utilised airspace only takes place in U3 and subsequently U4 when trajectories and tracking data are managed and deconflicted automatically. However, it is yet unclear how the necessary solutions for this will develop, thus making the transition from U2 to U3 quite challenging. He further points out that the regulations currently do not allow for stage U3 operations, and thus need to be updated and amended to allow for integration in the future (Garrity, 2021). Kies points out that integration is already possible and necessary today. Her vision of integration is not based on – currently still unavailable – technological detect-and-avoid systems, but rather on the situational awareness of all airspace participants and their ability to react to spontaneous changes in the situation

(Kies, 2021). Either way, the current regulation does not enable full utilisation of airspace capacities and needs to continuously evolve towards a more integrative approach.

Alternative A: The research and development efforts of regulatory bodies continue beyond the initial establishment of the market in order to continuously update legislation in accordance with the technological standards. Besides academic research, governing authorities promote and support test runs and trial stages to incorporate real-life experiences and detect new challenges and opportunities within the legal landscape of the UAS market. The U-Space blueprint and its four proposed stages of U-Space services can be transformed into reality.

Alternative B: The capacity of UAS operations is severely limited by mandated segregation. Research and development efforts are neglected after the initial take-off phase of the market is concluded. Regulation remains static and prevents innovative developments within the market.

4.3.2. Area B: U-Space infrastructure

4.3.2.1. Driver: Common Information Service Provider

The regulation on the framework for a U-Space infrastructure stipulates two distinct roles, the Common Information Service Provider (CISP) and the U-Space Service Provider (USSP). The CISP provides information for each designated U-Space airspace. These must include the distinct boundaries of the U-Space airspace, both vertically and horizontally as well as the performance requirements of each airspace regarding the UASs and the USSPs. Furthermore, they shall provide a list of certified USSPs including the services they offer, their identification and possible limitations of their certification. The provided information should also include all adjacent U-Space airspaces and any geographical zones that were defined by the Member State in accordance with regulation 2019/947 and are relevant to the particular U-Space airspace in question. Finally, all static and dynamic airspace restrictions limiting the airspace capacity must be included. This information must be made available in an open, secure, scalable, sustainable, and interoperable way across the European Union (European Commission, 2021).

The regulation provides two options to implement common information services. Member States can either follow a centralised approach with one designated CISP for each U-Space airspace, or they can have a decentralised setting where information is provided by the individual parties and collected in a digital cloud storage. According to European Commission member

Crivellaro, the initial idea was to enable a decentralised structure through digitalised and automated systems, however, several Member States and other stakeholders urged for the inclusion of a centralised CISP option (Crivellaro, 2021). The reasoning behind this centralised approach is to establish the CISP as a single source of truth, according to several experts in the industry (Garrity, 2021; Kies, 2021; Metzner, 2021; Meuleman, 2021; Ziegler, 2021). It is essential that all participants in one airspace act on a universal reference of data. Additionally, it is important to ensure a high quality of the data. The information services for UASs will be significantly more diverse and dynamic than traditional aeronautical information services (AIS). The geographic boundaries of U-Space airspaces include various man-made structures as well as terrain and infrastructures. Operations in VLL airspace must consider every tree, power line, mountain, or skyscraper, down to a moving crane. Thus, the geospatial information and mapping services have to be extremely detailed (SESAR JU, 2020). Garrity stresses that all the information must be accurate and reliable. In aviation this is commonly referred to as aeronautical data quality, or ADQ. Before these types of data can be used, they have to fulfil certain quality requirements relating to the sourcing of the data, for example (Garrity, 2021). From the viewpoint of Crivellaro, this quality of data is ensured through the certification process of the individual service providers (Crivellaro, 2021).

Meuleman from Unifly has pointed out that there is no provision in the regulation that includes the distribution of tracking information in the responsibilities of the CISP. This increases complexity in tactical deconfliction of UASs as all USSPs have to coordinate among each to deconflict in case of short-term changes in the airspace. Additionally, a centralised information service facilitates the provision of U-Space information to other stakeholders, such as police forces (Meuleman, 2021). Kies agrees that the interface between local authorities and the CISP is crucial in order to account for ad-hoc emergency missions. This includes police and medical helicopters, but also the installation of temporary no-fly zones (NFZ) in case of a crisis (Kies, 2021). Crivellaro claims the position that within each bubble of U-Space airspace the real-time management of UAS operations is possible and that all the technologies needed to deconflict in a distributed system are readily available. In case of a short-term disruption of the airspace, i.e., through military operations or emergency flights, the bubble dissolves and grounds the UASs until the disruption has passed (Crivellaro, 2021).

Lastly, it is left up to the Member States whether they want to appoint a single CISP for several or all U-Space airspaces nationwide or one CISP for each U-Space airspace. Garrity states that although it is possible to appoint multiple CISPs for separate airspace blocks, it seems expensive and inefficient (Garrity, 2021). Ziegler points out that it would make sense to have one centralised CISP for all blocks of U-Space airspace in one state as they would be able to provide a more comprehensive service portfolio, such as the USSP service registry or the geographic zones (Ziegler, 2021). Hartwich agrees that having a single centralised CISP reduces interfaces and shared responsibilities (Hartwich , 2021). Dirks from the German Transport Ministry declares that Germany will have one CISP per U-Space airspace and that it will not necessarily be a sovereign task but may well be organised in a competitive market. While he does admit that ANSPs have significant qualifications with regards to the CISP role, he could also envision foreign ANSPs, such as the Swiss aviation safety organisation or local German aviation safety organisations to assume that role (Dirks, 2021).

Many experts within the industry agree that there is a strong case to be made for the CISP role to be a sovereign responsibility in order to ensure the quality of the data and provide a single source of truth (Garrity, 2021; Hartwich, 2021; Heidger, 2021; Kies, 2021; Meuleman, 2021), although Crivellaro states that the quality of data is already ensured through the provisions in the regulation (Crivellaro, 2021). Ziegler goes one step further and mentions the possibility of actual state agencies such as the BMVI or the LBA to take over that task (Ziegler, 2021). More commonly, the experts point out that national ANSPs are in a uniquely qualified position to provide information services. Heidger declares that ANSPs have a profound knowledge and know-how about the workings of the aviation industry that many actors in the emerging UAS industry lack. He fears that political and economic interest may outweigh the safety considerations that have to be made in the context of UTM (Heidger, 2021). Garrity adds that even specialists in the industry still struggle to completely understand the finer technicalities of moving things in the air and that ANSPs have a good foundation as they have access to flight and aeronautical information already (Garrity, 2021). Kies further stresses that ANSPs have a distinct mindset with a strong focus on diligence and safety, which should not be underestimated in this context (Kies, 2021). Dirks agrees that the barriers for new entrants are quite high as they need to establish the necessary software and hardware first, and possibly purchase data and information from the ANSP. Nonetheless, he adds that he can imagine the national ANSPs covering 80-90% of the U-Space airspaces but that some blocks of airspace will be covered by other parties. The final organisation of the CISP role will depend on the outcome of testing sites and further research (Dirks, 2021).

Alternative A: A single CISP is designated and certified to collect, consolidate, and distribute all relevant information to the USSPs and other stakeholders. This CISP acts as a single source of truth and ensures the reliability and quality of the data they provide. Further, the role of the CISP is a sovereign function of a public administration and utilizes the know-how of AIS providers. It establishes a centralised governance of U-Space airspaces and creates situational awareness for all airspace participants by providing a comprehensive tracking and monitoring framework.

Alternative B: Common information services are distributed in a decentralised manner. This causes the need for a high degree of communication and coordination between the individual USSPs. Each interface between the competing providers bears the potential of conflict. Authorities with safety or security tasks do not have a centralised point of contact for the UTM system to incorporate short-term notices about changes in airspace or emergency operations.

4.3.2.2. Driver: U-Space Service Provider

Every certified U-Space Service Provider (USSP) must offer a minimum of the following services: a network identification service including a remote identification of the UAS, a geo-awareness service with all relevant geographical zones and their conditions, a UAS flight authorization service, and a traffic information service regarding manned air traffic, as well as other unmanned air traffic managed by other USSP. Further supplementary services include weather information services and conformance monitoring services and may be required in specific U-Space airspaces (European Commission, 2021). Metzner describes the role of the USSP as the enabler of a safe integration of UASs into national airspace systems, through a system that provides situational awareness beyond the pilot's visual line of sight (Metzner, 2021).

This federated network of USSPs in UTM deviates from the ATM model in manned aviation, where the provision of aeronautical services is centralised through the national ANSPs in controlled airspace. According to Crivellaro, the Commission pursued a decentralised approach to enable competition on a basis of common safety and security standards (Crivellaro, 2021). Ziegler from Frequentis supports the competitive approach and states that providing a system that is interoperable between multiple players also facilitates harmonized cross-border operations in the long run. Furthermore, a federated USSP system promotes the quality of services, which is often lacking in monopolistic systems (Ziegler, 2021). There are also some concerns in the industry as well, regarding competition in the USSP market. Garrity from SESAR JU points out that there are instances in which privatisation and competition has turned the market for the worse and has made it more expensive (Garrity, 2021). Additionally, any legal entity fulfilling the requirements to become a certified USSP is entitled to do so. This includes individual UAS operators, and companies who want to manage their own operations instead of having an external USSP doing so. Thus, Meuleman further indicates the threat of big tech companies such as Google or Amazon monopolizing the market through predatory pricing (Meuleman, 2021).

There is a general consensus between the Commission and the industry stakeholders that competition must be collaborative and cannot be based on safety critical information but rather on the commercial advantage of the services offered (Crivellaro, 2021; Garrity, 2021; Meuleman, 2021). Yet, how exactly the competitive landscape will look like in the long run is unclear. Meuleman claims that there is no room for competition for the essential services. One option to differentiate the services is via add-on benefits, such as fleet management or maintenance services. He draws a comparison to the telecommunications market, where the providers all base their services on the same network and gain strategic advantages through premium services, or service packages (Meuleman, 2021). Kies validates that comparison and adds intangible factors such as branding, image, and sympathies as drivers for competitive advantage (Kies, 2021). Another option is to have different USSPs for different blocks of U-Space airspace (Garrity, 2021). Dirks raises concerns regarding the economic focus of USSPs to enable the best possible service to their clients. He mentions the possibility of USSPs using false information to provide airspace access for their customers (Dirks, 2021). Crivellaro counters that all participating parties in the U-Space system will be certified and audited, thus ensuring the compliance with the regulation and its safety provisions (Crivellaro, 2021).

There are different ideas on how many USSPs will operate in any given Member State. Garrity offers the prospect of having a primary USSP and supplementary USSPs. He even points out the possibility of national ANSPs providing these services, stating that almost every country is starting off with the ANSP or a spin-off of the ANSP as USSP. Again, he refers to the well-founded knowledge of ANSPs on how to coordinate air traffic and utilizes airspace capacities (Garrity, 2021). Metzner estimates that it will be a highly consolidated system of only a few key players as is often the case in safety-intensive markets. She believes that the high initial costs of becoming a certified USSP and the associated safety requirements will prevent many players from entering the market (Metzner, 2021). Meuleman points out that the more distributed the USSP system is, the more complex the coordination and communication within the market becomes. Additionally, the exchange of information is not yet standardised (Meuleman, 2021). In any case, the various USSPs in each airspace need to make collective and coordinated decisions. These communication protocols between multiple USSPs and the exchange of data need to be established and standardised in a reliable and consistent manner (SESAR JU, 2020).

Alternative A: The high standards for certification and the initial cost of becoming a USSP cause the market to consolidate to a few key players. They offer their services based on the same network of information, but with different add-on services and commercial advantages. The competition in the market is comparable to the telecommunications industry with very few players and a high degree of homogeneity in the service portfolio.

Alternative B: There is a high degree of dispersion in the USSP market. Many larger companies and UAS operators enter the market either exclusively for their own fleet or as external service providers. The market operates in a balance between high safety requirements and cooperative processes on the one hand, and a competitive business environment on the other hand.

4.3.2.3. Driver: U-Space airspace

The distinct areas that will be designated as U-Space airspace will be defined by the Member States according to safety, security, environmental or privacy aspects. This designation must be based on a risk assessment and subsequently include requirements regarding the UAS capabilities and performance, the U-Space service performance, and the applicable operational conditions and airspace constraints for each individual U-Space airspace (European Commission, 2021). Crivellaro estimates that the initial set-up of U-Space airspaces will follow a corridor or bubble principle, completely segregated from manned aircraft (Crivellaro, 2021). Dirks confirms that Germany will not have one comprehensive layer of U-Space airspace, although other Member States might. He argues that UAS operators in rural or remote areas have no added benefit from paying for U-Space services. Thus, the assessment of the airspace will take into consideration whether there is an actual need for a UTM system. This will mainly be the case for agglomeration areas with high economic activity (Dirks, 2021). Dittrich supports this approach, stating that urban environments require a UTM system to increase the scalability of UAS operations, whereas rural environments can allow for numerous UAS routes without reaching excessive risk levels. However, outside of U-Space airspaces, every UAS route has to be communicated to all affected air traffic participants by putting out a Notice to Airmen (NOTAM) (Dittrich, 2021).

Inan adds that the designation of U-Space airspace is also linked to a cost calculation. For one, the establishment requires a thorough airspace assessment to determine air and ground risk. Additionally, he notes that some dynamic information services may be linked to specialised infrastructure, such as hyperlocal weather services, which may not be cost-efficient to establish over the entirety of a sovereign territory (Inan, 2021). This also impacts GA traffic as they currently often fly below 500 ft outside of urban areas, according to Boden (2021). With comprehensive U-Space airspace over the entirety of a state, GA would either face a strict minimum height limit of 500 ft or fly under U-Space regulation, including USSP services and electronic conspicuity, which Garrity sees as highly problematic (Garrity, 2021). Inan agrees and adds that regardless of the exact construct of U-Space airspaces, the overall airspace access of GA will be restricted, raising the question of who will cover the financial costs of this restriction (Inan, 2021).

Meuleman criticizes the approach of designating individual blocks of airspace as U-Space airspace, instead of establishing a comprehensive national U-Space airspace and then excluding the areas that do not allow for UAS operations, such as airports or power plants (Meuleman, 2021). Kies supports that argument and claims that individual blocks of airspace directly contradict the objective of the U-Space regulation, which is to enable the integration of UASs into existing airspace structures. She adds that separate areas of U-Space airspace result in more interfaces and subsequently increased conflict potential. Additionally, segregation negatively impacts airspace capacity as decades of managing manned air traffic have shown. Thus, true integration is needed to increase scalability of UAS operations (Kies, 2021). Ziegler questions the whole principle of creating a designated airspace specifically for UASs. He promotes the idea of maintaining equal access to the airspace for all players, no matter whether it is a private pilot or a helicopter, the systems of manned and unmanned traffic management need to be interoperable and integrated (Ziegler, 2021). The concept of equal access is also supported by Garrity, who stresses that the system has to work for everyone. If an integrated market is pursued, the requirements to partake in that market must be available and affordable for hobby, sports, and commercial pilots (Garrity, 2021).

Either way, Crivellaro stresses that the designation of these airspaces must include the contribution of regional authorities to consider the impact of UAS operations on local communities, in particular for urban operations (Crivellaro, 2021). There has to be a collaborative decision-making process between these communities and the Member States when the airspace is assessed for UTM potential (SESAR JU, 2020). Additionally, Dirks points out that each U-

Space airspace is also a geozone in accordance with regulation 2019/947 and is thus subject to special regulations, such as restricted operations or specific requirements (Dirks, 2021). However, in case of a U-Space geozone, any certified USSP is entitled to offer their services there. Meuleman points out that certain infrastructures, such as ports, may benefit from being exempt from U-Space services and coordinate the UAS traffic in their specific area as geozone managers (Meuleman, 2021).

Alternative A: U-Space airspaces are established in areas of high complexity and demand. There is a strong focus to provide UTM services to urban areas and industrial parks with high economic activity. Flight corridors or bubbles severely restrict airspace capacity but facilitate the co-existence of UASs and manned aircraft by segregating them into distinct areas, without compromising airspace access for GA traffic.

Alternative B: U-Space airspaces are comprehensively established. Safety sensitive infrastructure is excluded from UAS operations through NFZs or restricted geozones. All air traffic participants under 500 ft are required to abide by U-Space requirements. Integration mechanisms provide equal airspace access to all airspace participants. GA traffic will either be restricted in their airspace access or must conform to U-Space regulations in order to allow for integration.

4.3.3. Area C: Economic impact

4.3.3.1. Driver: Urban vs. rural operations

UASs have significant potential. As a means of transport, they provide cheaper, faster, and more sustainable services for various parts of the economy. The use cases range from just-in-time delivery to manufacturing sites, to air taxis which carry passengers and goods without the hindrance of congested streets. Furthermore, they can provide benefits beyond economic value by speeding up the transport of life-saving goods and equipment to sites of accidents, victims of cardiac arrest, or remote areas that are difficult to access on ground. In addition to these transport applications, UASs also provide revolutionary access to birds-eye views, without the costly and loud deployment of helicopters. This characteristic opens a range of use cases in inspection, surveying, mapping, photography, agriculture, and many more. However, the economic impact of UAS use cases strongly depends on whether they will solidify as large-scale routine operations. New applications for UASs are frequently being developed and tested. The feasibility of each use case depends on the regulatory framework as well as the economic viability (Merkert & Bushell, 2020). Industry expert Jörg Dittrich from the German Aerospace Centre DLR adds, that only use cases where the deployment of UASs is cheaper than the alternative will grow exponentially, and that the rest will remain niche services (Dittrich, 2021).

The vast majority of the business cases where UASs are already in operation take place in rural environments and in lowly frequented airspace. They are mainly focused on agricultural deployment, or inspection and surveillance of pipelines and power lines. However, many commercial and civil applications are expected to take place in urban airspaces as part of UAM. Garrity describes UAM as any flight operation that takes place in urban airspace, including helicopters and emergency services (Garrity, 2021). Operations in these airspaces are incredibly complex, for a variety of reasons. For one, there are numerous man-made structures that impact the airspace in which UASs are supposed to operate. This includes buildings, but also bridges and overhead cables. Secondly, UAS operations over assemblies of people are only feasible in the specific category so far and pose significant risk mitigation requirements under SORA. Additionally, urban airspaces are extremely likely to be covered under the U-Space regulation in most Member States, as the elevated density of these airspaces requires a higher degree of coordination and scalability. The complexity is further increased by ad-hoc emergency services and rescue helicopters that disrupt the scheduled flow of air traffic. Finally, ground infrastructure, such as take-off and landing ports, charging stations, as well as maintenance and storage facilities need to be established (Kellermann et al., 2019).

UAS operations in urban airspaces are typically focused on transport missions, such as medical and commercial goods, but also the transport of people and cargo in the long run. The transport of goods is already being tested in multiple environments and large players such as Google, Amazon, or DHL have been investing in it for years. The consumer goods delivery market is also heavily pursued by start-ups, such as Wingcopter or Flirtey (Cohen et al., 2021). Various trials and case studies have shown that the last-mile delivery of goods can be economically viable (Jenkins et al., 2017). However, establishing a consumer delivery business model requires very specific solutions for each individual consumer. This becomes increasingly complex for urban areas, where the recipients of the packages may not have backyards to drop the parcel. Additionally, Dirks from the German Ministry of Transport points out that German privacy laws require UAS operators to ask residents for permission before flying over private properties (Dirks, 2021). Liebsch adds that frequent UAS operations in residential areas may lead to a backlash from the public (Liebsch, 2021). According to Dittrich, these regulatory and technical challenges are less severe for point-to-point transport between fixed take-off and landing ports. This is often the case for medical deliveries, where blood or tissue samples are delivered between hospitals or laboratories (Dittrich, 2021).

The transport of passengers is even more restricted as it falls in the certified category of EU regulation 2019/947. This is a significant barrier for two reasons. For one, the requirements for this category have not yet been defined and secondly, there are currently no certified UAS platforms on the market. Thus, the passenger transport, or air taxi segment of the UAM market is inherently complex and at present downright impossible to do by UAS. Another challenge is the public acceptance of air taxis. Garrity speculates that the innovative concept may spark positive reactions with the public, provided there are very few safety incidents, if any (Garrity, 2021). But Meuleman points out that air taxi operations may be perceived as exclusive and for the wealthy (Meuleman, 2021). A study conducted by EASA on the societal acceptance of UAM in Europe concluded that while there is a generally positive attitude towards new means of mobility, the acceptance of UAM missions is higher if they serve the community over an individual (EASA, 2021b).

Alternative A: Regulation evolves to promote business-to-consumer UAS deliveries in urban environments. Airspaces above residential areas are freely accessible to UASs, and a comprehensive last-mile delivery market can be established. Thus, e-commerce retailers as well as small businesses can unlock the economic potential of private households. Once the details of the certified category are defined and published by EASA and the European Commission, unmanned passenger air transport operations will be added to the UAM system. The number of UASs in urban airspace will increase, possibly creating a negative effect in the public's acceptance of UASs.

Alternative B: Despite their economic potential, urban UAS delivery missions are severely restricted by regulatory barriers, technical complexities, and public acceptance. Urban operations will focus on point-to-point and business-to-business deliveries. The inclusion of consumers to UAS deliveries will be limited to rural and remote areas. UAM will develop further once the regulatory framework and availability of certified UASs enable an unmanned air taxi market, both for passengers and cargo.

4.3.3.2. Driver: Internal vs. external UAS services

There are two categories of UAS operations. Either a company establishes business-internal services (BIS) and conducts all their UAS operations in-house, or an external drone service provider (DSP) sells UAS operations to third parties (Drone Industry Insights, 2020). Kies expects both methods to persist in the market (Kies, 2021). The top three use cases for UASs in 2020 were inspection, mapping, and surveying, according to a study from market analyst Drone Industry Insights. Out of these three, the first two segments were mainly serviced by DSPs, while surveying was mostly done through in-house operations (Drone Industry Insights, 2020). Nonetheless, a tendency towards either can influence the market and its development.

DSPs offer several advantages. With UASs at the core of their business model they are more likely to have a firm and comprehensive understanding of the market and its regulations. The outsourcing of UAS operations to DSPs saves businesses the trouble of acquiring the necessary qualifications of a UAS operator, collating a concept of operations, and establishing a safety management system. Additionally, as a service provider they are likely to achieve a higher degree of capacity utilisation. These economies of scale can make DSPs more competitive in comparison to an in-house solution. Also, they can offer specialized services that would otherwise be economically unviable. This would encompass tasks with a very specific profile, or which are only incurred sporadically (Mageto et al., 2018).

On the other hand, companies have to consider the disadvantages of becoming dependent on a service provider. If the markets were to evolve into regional monopolies, the cost advantage could dwindle over time (Dinu, 2015). Also, the cost calculation could be influenced by bottlenecks in times of high demand. If a company is dependent on the availability of UAS services, it might be exposed to sharply rising prices. For example, the business model of Uber has shown that excessive demand can increase the price to the point in which demand can be met. While this concept of surge pricing is an economically sound model to find market equilibrium, it is wildly unpopular with customers and may lead to businesses refraining from using third party providers (Huarng & Hui-Kuang Yu, 2020). Additionally, industries that require high levels of specific knowledge may prefer to conduct their own UAS missions instead of outsourcing it to a third party. These considerations are likely to gain weight the more the company’s business model is centred around the availability of UAS services. Thus, an energy provider may be much more likely to outsource his UAS activities than a company providing air taxi services.

The DSP segment is likely to have significant consequences for the UAS market. DSPs could speed up the introduction of UAS services by offering companies solutions that are both cheaper and a lot less complex than their in-house alternatives. They further reduce the barrier for businesses to explore how UASs can be used within their specific business models or industries. For UAS manufacturers the effect might be negative. A high market share for DSPs would dampen the overall demand for UASs because of the higher degree of capacity utilization. On the other hand, this would advance the development of special-use UASs.

Alternative A: A stronger initial focus on DSPs allows the market to develop more quickly. A few DSP businesses familiarise themselves with the legal and operational requirements of the market and conduct a large share of the initial UAS operations. Large companies with specific-knowledge operations enter the market as business internal UAS operators. As more standard scenarios are added to the regulation and the regulative process of approving flight missions facilitates, small and medium sized companies may enter into the business internal market and build up their own UAS divisions.

Alternative B: The market penetration by DSPs evolves gradually. The early rollout of UAS business cases is slow as businesses try to navigate the complex regulatory landscape. The high initial cost of establishing a UAS division may further prevent smaller companies from exploiting UAS potentials within their industries.

4.3.4. Area D: Technological factors

4.3.4.1. Driver: Communications, navigation, and surveillance link

One of the core pillars of establishing extensive commercial UAS operations is the provision of Communication, Navigation and Surveillance (CNS) functionalities. The CNS link is the basis on which the remote pilot or the ground station communicates with the aircraft, the position of the aircraft is determined, and the flight path of the aircraft is made visible. It is also referred to as the Command-and-Control link, or C2-link for short. These services must not only be reliable and secure, but they also need to be affordable, scalable, and readily available. They are a prerequisite for BVLOS missions, as they not only provide the operator with control over their vehicle, but they also enable UTM infrastructure providers to deliver a comprehensive overview of airspace capacity and airspace users at any given time (Ponchak et al., 2019).

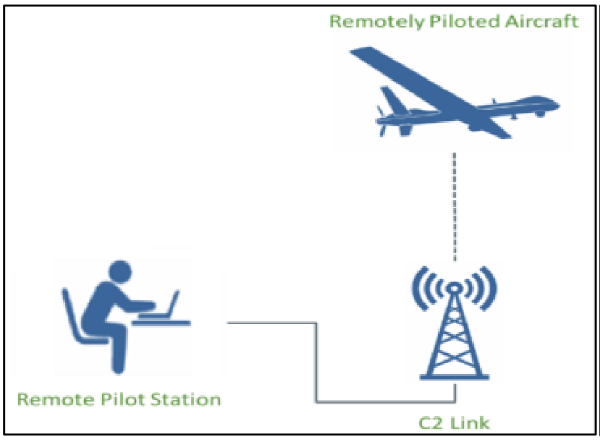
Communication links in traditional aviation follow a manual, voice-to-voice approach in which an Air Traffic Controller verbally instructs the pilot of an aircraft to follow specific waypoints, for example. With the emergence of UASs and increasingly automated flight operations, this approach will shift to a data link focussed system. Various different systems are being looked at to replace the analogue voice model. Most large UASs and manned aircraft currently use satellite links to transmit data as they are the only data link available over oceans. However, these links typically have a low transmission rate and can only support a few voice channels. Additionally, the transmission equipment, such as the antenna and receivers, is too large and heavy to be carried by sUASs (Ponchak et al., 2019). Thus, the industry is also looking at non-satellite based C2-links. Wi-Fi and Bluetooth connections constitute highly affordable, light-weight solutions for very close-range operations. While Wi-Fi connections can hold up to a few kilometres, Bluetooth connections usually cut out at around 30 metres. Nonetheless, they can be useful for follow-me operations or the coordination of multiple UASs in a swarm-like formation. Both technologies are already incorporated in every smartphone, which enables the operator to use their phone for controlling the UAS. Although they are not a viable CNS options for BVLOS UAS operations, they could serve as a secondary data link. For the time being, they are the most commonly used data link for sUASs (Ponchak et al., 2019).

In terms of navigation, most UASs are currently using the Global Positioning System (GPS) or Global Navigation Satellite Systems (GNSS). These systems generally provide an accurate, available, and continuous basis for many UAS operations. However, GPS signals can vary significantly between regions and are inherently susceptible to (un-)intentional interference. For example, urban infrastructures or high levels of signal transmissions can reduce the reliability of GPS (Ponchak et al., 2019). There are several techniques to improve signal performance and to counteract interference, such as Receiver Autonomous Integrity Monitoring (RAIM), Wide Area Augmentation System (WAAS), or Satellite-Based Augmentation System (SBAS). However, it is also possible to wilfully interrupt GPS signals by either blocking the signal altogether (Jamming) or overloading it with fake transmission signals to prevent the actual navigational data to pass through (Spoofing). These interferences can be counteracted to some extent by employing an Inertial Navigation System (INS) and Inertial Measurement Units (IMUs). Not only do they increase the positioning accuracy of the signal, but they also allow the vehicle to continue operations for short periods of GPS outages. Nonetheless, these systems should not be relied on as a standalone measure as this creates a single point of failure (Dill et al., 2016).

The third objective of the CNS link is surveillance. The ability to accurately monitor all air traffic participants is a prerequisite to provide the pilots with what is referred to as situational awareness. Situational awareness describes the principle of knowing the surroundings of one’s aircraft in terms of other aircraft, terrain, man-made obstacles, and weather phenomena. According to Heidger and Kies, it is the basis to create a functioning UTM system (Heidger, 2021;

Kies, 2021). The first step in creating situational awareness is making all airspace participants visible, or electronically conspicuous. Traditional detection and surveillance systems such as radar, radio frequency sensors or optical sensors have difficulties picking up smaller objects such as UASs, which will be described in more detail in subsection 4.3.5.1. on UAS Detection. Thus, the UAS has to be equipped with a device to make it electronically conspicuous. This concept of a remote ID is a provision of EU regulation 2019/945, which outlines the technical requirements of UASs, and describes the process of transmitting the UAS' positional data as well as its identification and some status information to one centralised receiver or other parties (European Commission, 2019a).

Currently, there are different methods being used to accomplish that. Manned aviation uses a combination of primary and secondary surveillance radars (SSR) as well as the Automatic Dependent Surveillance Broadcast ADS-B. All SSR and ADS-B transmissions run on the same 1090 MHz frequency, as it is a standardised and protected spectrum. This frequency is also used by the Traffic Alert and Collision Avoidance System TCAS. Garrity points out that the limited capacity of the frequency and the threat of reducing TCAS efficacy, combined with the limited number of unique transponder addresses, are the reasons why ICAO recommended that ADS-B should not be used on UASs (Garrity, 2021). Heidger mentions the increased complexity of German airspace, as it handles approximately 30% of all European flight movements and thus is almost at its limit in regard to the ADS-B bandwidth (Heidger, 2021). Sickert adds that the weight and size of the transponder necessary for satellite-link surveillance could pose another issue. Currently, the same type of transponder that is being used for commercial aircraft is used for UASs to establish an ADS-B link. These devices weigh around 600-800g, which severely impacts the size of the UAS necessary for such equipment and the payload it is able to carry (Sickert, 2021). General aviation and hobby pilots often use the Swiss proprietary system FLARM to become electronically conspicuous. There are several issues related to this. Ziegler points out that the system can be switched off, which is problematic for a safety relevant feature (Ziegler, 2021). Furthermore, Garrity states that FLARM runs on an unprotected frequency. This means that other systems can be built on that frequency and cause interference (Garrity, 2021). Garrity, Heidger, Meuleman and Ziegler agree that a commercial system with a monopolistic point of sale may be problematic in this context (Garrity, 2021; Heidger, 2021; Meuleman, 2021; Ziegler, 2021).



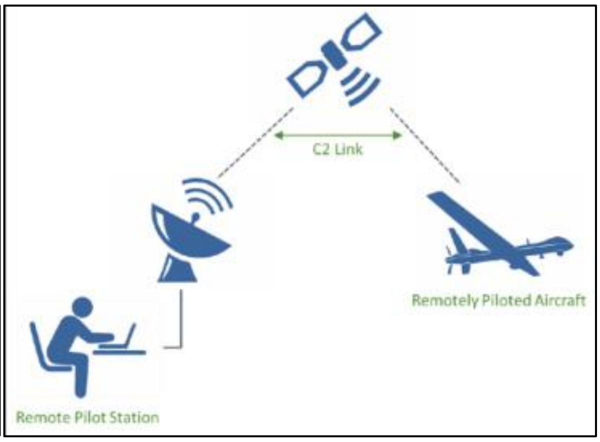


Figure 13: C2 link using cellular infrastructure (ICAO, 2015) *Figure 14: C2 link using satellite infrastructure (ICAO, 2015)*

One of the more promising ideas for establishing CNS functionalities is the use of cellular infrastructure (see Figure 13). Modems to access 4G or 5G networks are cost-efficient and easy to install even on sUASs. Metzner describes LTE connections as a viable option to transmit commands to the vehicle (Metzner, 2021) and Ziegler even claims that the telecommunications sector is the only party currently able and qualified to assess connectivity and provide a reliable C2 link over long distances (Ziegler, 2021). Heidger confirms that mobile networks provide the required bandwidth to depict all clients of a UTM in a collaborative interface. Thus, he declares that a cellular CNS solution is currently the least problematic option. The main issue lies in the coverage. Heidger explains that urban canyons or substantial geographic arrays such as valleys or mountain ranges may impair the connectivity of the network, which may require back-up systems that operate via satellite connections (Heidger, 2021) (see Figure 14). Metzner agrees that connectivity should be a factor when assessing airspaces and establishing U-Space airspaces and Ziegler expects that insufficient connectivity will be a valid reason to reject a flight request (Metzner, 2021; Ziegler, 2021). Additionally, the cellular network is designed for ground use, which weakens the connectivity in the sky (SESAR JU, 2020). In order to use cellular networks for large-scale UAS missions, the telecommunications sector must be incentivised to expand and adapt their network to provide safe and reliable connectivity for aerial operations. The evolution of CNS technology will play a crucial role in the establishment of a comprehensive UTM system and can significantly foster or hinder the growth of the UAS market.

Alternative A: A comprehensive and uniform solution for CNS functionalities is found. Currently the least problematic technology is the use of the telecommunications network. Cooperation between the aviation sector and the telecommunications sector increases to improve connectivity and optimise ground infrastructure for aerial use. Satellite systems are used as back-up to ensure a continuous and reliable connection between the UAV and its station, the pilot, and its tracking system. Additionally, a uniform CNS functionality facilitates the communication between aircraft and subsequently fosters the automation of operations. The CNS equipment is affordable and suitable for all airspace participants. Data about the quality of connectivity is incorporated into the UTM system and provided to the operators.

Alternative B: The technological advancement around the CNS link stagnates and no comprehensive solution to achieve the necessary reliability and accuracy is found. Participants of the same airspace continue to use a variety of systems, which drastically complicates the compilation of a comprehensive air map and subsequently impacts the situational awareness of all airspace participants. Further, the communication between different aircraft is hindered. Instead of the CNS link supporting UAS operations in all kinds of environments and mission plans, UAS operations need to be designed according to the available connectivity. This greatly impacts the use of airspace capacities as well as the feasibility of some use cases.

4.3.4.2. Driver: Separation management and deconfliction

To enable large-scale BVLOS UAS operations in VLL airspace, safety separation criteria must be set to avoid collisions. The varying types of UASs and their abilities increase the complexity of integrating them into mixed and multi-aircraft environment (Guan et al., 2020). Similar to manned aviation, there must be a minimum operating distance between UASs, which can vary depending on factors such as airspace class, flight phase, and flight conditions (Dolph, et al., 2017). If all airspace participants are made electronically conspicuous, these data points can be sent to a centralised receiver who can then create a comprehensive air map as described in the previous subsection. Based on this map, airspace coordinators can manage airspace capacities, grant or reject flight requests and incorporate separation criteria and strategic deconfliction of flights. However, air traffic is dynamic, and conflicts need to be resolved both preflight (strategic) and in-flight (tactical) (SESAR JU, 2020).

There are various reasons why a UAS may deviate from its original flight plan. The airspace capacities could be impacted by military blocks, emergency services, or temporary no-fly zones, weather phenomena could influence the speed and endurance of the aircraft, or simple human error could lead to a deviation from the planned route. All of these could cause a UAS to violate the separation criteria between itself and other airspace participants or objects (Duffy, et al., 2020). Once the minimal operating distance is breached, or a conflict is imminent, there are different options to deconflict. In U-Space airspaces the USSP is alerted about the arising conflict and can inform the remote pilot of the UAS in question so they can change course to avoid collision. In unclassified airspaces, the UAS operators have to coordinate among themselves to avoid collision. Garrity points out that the current system with human intervention is very safe, but inherently limited in its capacity (Garrity, 2021). Crivellaro agrees that for the number of projected UAS operations a digital system is needed that is not based on human intervention but on sensors and detect-and-avoid systems (Crivellaro, 2021). To eliminate the risk of human error and increase the scalability of the market, conflict resolution processes need to become fully autonomous. Thus, conflicts need to be detected by the UAS and the flight path must be adapted automatically to avoid collision (Davies et al., 2018).

Multiple options of creating a reliable on-board sense-and-avoid system that provides UASs with their own situational awareness are currently being examined. In order to autonomously deconflict, UASs must be able to detect obstacles, regardless of whether they are cooperative or non-cooperative. Remote ID is expected to enable UASs to detect other cooperative UASs, however, non-cooperative or electronically inconspicuous obstacles require on-board sensor solutions (Keller et al., 2020). The complexities of detecting non-cooperative aircraft will be examined in more detail in subsection 4.3.5.1. on UAS detection. Suffice it to say that there is currently no comprehensive and affordable solution to reliably detect UASs, particularly if it needs to be installed on an sUAS with limited payload capacity. However, even if the focus is put on electronically conspicuous aircraft that can be detected and localised, another challenge arises. The UASs need to have avoidance protocols in place and make autonomous decisions. Garrity points out that this level of automation is already stipulated in SESAR's U-Space blueprint for U3 level operations but is currently not yet feasible from either a technological or a regulatory perspective (Garrity, 2021). Ziegler, Liebsch and Meuleman agree that at present there is no technological solution to install a reliable and affordable, autonomous detect-and-avoid system on sUASs, with Meuleman claiming it may be years until the technology is available (Liebsch, 2021; Meuleman, 2021; Ziegler, 2021).

Garrity points out another issue in this context, relating to the altitude reference systems of different aircraft. He explains that height, altitude, and flight level are measured differently. Firstly, height describes the distance from ground to aircraft, or more specifically the distance from a designated reference point on the ground to the aircraft since the ground is not level. Secondly, altitude describes the vertical distance measured from sea level and, thirdly, once an aircraft passes a defined altitude, it often flies according to flight levels, which keep it at a fixed pressure altitude based on a pressure setting of 1013 hPa, as depicted in Figure 15. Both height and altitude can be calculated using either barometric pressure or geometric altitude based on GNSS. Although both systems can be used to derive the vertical distance of a specific vehicle above a specific point (e.g. the ground, point of departure, or sea level), it is necessary for all vehicles to use a common reference system, or convert between the two, to determine where they are in relation to each other and other traffic (Garrity, 2021). This is what allows for vertical separation of aircraft that are flying on the same altitude reference system.

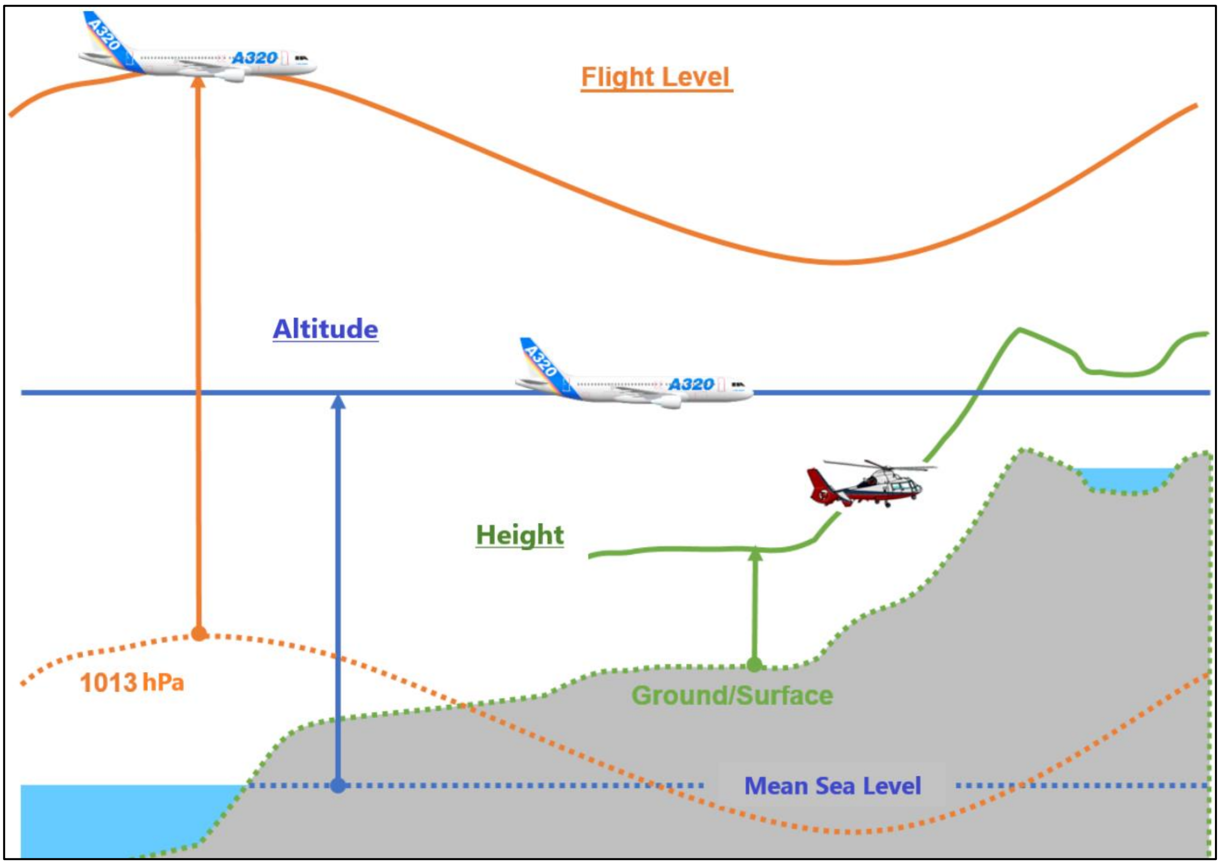


Figure 15: Height, altitude, and flight level (Eurocontrol, 2020)

The issue for UASs is that they currently use neither height nor altitude. Most commonly, UAS altimeters are GNSS-based and calculate the aircraft's position based on their starting point. This provides a different concept of 'height' for each UAS starting from a different take-off altitude (Hatfield et al., 2020). Thus, not only are UAS altitude reference systems not compatible with manned aircraft, but they may also not be compatible with other UASs. The lack of a common altitude reference system and the limited room in VLL airspace currently make it impossible for UASs to vertically separate. This complicates not only deconfliction but also limits the general airspace capacity. Remote pilots struggle to deconflict even in VLOS situations, due to the fast pace of some aircraft. Strategic vertical separation is a crucial factor with regards to the integration of UASs into national airspace structures (Eurocontrol, 2018a).

Alternative A: The technology for autonomous on-board detect-and-avoid systems is matured to the point where cost-effective and lightweight systems are available for all airspace participants. A common altitude reference system enables vertical separation not only between UASs, but also between UASs and GA traffic, which enables a more efficient use of airspace increasing scalability and facilitates the coordination of the market. Machine learning and artificial intelligence technologies are used to further minimise the operational separation criteria and support growing numbers of UASs.

Alternative B: Tactical deconfliction remains a manual process based on human intervention. A lack of a common altitude reference system prevents the market from fully integrating UASs into manned aviation airspace structures, which severely limits the potential of the market. The minimum operating distance is much larger as it must account for human error and latency in communication.

4.3.4.3. Driver: Propulsion systems

In order to create a sustainable and environmentally friendly UAS market, the focus has long been on alternative propulsion methods. Although there are UASs with combustion engines that run on fossil fuels, the industry is intensely researching low-emission methods. One of the favoured technologies is the use of lithium-ion battery cells. Electric propulsion has many advantages: it requires less maintenance than combustion engines, the noise emissions are significantly lower, as is the vibration strain on the airframe (Özbek et al., 2020). According to EASA, the efficiency of these battery cells has increased drastically with a cost decrease of 1000 €/kWh to 110 €/kWh between 2010 and 2020. In the same time frame, energy density increased from 150 Wh/kg to 300 Wh/kg (EASA, 2021b). However, the energy density of lithium batteries is still lower than piston engine fuel energy density and needs to be improved for longer endurance (Özbek et al., 2020).

Another option is to use on-board energy generation systems. The most promising method in this area is the deployment of fuel cells. They are electromechanical devices that can chemically create electric energy without moving parts, thus they have high efficiencies. To create this energy, they use pure hydrogen and combine it with oxygen from the air. As long as hydrogen is fed into the fuel cell stack, the system can generate continuous electrical power without producing CO2 emissions and with a higher energy rate than petroleum (Gang & Kwon, 2018). The most popular implementation of this is the Polymer Electrolyte Membrane Fuel Cell (PEMFC) due to its energy efficiency and low operating temperatures. Although the energy density for this technology is currently also quite low, significant research is done in this area and is expected to yield progress (Özbek et al., 2020). One downside to hydrogen use is the scarcity of its pure form in nature (Gang & Kwon, 2018). Additionally, fuel cells require more surface area for the heat transfer, which causes more drag to the aircraft (Badea et al., 2020). Other on-board energy generation systems rely on solar cells. This technology is well known from other areas of alternative fuel generation and is widely acknowledged to provide certain benefits: it provides limitless energy as long as it has sufficient access to sunlight, it is a low-cost alternative to other power sources, it does not need any additional equipment such as hydrogen or petrol and thus decreases the weight load of the UAS, and it is environmentally friendly. It does, however, also have significant downsides: its reliability is dependent on the weather conditions as well as on solar irradiance which is determined by the position of the earth in relation to the sun (Gang & Kwon, 2018).

So far, not one single source of alternative energy has matched the energy and power density of fossil fuels and combustion engines. Thus, there have been various attempts to establish a hybrid system that combines two or more of the aforementioned technologies. To ensure a continuous and efficient flow of power, on-board energy generation systems such as fuel cells or solar power can be used in combination with a back-up lithium-ion battery instalment. This way, the initial thrust of power necessary for take-off or complex manoeuvres can be supported by the comparatively high energy density of the battery cell, while cruise flight is powered by the on-board energy generation system. Another option is to combine two of these on-board systems and to cut out the battery entirely. Test runs have shown that it is already possible to calculate the specific power requirements in-flight and strategically alternate between two or more power sources as needed (Gang & Kwon, 2018).

Although, these systems are tested and ready to deploy, there are still some challenges to overcome. First and foremost, the propulsion system makes up for a significant share of the overall weight of the aircraft. For UASs, the relation between size, weight, and power (SWAP) is a highly relevant factor. Compared to traditional aircraft, the payload a UAV can carry is severely limited. Thus, it is crucial to maximise power while keeping size and weight of the propulsion system to a minimum (Babayomi & Makarfi, 2019).

Alternative A: Propulsion technology continues in its progressive development and the power-to-weight ratio of the powering systems improves. Battery propulsion is used to bridge the gap until fully sustainable propulsion methods are able to support heavier UASs over longer distances in a reliable and continuous manner.

Alternative B: The development of propulsion technology stagnates, and the market stays dependent on hybrid systems and a variety of propulsion methods. Limited payloads and endurance complicate the integration of UASs into IFR airspace as they largely remain unable to carry the necessary equipment. Lithium scarcity caused by high demand in the electric automobile industry and other industries reduces scalability and drives up the costs of resources. The use of batteries drives up the infrastructure requirements of UASs by depending on charging stations.

4.3.5. Area E: Security

4.3.5.1. Driver: UAS detection

Although there are many use cases through which UASs can provide significant economic and societal benefits, they can also pose a threat to public safety, national security, and the privacy of citizens. Whether intentional or by accident, UASs can have a significant disruptive effect on other aerial operations. A prime example of this is the incident at Gatwick airport near London in 2018, when hundreds of flights had to be cancelled due to UAS sightings (Wang et al., 2021). The German ANSP DFS, who has been tasked with the detection of UASs at Germany's international airports, reports numerous disruptions of air traffic every year. Most recently, the highest number of incidents of the year 2021 were reported in August with 23 disruptions. This brings up the total number of disruptions in 2021 to a total of 82 (DFS, 2021). The Federal Aviation Administration (FAA) in the United States has further pointed out the hazard of hobby UAS operators flying their vehicles near wildfires or other scenes of crisis, where they disturb the aerial rescue efforts of first responders (Federal Aviation Administration, n.d.). Besides the disruption of manned air traffic and endangerment of third parties, UASs can also be used to collect sensitive information about certain infrastructures, such as nuclear power plants or military bases, or simply to intrude on the privacy of citizens (Wang et al., 2021). In more malicious exploitations of UAS technologies, they have been used to smuggle contraband into prisons or drugs across borders. The most extreme case of UAS abuse is the equipment of the vehicle with explosives with the intent to pursue terroristic actions (Michel, 2018).

Generally, the regulations governing the operation of UASs should prevent these types of occurrences. However, there need to be provisions in place in case of negligent ignorance of the rules or even malicious abuse of a UAS. The protection against unwanted UAS operations is made up of two layers – the detection and the interception of the aircraft. According to Kies, the detection process is as follows: (1) detect the UAS, (2) determine the location, (3) assess whether it is in fact a UAS, (4) establish the identity and whether the UAS is allowed to fly there. As soon as a UAS deviates from its authorised flight path it is considered ‘uncooperative’ (Kies, 2021). For cooperative UASs over 250 g, all four steps should be resolved through the remote ID transmission. Meuleman thus points out, that the UTM system must be linked to the UAS detection infrastructure to determine which of the detected UASs are known and cooperative, which are known and uncooperative, and which are neither known nor cooperative (Meuleman, 2021). However, if a UAS is truly uncooperative and attempts to enter restricted airspace on purpose, surveillance technology must be able to detect, identify and track it. There are several technologies being tested for the detection of UASs, however, none are mature and scalable enough to provide complete protection (Wang et al., 2021).

Traditional anti-aircraft radars, that are used in military contexts are ineffective for UAS detection as they target large and fast-moving objects and often miss the slower-moving and smaller UASs (Michel, 2018). According to Heidger, the primary radars that are used to detect commercial aircraft are also capable of detecting UASs, however they are extremely expensive in terms of acquisition, maintenance, and data processing. Additionally, they have a high rate of detecting false positives, such as birds (Heidger, 2021). Another promising technology is radio frequency (RF) detection. It picks up communication signals between the UAV and its ground station or pilot and can trace it back to both parties. Finding the actual position of the pilot and not just their registered address can be crucial in the aforementioned types of situations to eliminate the threat as quickly as possible. The downside of RF detection is that it only scans for specific frequencies that are commonly used for UAS operations. If a UAS transmits on another frequency or is programmed to fly autonomously without C2-communication, the RF radar is unable to detect it. Furthermore, the performance of this technology is impaired if there is not direct line of sight between the radar and the UAV (Michel, 2018).

Acoustic sensors are employed to pick up the noise signature of UASs. These are commonly used in sensor arrays around restricted areas. They are light weight and affordable as well as easy to assemble and deploy. However, they classify the detected noise signatures according to a database of known UAS audio emissions. Thus, this database needs to be extremely comprehensive and continuously updated to account for the constant development of new UAS platforms and models. Furthermore, the performance of the acoustic sensors is subject to weather conditions and benefits from a direct line of contact to the UAS. Trials in this area have shown that acoustic sensors are capable of picking up individual incoming UASs, but not on a large scale. Additionally, they do not pick up on any identification criteria (Wang et al., 2021).

Acoustic sensors are often used in combination with visual sensors, such as electro-optical sensors or infrared sensors. These sensors use image processing to detect UASs and ideally even identify them. However, there are some drawbacks. For one, it is difficult to distinguish between UASs and background imagery, such as birds, especially in variable and complex environments. Secondly, they only work during the day and require a direct line of sight to the UAV (Michel, 2018). Meuleman describes an incident where a large UAS with a length of 4 metres was nearly impossible to detect visually as it was mostly chrome (Meuleman, 2021). Additionally, direct sunlight can also severely impact the performance of visual sensors (Wang et al., 2021). Thus, visual sensors are often used to confirm the existence of an incoming UAS once the acoustic sensors have picked up a fitting noise signature (Michel, 2018).

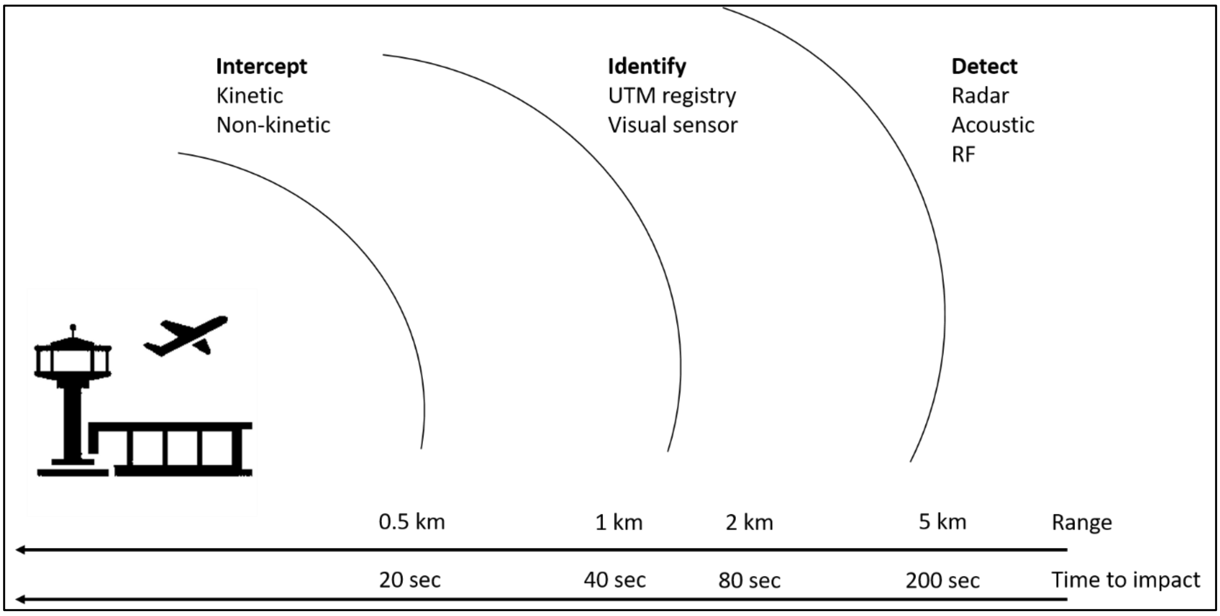


Figure 16: Exemplary detection and interception process (created by author)

Since none of these methods provide a failproof detection of all UASs in a specific area, they are often used in combination. A multi-type data fusion combines the advantages of the different technologies, while reducing some of their drawbacks. Dirks mentions that there have been some favourable results in this area of research regarding multisensory detection mechanisms, and Meuleman adds that this is the only way to reliably detect different types of UASs (Dirks, 2021; Meuleman, 2021). However, Heidger points out that these systems are often expensive and only cover a limited range. For larger infrastructures, such as airports, they are often insufficient. Furthermore, a lack of standardisation of surveillance mechanisms causes the signals of the UASs to be detected by multiple sensors leading to multiple tracks and duplicates for one and the same vehicle. These tracks need to be fused into one distinct tracking path. This process is called multi-sensor-data-fusion (MSFD) and is already applied in the tracking of manned aviation (Heidger, 2021). Kies adds that this process requires significant software know-how and complex algorithms (Kies, 2021). Dirks further elaborates on the difficulty of detecting fast UASs. He stresses that if a UAS can fly up to 140 km/h, it needs to be detected over long distances in order to be able to prevent the intrusion of the aircraft into sensitive areas (Dirks, 2021). Sickert from Fraport agrees that UAS operations with malicious intent will be able to bypass the aforementioned systems and enter restricted areas undetected, for example by using faster UASs (Sickert, 2021). An exemplary detection and interception process is presented in Figure 16.

Alternative A: Safety sensitive infrastructure is equipped with an array of different technologies and sensor types to ensure a comprehensive detection of all intruding UASs. The cost effectiveness and technological effectiveness of these systems improves over time and can be extended to further infrastructures. An interface between the security system and the UTM system enables the visualisation of all cooperative UASs and identifiable UASs that have deviated from their assigned flight path. This enables the focus of security measures on non-cooperative and malevolent UASs.

Alternative B: The detection of uncooperative UASs is inefficient to the extent where malicious abuse of UASs happens regularly and poses a significant safety and security risk. Especially airports are heavily affected through disruptions of manned air traffic.

4.3.5.2. Driver: Counter measures

Once an uncooperative UAS is detected, counter measures have to be taken to eliminate the security risk. Dirks estimates that the remote ID will prevent most of the negligent intrusions of UASs, which according to him make up for approximately 95% of all intrusions. He states that if an operator enters a restricted zone due to carelessness, the operator can be localised and fined and that there will be a learning effect for operators to mind restricted zones (Dirks, 2021). However, remote ID is not mandatory for UASs under 250 g, which are often operated by hobby pilots, who are not necessarily well informed about restricted geozones or NFZs. To reduce the security risk for these types of operations as well, geofences can be used (Boselli, et al., 2017). These geofences should be provided in real-time and be able to be updated or removed dynamically. They should be treated like a physical barrier by the UASs (SESAR JU, 2020). Liebsch agrees by saying that some UAS manufacturers such as DJI already incorporate geofences about certain infrastructure in their UAS designs. This requires the operator to ask for a special a special clearance to enter restricted zones. Additionally, manufacturers can incorporate alarms into their UAS operating system that notify the operator of impending restrictions (Liebsch, 2021).

However, Sickert points out that these protocols can be switched off with certain technological know-how (Sickert, 2021). Garrity adds that UASs can easily be built at home and Liebsch agrees that an operator with malicious intentions is unlikely to use a geofence protected UAS (Garrity, 2021; Liebsch, 2021). Thus, there is a need to protect against truly uncooperative UAS that are being operated with malevolent objectives. Various concepts are being tested. Generally, they can be categorised into kinetic and non-kinetic interdiction methods. The latter category includes cyber mechanisms such as jamming and spoofing. Jamming describes the process of overloading the UAS' data links and preventing from communication signals from getting through. This can impact the radio frequency link between the UAV and the operator, or the GPS link between the UAV and the satellite. Spoofing describes the process of sending a strong but false signal to the UAS in order to hijack it and take over control (Rao et al., 2016). Kinetic interdiction methods generally involve grounding the UAV by deploying lasers or electromagnetic pulses, nets, projectiles, and even large birds of prey (Michel, 2018).

The most commonly used interception method is jamming. The blocking of a UAS' GPS or communication signal usually triggers a loss-of-link response. These include landing, returning to home, or hovering on the spot (Baum et al., 2020). Thus, it eliminates the threat of an unauthorised UAS without causing damage to the vehicle or to objects on the ground. It can further be employed on a large-scale to intercept swarm formations or multiple individual UASs. The major downside of this method lies in the fact, that it is ineffective for UASs that are programmed to operate without an active communications link. Even GNSS jamming is futile against UASs that can operate in GPS-denied environments or are equipped with an IMU as elaborated in subsection 4.3.1.1. on CNS links. Furthermore, if a jamming procedure is not directed properly, it can affect other crucial communication protocols, which is why the FAA has advised not to use it at airports as to avoid compromising ATC communication to on-board pilots (Michel, 2018). Spoofing shares the zero-damage advantage of jamming and is generally a good option if the defending party wants to take control of the intruding aircraft. However, it may be ineffective against protected communication protocols (Wang et al., 2021).

All kinetic interdiction methods follow the same general principle. They aim to shoot something at the UAV in order to cause it to fall to the ground. These physical capture approaches are typically lightweight, quickly assembled, and cost-efficient. However, there are some drawbacks. For one, they must be deployed from a relatively short distance. As interdiction technologies can be deployed from ground-stations, hand-held platforms or even other UASs, this is not an insurmountable challenge, but it does require a more widespread infrastructure than non-kinetic methods. More severely, causing the intruding UAS to crash to the ground always bears the risk of damages to third parties. Some nets are equipped with parachutes to slow down the descent, but even then, the UAV could crash with considerable impact (Michel, 2018). Further, Sickert points out the notable difficulty of shooting down a small moving object with projectiles and the training required to do this effectively (Sickert, 2021). Thus, similarly to the detection technologies, there is not one interception method that provides comprehensive protection against uncooperative UASs, and a multi-technique approach may be required.

There are some further challenges to be overcome, besides the effectiveness and hazardousness of some of the interference techniques. For one, the counter UAS market develops in step with the technological advancements of the UAS market, both benevolent and malevolent. And progress in one area may trigger progress in the other. Thus, for each protective mechanism that gets established, an evasion technique may be developed, too. Additionally, the interception methods must work for a whole range of different UASs, with new models entering the market frequently and home-built UASs becoming increasingly popular (Michel, 2018). Secondly, the interception of UASs also provides a range of legal challenges. Although the task of UAS interdiction will most likely remain a sovereign function, according to multiple experts in the industry (Kies, 2021; Garrity, 2021; Sickert, 2021), it is quite restricted or even illegal in most developed countries. There is a need for updated regulation and standardisation on this issue (Michel, 2018). Finally, Sickert questions the cost-benefit of employing these highly complex and expensive systems if the majority of intrusions are expected to stem from negligence and can be phased out through geofences and education of the operators. He explains that constructing, operating, and regularly maintaining this infrastructure could easily cost tens of millions of Euros. He further points out that other forms of attack, such as portable ground-based missiles, are also not protected against, and that 100 % security is impossible (Sickert, 2021). Garrity on the other hand warns about the growing number of weaponised UASs and stresses the importance of further research in this area (Garrity, 2021). This is also supported by Heidger (2021) and Meulemann (2021). While Dirks agrees that comprehensive protection against terroristic attacks is impossible not only in aviation but in other industries as well, he emphasises that there are still various research projects ongoing to further mature the C-UAS technologies (Dirks, 2021).

Alternative A: The counter UAS market and the interception technologies develop faster than the manipulative efforts to circumvent the protective measures. Regulation adapts accordingly and provides authorities with legal basis to intercept UASs as necessary. Future focus lies on non-kinetic interception methods to reduce harm to UAV and to third parties on the ground. Manufacturers and public authorities focus on reducing the number of negligent geozone infractions by fostering education among UAS operators and incorporating binding geofences into UAS operating systems.

Alternative B: Counter UAS measures fail to provide sufficient protection of safety sensitive infrastructure and public events. The looming tendency to use UASs in a malevolent manner increases and triggers further restrictions and obstacles in the market.

4.3.5.3. Driver: Hacking prevention

Besides the protection against other UASs, it is also important to have protection mechanisms in place to protect one's own UAS. This includes the vehicle itself as well as the protection of collected and transmitted data between the UAV and its ground station. According to Heidger, communication protocols are already quite secure through encryption and decryption processes (Heidger, 2021). Liebsch, an expert on industrial standards and norms and a former employee at DJI further explains that the encryption efforts should be in relation to the UAS platform and its use case since strong protection mechanisms, such as two-factor authentication processes, can also impair the practicability of a UAS (Liebsch, 2021).

The safeguarding of the communication protocols has a twofold impact. For one, it prevents cyber-attacks aimed at accessing the collected data, such as photo and video material or sensorics data, depending on the operation. Additionally, it creates a barrier against spoofing attacks and attempts to hijack the system. A hijacked UAS can either be used to steal the transported goods, or to weaponize it and use it to cause damage to people or infrastructure (Manesh et al., 2019). Liebsch further points out that by controlling the UAS via internet or satellite links, the safeguarding of the C2 link becomes increasingly susceptible to hacking attempts (Liebsch, 2021). However, as exploiting weaknesses in the communications signal is an interdiction method for security forces as well as a threat to commercially operated UASs, an advancement in this technology means both an increase and a decrease in security. Successfully protecting against spoofing attacks also means that spoofing cannot effectively be used to protect against malicious abuse of UASs.

Alternative A: The degree of cyber protection increases in relation to the sensitivity of the mission. UAS that transmit sensitive data or carry valuable payload are protected through cyber protection mechanisms that become more advanced and render spoofing attempts futile in the long run.

Alternative B: UASs are frequently hijacked. The transport of valuable goods and the collection of sensitive data are severely limited through ineffective protection protocols, which negatively influences the public's and the market's level of trust in this mode of transport.

4.3.6. Area F: Public acceptance

4.3.6.1. Driver: Area of operations

The first distinction to be drawn in regard of the public acceptance of UAS operations is the area of use. This includes both the regional area of operation and the type of use case. While there is a general positive tendency towards the civil and commercial deployment of UASs, this tendency decreases the closer the operations get towards peoples' lives (VUL, 2017). Studies have shown that the support for UASs is generally higher in rural areas than in urban environments. However, there are also distinctions to be made within that urban environment. People react differently to seeing a UAV, depending on whether they are in residential, commercial, industrial, or recreational areas. Generally, the fears and concerns regarding UASs revolve around privacy, data protection, noise and visual pollution, as well as environmental factors. However, these fears decrease with the visibility of the UASs, meaning they are less prominent in industrial areas as opposed to residential areas and other high-frequented areas (Lin Tan et al., 2021). Meuleman points out that UAS operations in harbour environments, for example, have little to no impact on the public and are thus generally accepted (Meuleman, 2021).

While the concerns regarding UASs typically remain constant in all areas where they are visible to a large number of people, the perceived benefits fluctuate depending on the use case (Lin Tan et al., 2021). A study conducted on the acceptance of urban UAS operations shows that the public is more supportive towards use cases that benefit society over an individual. The highest ranked use cases all revolved around medical and emergency transport, such as the transport of injured persons, the delivery of medical supplies, the transport of emergency personnel and the deployment of UASs for disaster management (EASA, 2021b). This perspective is reflected by many of the experts that contributed to this research. Boden and Liebsch state that the type of use case is of primary importance for public acceptance and that everything else, such as noise concerns, come second (Boden, 2021; Liebsch, 2021). Liebsch further emphasizes the importance of promoting benefits of UAS use cases through tools like the Drone Rescue Map, which depicts geographic locations in which a UAS successfully contributed to saving a life (Liebsch, 2021). Konzock agrees that the societal benefits of UASs are not sufficiently publicised, and that the media tends to focus on e-commerce delivery models instead of promoting humanitarian applications like medical transports or blood sample delivery (Konzock, 2021). Meuleman agrees that the public acceptance for consumer deliveries is critical in both dimensions: geographic area of operation and serving the individual over society. He explains that the large volumes of deliveries connected to an e-commerce infrastructure not only increase the visibility of the UASs and thus the level of concerns, but that they also operate in residential areas, where privacy concerns are especially high (Meuleman, 2021).

Dittrich questions the whole concept of conducting public acceptance surveys at this stage in the market development. He claims that no one supports change unless they can see the personal or societal benefits to be gained from it. His position is to let UASs demonstrate their societal and humanitarian advantages and the public's acceptance will increase automatically (Dittrich, 2021). Kies agrees and asserts that public acceptance will develop along with the market and that it is beneficial to start with humanitarian use cases (Kies, 2021). Hartwich adds that beside humanitarian benefits, UASs also provide significant potential in the creation of new jobs and economic value creation. She emphasises the importance of communicating these aspects to the public in a transparent manner (Hartwich , 2021). Sickert is concerned that the public acceptance of air taxis may be problematic as they are likely to fly over residential areas and trigger increases concerns about noise, privacy, and safety (Sickert, 2021). However, Crivellaro counters that once a general basis of public acceptance is established, further use cases such as air taxis will also be widely accepted (Crivellaro, 2021).

Alternative A: UAS operations focus on remote or industrial areas, where people are not directly impacted by UAS sightings. At the same time, the societal benefits of UASs, such as the provision of remote areas with essential goods, are promoted. These benefits not only include the actual UAS operations, but also economic benefits in terms of job creation, environmental benefits, and resource optimization. The public has a positive or at least indifferent attitude towards UAS deployment.

Alternative B: UAS are widely deployed in urban areas as large companies such as Amazon or Google push ahead with e-commerce deliveries for consumers. Residential areas will be particularly impacted by these deliveries. The higher visibility of drones will reduce public acceptance, especially in residential areas.

4.3.6.2. Driver: Privacy and data protection

A study from the German Unmanned Aviation Association (Verband Unbemannte Luftfahrt; VUL) from 2017 shows that the primary concern citizens have regarding UAS operations is the intrusion of their own privacy and the protection of their data (VUL, 2017). This concern fortifies for operations in the vicinity of residential areas and in urban airspace. Even small UASs can be equipped with a camera, and it is difficult for private citizens to discern whether the UAV flying over their property or outside their apartment is carrying surveillance equipment (Lin Tan et al., 2021).

According to EU regulation 2018/1139, UAS operations must be carried out in accordance with the General Data Protection Regulation (2016/679) (European Parliament, 2018). This means that all UAS operators are subject to the six principles (i) lawfulness, fairness, transparency, (ii) purpose limitation, (iii) data minimization, (iv) accuracy, (v) storage limitation, and (vi) integrity and confidentiality. However, it is up to the data controller how to implement these principles following the general principle of 'data protection by design'. Furthermore, Article 35 of the same regulation stipulates that the threat to personal freedoms through new technologies warrant a risk-assessment of the data processing activity referred to as the data protection impact assessment (DPIA) (European Parliament, 2016). This process can be directly linked to the risk-based approach of UAS operations assessment.

The SORA concept does not only include safety risks but also includes further risks to people on the ground, such as data protection (Bassi, et al., 2019). Additionally, EU regulation 2021/664 on the framework for U-Space operations lists privacy as one of the four foundations for implementing U-Space airspaces and geographical zones. Thus, the threat of privacy and data protection infringements should be included in the geographic zones designated by the Member States (European Commission, 2021). These zones may either prohibit flights entirely in the respective zones, or they can restrict them according to use case priority and payload. Dirks explains that the German regulation has high requirements regarding privacy. For example, a UAS operator can only fly over private property if the residents have given their permission. If the operator has tried within reason to obtain permission but could not reach the residents, they can fly over the property but have to stay above 100 metres off the ground. Additionally, they can fly over that same property no more than four times a year. Dirks shows confidence that data protection laws are already sufficient to ensure the privacy of citizens. He further estimates that the threat of privacy infringement is currently overestimated, as is often the case with new technologies, and that concerns will decrease over time (Dirks, 2021).

Experts estimate that the obligation to incorporate a remote ID into UASs can help alleviate privacy concerns for two reasons. For one, Liebsch expects an identification tool to trigger an increased sense of responsibility with the pilots of the aircraft to be mindful about how they impact others. Meuleman adds that public access to the UTM system and the remote IDs may help decrease worries over time, as people can see which operator a specific UAS belongs to and UAS operations become more transparent. They both agree with Dirks that the current data protection laws are sufficient and do not need to be extended (Liebsch, 2021; Meuleman, 2021).

Alternative A: Member States include privacy concerns in their designation of geographic zones. Residential areas and other areas with strong concerns about data protection are either fully excluded from flight operations or linked to high requirements for UAS operators. This leads to severe limitations of airspace capacity, particularly in urban areas. Operations are mainly possible along specific corridors in accordance with a DPIA assessment.

Alternative B: Member States rely on the provisions of the GDPR and its principle of accountability. The public is further reassured by being provided with a remote ID of the UAS flying overhead. Concerns about privacy diminish over time as people get used to the new technology and incorporate it as part of their lives.

4.3.6.3. Driver: Safety and security

Safety is one of the leading drivers for the acceptance of unmanned aircraft. People are worried about UASs crashing into the ground or into buildings and raining debris down on the public. This is especially true for UAS operations relating to passenger transport in and around urban airspace, where safety and security become the public’s first priority (EASA, 2021b). The support for UAS operations would increase significantly if the standards of safety for all UASs were required to be the same as those in manned aviation. However, Garrity points out that these standards were developed over close to 100 years through rigorous testing, training, and the consequent establishment of stringent certification practises. He clarifies that transferring them categorically to all UAS operations would drastically hinder the market’s development and possibly prevent the market from establishing altogether (Garrity, 2021). For urban operations however, where concerns are the highest, Boden claims that the risk assessment according to SORA very quickly results in SAIL classifications between IV and VI. For these classes, certified UASs are necessary with very similar safety standards as those in manned aviation (Boden, 2021). Konzock points out that a good safety record is crucial for the development of the market, as accidents may cause the public to urge for stricter regulations and set the market back for years (Konzock, 2021). Garrity agrees stating that in the case of passenger transport UASs a few fatal crashes could kill this market segment entirely (Garrity, 2021). Dittrich warns about the double standard of allowing no UAS accidents while tolerating thousands of traffic fatalities through other modes of transport every year due to the advantages that can be derived by them (Dittrich, 2021).

Security is also a growing concern in society. For one, people fear that the data links are not sufficiently secure to (1) prevent their data from being intercepted and (2) prevent the whole aircraft from being highjacked and used for malicious purposes. Of course, the abuse of UASs does not require the hijacking of someone else's UAV. There have been reports of UASs being used to smuggle contraband across borders or into prison facilities, or for terroristic attacks on public infrastructure (Michel, 2018). Meuleman claims that the public is less aware of the security threats UASs pose than the authorities, but that this could quickly change, should the weaponised incidents regarding UAS increase (Meuleman, 2021). Dirks counters that no aspect of public life provides 100 % protection against terroristic attempts. He gives the example of car bombs and their lack of significant impact on the public's perception of automobiles (Dirks, 2021). While Dirks is confident that security threats will not eliminate the market's potential, they do have some influence on the development of the market. For example, an increase in security incidents may cause Member States to impose stricter regulations on UAS operations and limit airspace capacity by redefining geographic zones. It is crucial to invest not only in technological safety and security standards, but also to inform all relevant stakeholders and participants of the market of their responsibilities and best-practice approaches (SESAR JU, 2019).

Alternative A: The UAS market maintains a good safety record. Regulations monitor the risk-based approach of safety measures and are adapted when required, without imposing restrictions on the market, that are not imposed on other means of transport. The public evaluates the benefits of UASs against their risks and accepts the occasional incident. The safety record further improves with advancements in technology and incorporation of incident evaluations into regulatory and technical design.

Alternative B: Few but significant safety or security incidents within the early years of market development diminish public acceptance of UASs. Regulatory authorities impose strict constraints on the market, severely limiting its economic potential and growth.

4.3.6.4. Driver: Environmental factors

Compared to traditional aviation and especially helicopters, UASs emit significantly less CO_2 into the atmosphere. This is mainly due to the types of propulsion systems, which are mostly electric or hydrogen-based. However, that does not mean that UAS operations have no environmental impact. A study conducted by EASA has shown that people are concerned about the sustainability of the UAS market. This includes the environmental costs of development and production and the life cycles of the hardware that is being used. However, the most prominent concern was the impact on wildlife. Especially for urban UAS operations, respondents of the survey fear that an increase in flight operations in lower airspace will negatively impact the habitats of birds and insects (EASA, 2021b). Still, Liebsch points out that UAS are not only cleaner and reduce global emission levels by replacing helicopters, but they are also a crucial driver in the electrification and digitalisation of the whole aviation industry and other related industries. Thus, he is confident that overall, the environmental impact of UASs will be a positive factor in society (Liebsch, 2021).

Additionally, the increase in noise and visual pollution is a factor to be considered. Although UASs are significantly quieter than helicopters, they do emit perceivable noise levels. This is especially problematic for take-off when the aircraft requires high energy levels and is close to the ground. Studies have also shown that people are able to distinguish between the noise levels of a hexarotor and a quadrotor, with the UAV with six rotors causing significantly higher levels of annoyance (Ivoševic et al., 2021). Garrity adds that not only the level of noise pollution but also the quality of the noise must be considered. It is unfamiliar to most people and thus stands out more against other noises (Garrity, 2021). Liebsch agrees that the high whirring sound of a UAS is often compared to a large insect and negatively connotated in the public. He further criticized that the noise specifications in the regulations have been set without any significant acceptance studies (Liebsch, 2021). Nonetheless, part of the negative perception of UAS noise could be the unfamiliarity of the sound and may decrease over time. However, the number of UASs that are projected to be operating within the next few years may well exceed the public's tolerance for noise pollution, according to Garrity. He further mentions the impact of the visual pollution (Garrity, 2021). The projected numbers from EASA's market study expect between 3000 and 3500 UAS in the Paris metropolitan area by 2030 used for the transport of passengers and goods. While a focus on humanitarian use cases and good safety and data protection records may play a mediating role, the sheer number of UASs may significantly decrease the level of public acceptance for this new mode of mobility. Especially if the associated infrastructure drastically alters the city landscape and disturbs the historic atmosphere of many European cities (EASA, 2021b).

Alternative A: The industry puts a stronger focus on promoting the environmental benefits of UASs and the use cases dedicated to protecting and maintaining wildlife stock. In the long run, environmental concerns are not only alleviated but turned into active benefits of UASs. This effect is multiplied once the electric propulsion systems of UASs start expanding into other industries and thus further reduce the global carbon footprint. Additionally, noise levels decline with improving technology and UAS infrastructure is incorporated into existing landscapes in a mindful manner towards historic sites.

Alternative B: Visual pollution and noise pollution cause a reciprocal effect of triggering a negative reaction within the public. The public puts pressure on regulatory authorities to limit UAS operations near inhabited areas, significantly limiting the viable use cases of UASs.

4.4. Consistency check

Following the structure of the scenario analysis, the fourth step presents a consistency check. This step is crucial to ensure that the scenarios that are derived from the analysis are logical and consistent. In other words, alternatives that logically cannot be combined must be sorted into different scenarios. Therefore, each alternative must be weighed against all others to determine how they can coexist. Typically, this is done in a group setting and may result in more than two consistent scenarios. However, as this study is restricted to the two scenarios laid out in the methodology section of the paper, the consistency check was conducted by the author with the primary goal of excluding highly inconsistent scenarios from being bundled into the same scenario. The results of this assessment are entered into a consistency matrix in order to provide a clearly arranged overview. The alternatives are weighed against each other using the following evaluation scheme:

1	Total inconsistency, cannot be logically bundled into one scenario
2	Partial inconsistency, must be evaluated individually
3	Neutral or independent
4	Consistent
5	Consistent and interrelated

Table 5: Coding of consistency matrix (created by author)

Thus, a combination of alternatives that is valued at 1 is logically contradictory – the alternatives cannot coexist in the same scenario. Inversely, alternatives that are valued at 5 are not only logically combinable, but also present a certain level of interrelation. For example, the efficiency of the interdiction of unmanned aircraft systems strongly depends on whether the aircraft are detected in the first place. Thus, inefficient detection technology cannot coexist with efficient interdiction methods. Subsequently, these two alternatives must be sorted into separate scenarios. By contrast, an improvement in detection mechanisms can plausibly coexist in the same scenario with an improvement in interdiction methods. Although they may not be causally correlated, it is conceivable that technological advancement in one field may be linked to progress in the other field.

Once all values are assigned, the combinations of alternatives that are valued at 1 are excluded from being sorted into the same scenario. Furthermore, alternatives with high consistency are sorted into one scenario bundle. Following the order of importance derived through the interconnectedness matrix, the first strong correlation occurs between [economic impact, urban vs. rural operations, alternative A] and [regulation, flight authorisation, alternative A] as well as [regulation, certified UASs, alternative A]. Thus, these three alternatives were bundled into one scenario. Subsequently, all alternatives that were consistent with either of these three alternatives were also added to the scenario. The process was repeated until each driver was represented with one alternative in each scenario bundle.

If an inconsistency occurred, each case was evaluated on an individual basis. For example, one inconsistency was found in the consolidation of the security drivers. Generally, all alternatives that lead to a higher efficacy of security measures should be sorted into the same scenario, as they are logically related to each other. However, in the case of spoofing an increase in performance efficiency also has an unwanted side effect: it leads to a decrease in hacking prevention (driver: counter measures, driver: hacking prevention) because malevolent individuals will find it easier to carry out spoofing attacks on aviation facilities. This inconsistency was resolved by arguing that spoofing is just one of the mechanisms referred to in these subsections and not sufficient to cause a contradictory scenario. The complete consistency matrix can be found in appendix C and the allocation of the alternatives into the two scenarios in appendix D.

4.5. Scenario creation

4.5.1. Scenario A: Full integration of UASs into national airspace systems

Scenario A describes a full integration of UASs into national airspace systems. This integration is achieved by pursuing short-, medium-, and long-term goals. While complete integration is the long-term goal of the industry, its foundations are being established within the next two years. The first step in enabling integration of UASs with other airspace participants is the overhaul of the flight rules, or rules of the air. For one, a new class of flight rules for UASs is established, as they cannot fly under VFR or IFR. More importantly, the flight rules are rewritten in a way that supports integration. That means they stipulate protocols that manage the interaction between manned and unmanned actors in uncontrolled airspace to ensure safe separation mechanisms. To reduce human intervention and increase the automation of UAS operations, separation management is conducted by making other airspace participants visible to the UASs. Until on-board detect-and-avoid systems are advanced enough to mimic human eyesight and enable UASs to fly in VFR airspace, all participants flying under 500 ft must be electronically visible. For UASs, this is achieved by developing an affordable, reliable, and comprehensive CNS link. In the early stages of the UAS market, UAS operators utilise external DSP services to explore UAS potential within their market segment without being burdened by regulatory and bureaucratic barriers. In favour of integration, additional interfaces are eliminated by establishing one comprehensive U-Space airspace over national territory. While the initial costs of conducting a comprehensive risk assessment and providing the required U-Space service infrastructure are higher, one single U-Space airspace reduces complexity, increases airspace capacity, and facilitates integration in the long run. This is also reflected in the role of the CISP. Not only does the single CISP serve as a centralised point of governance in the U-Space infrastructure, but it also constitutes a single point of contact to other stakeholders, such as local authorities. More importantly, it serves as a centralised interface to ATM services, which further facilitates integration efforts in the long run. Member States who appoint the national ANSP as CISP benefit from the extensive experience and know-how of these institutions and a natural point of convergence of UTM and ATM.

In the medium run, between two and five years, scalability will become the focus of the market. This means that successful niche or test operations can be transformed into a large-scale deployment of UASs. In order to allow for a broad variety of UAS operations and to realise the full potential of the market, an equilibrium between safety requirements and operational freedom must be found. Thus, regulatory processes, such as flight authorisations and the associated SORA method, are facilitated. The data that has been collected since the regulation on UAS operations went into effect in 2020 is used to continuously streamline authorisation procedures. This requires the incorporation of additional standard scenarios into the regulation and the reduction of the workload for competent authorities by encouraging operators to acquire a LUC. Subsequently, the regulatory framework for the certified class of UAS operations is finalised at this point, as are the AMCs and GMs for the whole regulation. This unlocks additional operational potentials and thus increases the need for scalability. For example, urban operations that often require certified UASs can now be conducted. Additionally, the simplified procedures and newly accessible market potential cause larger businesses to establish their own UAS divisions instead of relying on external DSPs. U-Space services play an integral part in managing dense traffic structures. A consolidation of USSPs to a select few that coexist in collaborative competition decreases the number of interfaces in the UTM system and benefits automation processes. Member States that have pursued a segregate approach of U-Space airspaces, can benefit from converging towards a comprehensive U-Space airspace to further reduce the interfaces and provide a level airspace structure for all air traffic participants.

Along with the developments in the short and medium run, there are some processes that need to be continuously monitored and fostered. For one, public acceptance needs to be improved. The analysis has shown that the public is less inclined to support UAS operations that are close to their living spaces as well as operations that benefit the individual rather than society. However, a scenario that fosters integration and scalability of the UAS market inherently supports high traffic volumes of UASs, across all areas of operation. Furthermore, high visibility and traffic volume increase the strain of visual and noise pollution. Thus, an integrative approach has a negative impact on public acceptance and requires more focussed efforts to mediate this effect. Another driver of public acceptance is the safety and security record of UASs. While safety standards are incorporated at every level of the UAS market, security concerns need to be addressed separately and the technologies and methods surrounding the security of UASs need to be further developed. Specifically, the rate and accuracy of the detection of UASs need to be improved, counter mechanisms need to become more effective, precise, and affordable, as need the protective mechanisms against the hijacking of UASs or data flows.

In the long run, security and public acceptance concerns are mediated and develop in line with the market. Through technological advancements and a dynamic regulatory framework, the level of integration that is envisioned in SESAR’s U-Space blueprint is achieved. The deployment of autonomous detect-and-avoid systems increases automation in the market and further facilitates the coexistence of manned and unmanned air traffic participants in the same airspace. Additionally, innovative propulsion methods and improvements concerning the size, weight, and power ratio of UAS engines enables UASs to transport payloads over longer distances. This paves the way for UASs to carry the necessary equipment for IFR flights and their proliferation into higher airspace levels. This convergence and the automation levels associated with U4 services will trigger fundamental changes in ATM services as automated processes increase and subsequently decrease the level of human intervention in air traffic management systems.

4.5.2. Scenario B: Segregated airspaces for UASs and manned aviation

Scenario B describes the segregation of UASs from manned aviation. The initial implementation of UAS operations is hampered by the high complexity of SORA and the lengthy bureaucratic requirements for UAS operations. Small companies are unable to explore UAS potential within their business model, as bureaucratic cost outweigh prospective benefits. Thus, the UAS market develops around large companies such as Google and Amazon, who have the resources to establish their own UAS division. The business internal focus of these companies leads them to coordinate their own fleets and operations as USSP as well, leading to a high degree of dispersion of service providers. The lack of a centralised CISP role that governs USSP activities and consolidates data into a single source of truth requires more extensive auditing efforts of USSP actors, to ensure that safety requirements are not neglected in favour of competitive advantage. Furthermore, the lack of a uniform and comprehensive CNS link complicates the tracking efforts of USSPs as different sensors are required to receive the signals of different transponders. This spectrum of signals further increases the complexity of fusing the signals from several receiving stations into one distinct track for each UAS. Due to a lack of autonomous detect-and-avoid systems, tactical inflight deconfliction will continue to depend on human intervention and pilot competency in the short run. In U-Space airspaces this is done via mandatory electronic conspicuity and tracking efforts by USSPs. However, U-Space airspaces are exclusively established around areas with high expected economic activity, such as urban environments, industrial areas, or ports. Outside those areas, the interaction of UASs and other air traffic participants is regulated by flight rules. Although they have been amended to include a class of rules specifically for UASs, the high economic cost and strong pushback from the GA industry have prevented mandatory electronic conspicuity. Subsequently, there is a significant threat of UASs encountering manned aircraft that are not electronically conspicuous and thus invisible to the UASs. As the safety separation between the two cannot be reliably ensured, UASs have to operate in segregation from manned aviation. In instances where segregation cannot be assured, UASs have to inform all other air traffic participants of their planned flight path via NOTAMs, which significantly decreases the scalability of the market.

Meanwhile the performance of detection mechanisms remains ineffective and expensive. Obligatory remote ID and an increased sense of responsibility of UAS pilots reduce the number of negligent intrusions of UASs into restricted airspace. However, intentional intrusions by UASs without a remote ID are only sporadically detected and located in time to prevent a security incident. In addition, counter mechanisms remain ineffective against fast-moving UASs. The detection and interdiction of UASs in restricted airspace requires extensive infrastructure and a variety of different sensors and radars, leading to frequent incidents and security threats caused by UASs. Additionally, a UAS's collected data or transported cargo are frequently endangered by hijacking attempts. This strongly decreases public acceptance for UAS operations. For one, safety and security incidents lower the trust of the public in this technology. Secondly, the increased threat of data protection violations causes the public to urge for stricter limitations on UASs flying over residential areas.

The development of urban UAS operations is slowed down, as upper SAIL categories of the specific category are restricted due a delayed development of the AMCs and GMs regarding certified UASs. Once they do take off, the economic potential of urban operations is limited by the inaccessibility of residential areas and strong pushback by the public. B2C operations are restricted to rural areas, significantly hampering the development of large traffic volumes. The resulting reduction in market potential impedes research efforts and technological advancement. Slow progress in the development of autonomous flight systems and higher endurance propulsion methods hinder the UASs' ascent into higher airspace levels and thus effectively prevent integration and scalability of the market.

5. Scenario transfer

Scenario A and B define the future environment in which ANSPs will operate. They describe chances which the ANSPs can exploit, but also show risks which need to be defused. With the industry goal of full integration in mind, scenario A has to be the clear preference of UAS industry stakeholders. If substantial parts of scenario A are realised, these stakeholders can profit from a scalable and structured UAS market. The preference for scenario A applies in particular to ANSPs such as DFS. These institutions play an integral part in the integration of unmanned aircraft into the aviation system. One of the core strengths of ANSPs is their extensive know-how and experience regarding the management of air traffic flows. They have an in-depth understanding of monitoring and tracking aircraft in the sky, directing traffic volume to maintain safety separation, and providing aeronautical information to the pilots. Additionally, ANSPs often cultivate their corporate identity over the course of decades with one core focus: safety. This mentality and their air traffic expertise put them in a uniquely qualified position to take on a dominant role in the coordination of the UAS market. DFS is pursuing this role in the U-Space test site that has been constructed inside the port of Hamburg, Germany. In this controlled environment, they are assuming the role of the single CISP and consolidating and verifying data from the USSP to establish electronic situational awareness.

A potential weakness of the ANSP business model is the manual approach of ATM. As ATM and UTM are expected to converge in favour of full integration, UTM's focus on automated processes and reduction of human intervention will almost certainly outperform the current ATM system. To maintain their position in the air traffic industry, ANSPs must diversify their portfolio and pursue their own automation processes. Thus, ANSPs benefit from getting involved in the USSP role as well. As the USSP role has a more pronounced economic focus than the CISP, it should be established as a stand-alone division or subsidiary. This way, ANSPs can minimise the cost of establishing a functional UTM infrastructure by translating their expertise in AIS into the UAS domain. DFS is pursuing this approach through their joint venture with the German telecommunications provider Deutsche Telekom AG. Together, they consolidated aeronautical expertise with telecommunications infrastructure to form the potential future USSP Droniq GmbH. Not only does this provide DFS with the opportunity to serve as a connector between Droniq's UTM services and their own ATM services, but it also diversifies their portfolio and solidifies their position in the UAS market.

To stay competitive in the market of air traffic service provision, ANSPs need to actively participate in research efforts regarding the automation of processes and the digitalisation of ATC. Co-operations or joint ventures with other industry stakeholders, such as software providers, research facilities, or regulatory authorities not only keep ANSPs more heavily involved with the UAS business, but also enable them to incorporate findings from UTM research into their ATM procedures and to advance their skill set beyond the management of manned traffic. With the emergence of air taxis and certified UASs, air traffic control procedures must be increasingly capable to coordinate unmanned traffic as well as manned traffic. In addition, the portfolio of ANSPs can be further diversified by offering their growing expertise on UAS traffic to interested parties in the form of a consultancy business, such as DFS' Aviation Services DAS.

From their ATM perspective, ANSPs are also heavily impacted by security and safety concerns caused by UASs. DFS has been commissioned by the German Ministry of Transport to establish UAS detection infrastructure around Germany's international airports. Besides the focus on technological solutions for detecting UASs around airports, ANSPs can profit from preventing these occurrences in the first place. Establishing and promoting educational programs about the remote pilots' responsibilities and the code of conduct of UAS operations can help reduce ignorant intrusions into restricted geozones. Similarly, image campaigns can help highlight the humanitarian and economic benefits of UAS operations and contribute to the improvement of societal acceptance of UASs.

6. Conclusion

The development of the UAS industry is a complex and intricately connected process. While there are still substantial challenges to overcome, the foundation for a regulated and scalable market is already taking shape. At present, UAS operations are mainly conducted in VLOS settings and in low-risk environments. The analysis of regulatory requirements, U-Space infrastructure, economic potential, technological capabilities, security concerns, and public acceptance has shown that there are various measures to be taken to promote the full integration of UASs into national airspace systems. One of the main takeaways from interviewing a number of experts in the industry is that although regulatory processes are moving along and solidifying the operational and technological requirements of UAS operations, they are still one of the major hindrances in the market. Without legal provisions on certified UASs, the market is mainly limited to rural operations. Subsequently, this reduces the necessity of implementing U-Space as a tool of scalability. Another major issue is the coordination of manned and unmanned air traffic. The assurance of safe operating distances is an essential prerequisite of allowing these two groups to operate in the same airspace. On the other hand, a complete segregation is almost impossible to enforce. Thus, a solution to ensure safe co-existence of VFR and UAS traffic is a crucial step in the development of the market.

The scenario analysis provided a comprehensive overview of open questions and possible developments in the market. The results showed that while the goal of integration can be achieved, a mostly segregated market is also conceivable if some of the key issues are not resolved. However, it is important to note that the scenarios presented in the analysis are not a comprehensive representation of possible future developments. They present the most favourable outcomes for an integrative approach on the one side, and outcomes that lead to segregated airspace on the other side. Most likely, the actual development of the market will happen somewhere in between. Nonetheless, the integration of UASs into air traffic structures also opens up unique opportunities for manned aviation and ANSPs. An increased focus on automated processes and technological capabilities paves the way for decreasing the human factor in traditional air traffic.

There are some noteworthy limitations to this study and potential for future research. For one, the UAS market is developing with high speed and flexibility. While this research was conducted to the best of the author's knowledge, new findings are published every week that may impact the accuracy of this paper. Secondly, the scenario technique is typically used by businesses to assess their position and favourable courses of development within a market. Thus, the data used for the analysis is usually collected by working together with a group of experts. This research attempted to recreate that pool of knowledge by conducting expert interviews and collecting data from contributions to scientific literature. Although the experts were selected in a way that covered the majority of stakeholders, a slight bias in the data cannot be ruled out. For instance, while two experts were included from DFS, no representative of the General Aviation stakeholder group was found, as it consists mostly of private citizens with varying levels of interest in the market.

Lastly, some aspects of the UAS market were disregarded in this research as they simply would have exceeded the scope of the thesis. One major point that requires further research is the aspect of financial responsibility. It remains unclear how the initial establishment of a U-Space infrastructure will be financed. For one, this includes the dynamic airspace reconfiguration that is specified in the regulation on U-Space and imposed on ANSPs in addition to their regular duties. But also, the initial deployment of the U-Space infrastructure has to be covered in terms of cloud infrastructure and service provision. Another point that will require more extensive research in the long run is the issue of very high-altitude UAS operations. The upper boundaries of sovereign airspace are defined almost arbitrarily and UAS operations that cross over multiple borders need their own regulatory framework.

Bibliography

Alamouri, A., Lampert, A., & Gerke, M. (2021). An Exploratory Investigation of UAS Regulations in Europe and the Impact on Effective Use and Economic Potential. *Drones, 5*(3). doi:10.3390/drones5030063

Alhawi, O., Mustafa, M., & Cordeiro, L. (2019). *Finding Security Vulnerabilities in Unmanned Aerial Vehicles Using Software Verification.* Technical Report, Unmanned Aerial Vehicle Vulnerabilities.

Austin, R. (2010). Introduction to Unmanned Aircraft Systems (UAS). *Unmanned Aircraft Systems: UAVS Design, Development and Deployment*.

Australian UAV. (2016, June). Drone Types: Multi-Rotor vs Fixed-Wing vs Single Rotor vs Hybrid VTOL. (A. Chapman, Ed.) *Australian Drone Magazine*(3).

Austro Control. (2019). *Organisation: Aufgaben*. Retrieved September 14, 2021, from https://www.austrocontrol.at/unternehmen/profil/organisation/aufgaben

Ayamga, M., Akaba, S., & Nyaaba, A. A. (2021). Multifaceted Applicability of Drones: A Review. *Technological Forecasting & Social Change*. doi:10.1016/j.techfore.2021.120677

Babayomi, O. O., & Makarfi, A. U. (2019). Energy Efficiency in Unmanned Aircraft Systems: A Review. *2019 IEEE PES/IAS PowerAfrica* (pp. 569-574). Abuja, Nigeria: IEEE Xplore. doi:10.1109/PowerAfrica.2019.8928766

Badea, C. A., Prabhakar, N., & Karbowski, D. (2020). Mission-Driven Simulation of a Multi-rotor Unmanned Aerial System for Energy Consumption Analysis. *2020 IEEE Aerospace Conference* (pp. 1-8). Big Sky, Montana, USA: IEEE Xplore. doi:10.1109/AERO47225.2020.9172757

Bassi, E., Bloise, N., Dirutigliano, J., Fici, G., Pagallo, U., Primatesta, S., & Quagliotti, F. (2019). The Design of GDPR-Abiding Drones Through Flight Operation Maps: A Win–Win Approach to Data Protection, Aerospace Engineering, and Risk Management. *Minds and Machines*(29), pp. 579-601. doi:https://doi.org/10.1007/s11023-019-09511-9

Baum, D. M., Neto, E. C., Rady de Almeida Jr., J., Camargo Jr., J. B., & Cugnasca, P. S. (2020). A Mindset-Based Evolution of Unmanned Aircraft System (UAS) Acceptance Into the National Airspace System (NAS). *8,* pp. 30938-30952. doi:10.1109/ACCESS.2019.2952973

BDL. (n.d.). *Der Verband: Unser Auftrag*. Retrieved September 14, 2021, from https://www.bdl.aero/de/der-verband/unser-auftrag/

BMVI. (2020). *Unbemannte Luftfahrtsysteme und innovative Luftfahrtkonzepte - Aktionsplan der Bundesregierung.* Aktionsplan, Bundesministerium für Transport und Digitale Infrastruktur, Berlin.

BMVI. (2021). *Aufgaben und Struktur - Das Ministerium stellt sich vor*. Retrieved September 14, 2021, from https://www.bmvi.de/DE/Ministerium/Aufgaben-Struktur/aufgaben-struktur.html

Boden, R. (2021, August 29). Expert Interview with Richard Boden from Wingcopter. (E. Pfister, Interviewer)

Boselli, C., Danis, J., McQueen, S., Breger, A., Jiang, T., Looze, D., & Ni, D. (2017). Geo-fencing to Secure Airport Perimter Against sUAS. *International Journal of Intelligent Unmanned Systems, 5*(4).

CANSO. (2011). *ANSP Considerations for Unmanned Aircraft Systems (UAS) Operations.* Civil Air Navigation Services Organisation (CANSO) Operations Standing Committee.

Cohen, A. P., Shaheen, S. A., & Farrar, E. M. (2021). Urban Air Mobility: History, Ecosystem, Market Potential, and Challenges. *IEEE Transactions on Intelligent Transportation Systems*. doi:10.1109/TITS.2021.3082767

Crivellaro, G. (2021, August 05). Expert interview with Giancarlo Crivellaro from the European Commission. (E. Pfister, Interviewer)

Davies, L., Bolam, R. C., Vagapov, Y., & Anuchin, A. (2018). Review of Unmanned Aircraft System Technologies to Enable Beyond Visual Line of Sight (BVLOS) Operations. *2018 X International Conference on Electrical Power Drive Systems (ICEPDS).* IEEE Xplore. doi:10.1109/ICEPDS.2018.8571665

DFS. (2021). *Drohnen Report - Stand: August 2021.* Monthly report, DFS - Deutsche Flugsicherung GmbH.

DFS. (n.d.). *Über Uns*. Retrieved September 14, 2021, from https://www.dfs.de/dfs_homepage/de/Unternehmen/%C3%9Cber%20uns/

Dill, E. T., Young, S. D., & Hayhurst, K. J. (2016). SAFEGUARD: An Assured Safety Net Technology for UAS. *2016 IEEE/AIAA 35th Digital Avionics Systems Conference (DASC)* (pp. 1-10). Sacramento, California, USA: IEEE. doi:10.1109/DASC.2016.7778009

DIN. (2021a). *DIN 5452-6 Luft- und Raumfahrt - Unbemannte Luftfahrzeugsysteme (UAS) - Teil 6: Geodatenmanagement für UTM Systeme.* Deutsches Insitut für Normung (DIN). Beuth Verlag.

DIN. (2021b). *DIN: Kurz erklärt*. Retrieved September 14, 2021, from https://www.din.de/de/ueber-normen-und-standards/basiswissen

Dinu, A.-M. (2015). The Risks and Benefits of Outsourcing. *Knowledge Horizons - Economics, 7*(2), pp. 103-104.

Dirks, J. (2021, August 17). Expert interview with Jan Dirks from Bundesministerium für Verkehr und Digitale Infrastruktur BMVI. (E. Pfister, Interviewer)

Dittrich, J. (2021, August 11). Expert interview with Jörg Dittrich from Deutsche Zentrum für Luft- und Raumfahrt. (E. Pfister, Interviewer)

DJI. (2021). *Kameradrohnen*. Retrieved September 14, 2021, from https://www.dji.com/de/camera-drones?site=brandsite&from=homepage

DLR. (2021). *DLR at a Glance*. Retrieved September 14, 2021, from https://www.dlr.de/EN/organisation-dlr/dlr/dlr.html

Dolph, C. V., Logan, M. J., Glaab, L. J., Vranas, T. L., McSwain, R. G., Johns, Z. R., & Severance, K. (2017). Sense and Avoid for Small Unmanned Aircraft Systems. *AIAA Information Systems-Infotech At Aerospace Conference.* Grapevine, Texas, USA: Aerospace Research Central. doi:10.2514/6.2017-1151

Drone Industry Insights. (2020). *The Drone Industry Barometer 2020 - Consolidating New Trends and Perspectives of the Commercial Drone Industry.* Whitepaper.

Droniq. (2021). *About Us*. Retrieved September 14, 2021, from https://droniq.de/en/pages/uber-uns

DTI & AUVSI. (2019). *Global Trends of Unmanned Aerial Systems.* Danish Technological Institute & Association for Unmanned Vehicle Systems International.

Duffy, B., Balachandran, S., Peters, A., Smalling, K., Consiglio, M., Glaab, L., . . . Munoz, C. (2020). Onboard Autonomous Sense and Avoid of Non-Conforming Unmanned Aerial Systems. *2020 AIAA/IEEE 39th Digital Avionics Systems Conference (DASC).* San Antonio, Texas, USA: IEEE Xplore. doi:10.1109/DASC50938.2020.9256776

EASA. (2019). *Opinion No 05/2019 - Standard Scenarios for UAS Operations in the 'Specific' Category.* European Union Aviation Safety Agency.

EASA. (2021). *Certfied Categtory - Civil Drones*. (EASA, Editor) Retrieved August 23, 2021, from https://www.easa.europa.eu/domains/civil-drones-rpas/certified-category-civil-drones

EASA. (2021). *Study on the Societal Acceptance of Urban Air Mobility*. Retrieved from https://www.easa.europa.eu/sites/default/files/dfu/uam-full-report.pdf

Emergen Research. (2020). *Counter UAS Market by Type, by Application, by End-Users, by Product, by Power, by Range and Regions Forecasts to 2027.*

Eurocae. (n.d.). *The European UAS Standards Coordination Group (EUSCG)*. Retrieved September 04, 2021, from https://www.eurocae.net/about-us/euscg/

Eurocontrol. (2018a). *UAS ATM CARS - Common Altitude Reference System.* European Organisation for the Safety of the Air Navigation.

Eurocontrol. (2018b). *UAS ATM Flight Rules.* Discussion Document, European Organisation for the Safety of the Air Navigation.

Eurocontrol. (2018c). *Unmanned Aircraft Systems (UAS) ATM Integration - Operational Concept.* European Organisation for the Safety of Air Navigation.

Eurocontrol. (2020). *Vertical Limits of Airspace*. Retrieved September 15, 2021, from www.ext.eurocontrol.int: https://ext.eurocontrol.int/aixm_confluence/display/ACGAIP/Vertical+Limits+of+Airspace

Eurocontrol. (n.d.). *Unmanned Aircraft Systems - Helping to Make Europe's Skies Safe and Accessible to All*. Retrieved September 04, 2021, from https://www.eurocontrol.int/unmanned-aircraft-systems

European Commission. (2019a). *Commission Delegated Regulation (EU) 2019/945 of March 12 2019 on Unmanned Aircraft Systems and on Third-Country Operators of Unmanned Aircraft Systems.* Official Journal of the European Union.

European Commission. (2019b). *Commission Implementing Regulation (EU) 2019/947 on the rules and procedures for the operation of unmanned aircraft.* Official Journal of the European Union.

European Commission. (2021). Commission Implementing Regulation (EU) 2021/664 of 22 April 2021on a regulatory framework for the U-space. *Official Journal of the European Union*.

European Commission. (n.d.). *Mobility and Transport*. Retrieved September 14, 2021, from https://ec.europa.eu/info/departments/mobility-and-transport

European Parliament. (2016). Regulation (EU) 2016/679 of the European Paliament and of the Council on the protection of natural persons with regard to the processing of personal data and on the free movement of that data. *Official Journal of the European Union*.

European Parliament. (2018). Regulation (EU) 2018/1139 of the European Parliament and of the Council of 4 July 2018 on Common Rules in the Field of Civil Aviation and Establishing a European Union Aviation Safety Agency. *Official Journal of the European Union*.

Federal Aviation Administration. (n.d.). *Drones & Wildfires - Digital Toolkit.* Retrieved August 08, 2021, from https://www.faa.gov/uas/media/FAA_drones_wildfires_toolkit.pdf

Fraport. (2021). *Fraport AG: Konzern: Über Uns*. Retrieved September 14, 2021, from https://www.fraport.com/de/konzern/ueber-uns.html

Frequentis. (n.d.). *Über Uns*. Retrieved September 14, 2021, from https://www.frequentis.com/de/about-us

Gang, B. G., & Kwon, S. (2018). Design of an Energy Management Technique for High Endurance Unmanned Aerial Vehicles Powered by Fuel and Solar Cell Systems. *International Journal of Hydrogen Energy, 43*(20), pp. 9787-9796. doi:10.1016/j.ijhydene.2018.04.049

Garrity, R. (2021, July 08). Expert interview with Robin Garrity from SESAR JU. (E. Pfister, Interviewer)

Gausemeier, J., Pfänder, T., & Lehner, A.-C. (2017). Strategische Unternehmensführung mit Szenario-Management. In D. Spath, E. Westkämpfer, H.-J. Bullinger, & H.-J. Warnecke, *Neue Entwicklungen in der Unternehmensorganisation* (pp. 97-111). Berlin: Springer Vieweg. doi:10.1007/978-3-642-45370-0_15-1

geo-konzept. (2021). *Die Neue EU-Drohnenverordnung 2021: Ratgeber - Was sich für Sie ändert*. Retrieved September 15, 2021, from https://geo-konzept.de/lp-eu-drohnenverordnung-2021/

Guan, X., Lyu, R., Shi, H., & Chen, J. (2020). A survey of safety separation management and collision avoidance approaches of civil UAS operating in integration national airspace system. *Chinese Journal of Aeronautics*, *33*(11), pp. 2852-2861.

Hartwich , T. (2021, June 23). Written Questionnaire with Tamara Hartwich from the German Aviation Association (Bundesverband der Deutschen Luftverkehrswirtschaft). (E. Pfister, Interviewer)

Hassler, S. C., & Baysal-Gurel, F. (2019). Unmanned Aircraft System (UAS) Technology and Applications in Agriculture. *agronomy, 9*(10). doi: 10.3390/agronomy9100618

Hatfield, M., Cahill, C., Webley, P., Garron, J., & Beltran, R. (2020). Integration of Unmanned Aircraft Systems into the National Airspace System - Efforts by the University of

Alaska to Support the FAA7NASA UAS Traffic Management Program. *Remote Sensing, 12*(19). doi:10.3390/rs12193112

Heidger, R. (2021, July 22). Expert interview with Ralf Heidger from DFS - Deutsche Flugsicherung GmbH. (E. Pfister, Interviewer)

Hosseini, N., Jamal, H., Haque, J., Magesacher, T., & Matolak, D. W. (2019). UAV Command and Control, Navigation and Surveillance: A Review of Potential 5G and Satellite Systems. *2019 IEEE Aerospace Conference* (pp. 1-10). Big Sky, Montana, USA: IEEE Xplore. doi:10.1109/AERO.2019.8741719

Huarng, K.-H., & Hui-Kuang Yu, T. (2020). The Impact of Surge Pricing on Customer Retention. *Journal of Business Research, 120*, pp. 175-180. doi:10.1016/j.jbusres.2020.07.043

ICAO. (2015). Technology Workshop ICAO RPAS Manual - C2 Link and Communications. *Remotely Piloted Aircraft Systems Symposium 23-25 March 2015.* Montréal, Canada.

ICAO. (2020). *Remotely Piloted Aircraft System (RPAS) Concept of Operations (CONOPS) for International IFR Operations.* International Civil Aviation Organization. Retrieved August 13, 2021, from https://www.icao.int/safety/UA/Documents/ICAO%20RPAS%20CONOPS.pdf

Inan, B. (2021, September 03). Expert Interview with Berkay Inan from Austro Control. (E. Pfister, Interviewer)

Ivoševic, J., Ganic, E., Petošic, A., & Radišic, T. (2021). Comparative UAV Noise-Impact Assessments through Survey and Noise Measurements. *International Journal of Environmental Research and Public Health*(18). doi:10.3390/ijerph18126202

JARUS. (n.d.). *What's JARUS: Who we are*. Retrieved September 14, 2021, from http://jarus-rpas.org/who-we-are

Jenkins, D., Vasigh, B., Oster, C., & Larsen, T. (2017). *Forecast of the Commercial UAS Package Delivery Market.* Embry-Riddle Aeronautical University.

Justin, C., Ramamurthy, A., Beals, N., Spero, E., & Mavris, D. (2018). On-Demand Small UAS Architecture Selection and Rapid Manufacturing Using a Model-Based Systems Engiineering Approach. *31st Congress of the International Council of the Aeronautical Sciences 2018 (ICAS 2018_0851).* Belo Horizonte, Brazil.

Kabo, D., Osedo, A., & Yasui, I. (2020). Low Altitude Situational Awareness Enhancement Using Remote ID Broadcasted From Small UAS. *AIAA Aviation 2020 Forum.* American Institute of Aeronautics and Astronautics. doi:10.2514/6.2020-2867

Keane, J. F., & Carr, S. S. (2013). A brief history of early umanned aircraft. *Johns Hopkins APL Technical Digest, 32*(3), pp. 558-571.

Keller, J., Deng, B., Gore, D., & Minnix, J. (2020). Effective Non-Cooperative Surveillance for UAS Situational Awareness. *2020 Integrated Communications Navigation and Surveillance Conference (ICNS)*, (pp. 2E2-1-2E2-10). doi:10.1109/ICNS50378.2020.9222908.

Kellermann, R., Biehle, T., & Fischer, L. (2019). Drones for Parcel and Passenger Transportation: A Literature Review. *Transportation Reseach Interdisciplinary Perspectives, 4*. doi:10.1016/j.trip.2019.100088

Kies, A. (2021, July 20). Expert interview with Angela Kies from DFS - Deutsche Flugsicherung GmbH. (E. Pfister, Interviewer)

Kilbourne, T., Roy, A., & Wieland, F. (2020). Validation of UAS Command and Control Link Switchover Internetworking and Security Requirements. *2020 AIAA/IEEE 39th Digital Avionics Systems Conference (DASC)* (pp. 1-8). San Antonio, Texas, USA: IEEE Xplore. doi:10.1109/DASC50938.2020.9256775

Konzock, C. (2021, June 10). Expert interview with Carsten Konzock from LBA. (E. Pfister, Interviewer)

Kyrkou, C., Timotheu, S., Kolios, P., Teocharides, T., & Panayiotou, C. (2019). Drones: Augmenting our Quality of Life. *Smart Consumer Electronics Systems, 38*(1), pp. 30-36. doi:10.1109/MPOT.2018.2850386

LBA. (2019). *Aufgaben und Ziele des Luftfahrt-Bundesamtes*. Retrieved September 14, 2021, from https://www.lba.de/DE/LBA/Aufgabe/Aufgaben_node.html;jsessionid=B4502FEF1F44F16B69D7FBC9D528A430.live21301

Liebsch, R. (2021, August 09). Expert interview with Ronald Liebsch from Deutsches Institut für Normung. (E. Pfister, Interviewer)

Lin Tan, L., Lim, B., Park, G., Low, K., & Seng Yeo, V. (2021). Public acceptance of drone applications in a highly urbanized environment. *Technology in Society*(64). doi:10.1016/j.techsoc.2020.101462

Liu, Z., Cai, K., & Zhu, Y. (2021). Civil Unmanned Aircraft System Operation in National Airspace: A Survey from Air Navigation Service Provider Perspective. *Chinese Journal of Aeronautics, 34*(3), pp. 200-224. doi:10.1016/j.cja.2020.08.033

Mageto, J., Prinsloo, G., & Luke, R. (2018). The Extent of Logistics Outsourcing Among Small and Medium-Sized Manufacturing Enterprises in Nairobi. *Journal of Transport and Supply Chain Management, 12*, pp. 1-9. doi:10.4102/jtscm.v12i0.346

Manesh, M. R., Kenney, J., Hu, W. C., Devabhaktuni, V. K., & Kaabouch, N. (2019). Detection of GPS Spoofing Attacks un Unmanned Aerial Systems. *2019 16th IEEE Annual Consumer Communications & Networking Conference (CCNC)* (pp. 1-6). IEEE.

Markets and Markets. (2021). *Unmanned Aerial Vehicle (UAV) Market by Point of Sale, Systems, Platform (Civil & Commercial, and Defense & Governement), Function, End Use, Application, Type, Mode of Operation, MTOW, Range, and Region - Global Forecast to 2026.* Market Research Report.

Marshall, D. M., & Trapnell, B. (2021). History. In K. R. Barnhart, D. M. Marshall, & E. Shappee, *Introduction to Unmanned Aircraft Systems* (3 ed.). CRC Press.

McHann, S. E. (2021). Implementing Unmanned Aerial System Sensors and Technology to Improve Distribution and Transmission System Inspections with Measurable Results. *2021 IEEE Rural Electric Power Conference (REPC),* (pp. 47-51). doi:10.1109/REPC48665.2021.00010

McKinsey & Company. (2017). *Commercial Drones are Here: The Future of Unmanned Aerial Systems.* Capital Projects & Infrastructure.

Merkert, R., & Bushell, J. (2020). Managing the Drone Revolution: A Systematic Literature Review into the Current Use of Airborne Drones and Future Strategic Directions for their Effective Control. *Journal of Air Transport Management, 89*. doi:10.1016/j.jairtraman.2020.101929

Metzner, N. (2021, August 03). Expert interview with Dr.-Ing. Nora Metzner from Droniq. (E. Pfister, Interviewer)

Meuleman, K. (2021, June 24). Expert interview with Koen Meuleman from Unifly. (E. Pfister, Interviewer)

Michel, A. H. (2018). *Counter-Drone Systems.* The Center for the Study of the Drone at Bard College.

Millett, S. (2011). *Managing the Future: A Guide to Forecasting and Strategic Planning in the 21st Century*. Triarchy Press.

NASA. (2020). *Unmanned Aircraft Systems (UAS) Traffic Management (UTM) Concept of Operations.* Washington, DC: U.S Department of Transportation.

Nikodem, F., Bierig, A., & Dittrich, J. S. (2018). The New Specific Operations Risk Assessment Approach for UAS Regulation Compared to Common Civil Aviation Risk Assessment. *DLRK 2018.*

Özbek, E., Yalin, G., Ekici, S., & Karakoc, H. (2020). Evaluation of Design Methodology, Limitations, and Iterations of a Hydrogen Fuelled Hybrid Fuel Cell Mini UAV. *Energy, 213*. doi:10.1016/j.energy.2020.118757

Page, V., Dadswell, C., Webster, M., Jump, M., & Fisher, M. (2021). Towards the Determination of Safe Operating Envelopes for Autonomous UAS in Offhore Inspection Missions. *Robotics, 10*(3), p. 97. doi:10.3390/robotics10030097

Ponchak, D. S., Templin, F. L., Sheffield, G., Taboso, P., & Jain, R. (2019). Advancing the Standards for Unmanned Air System Communications, Navigation and Surveillance. *2019 IEEE Aerospace Conference* (pp. 1-9). Big Sky, Montana, USA: IEEE. doi:10.1109/AERO.2019.8742246

Pop, S., Luchian, A., Zmădu, R. G., & Olea, E. (2017). The evolution of unmanned aerial vehicles. *Review of the Air Force Academy*(3), pp. 125-132.

Rao, B., Gopi, A. G., & Maione, R. (2016). The Societal Impact of Commercial Drones. *Technology in Society, 45*, pp. 83-90. doi:10.1016/j.techsoc.2016.02.009

SESAR JU. (2019). *CORUS - U-Space Concept of Operations.* Enhanced Overview.

SESAR JU. (2020). *U-SPACE: Supporting Safe and Secure Drone Operations in Europe - Consolidated Report on SESAR U-Space Research and Innovation Results.* Luxembourg: Publications Office of the European Union. doi:10.2829/55322

SESAR JU. (2021). *About: Vision*. Retrieved September 14, 2021, from https://www.sesarju.eu/vision

SESAR JU. (n.d.). *About - Discover SESAR*. Retrieved September 05, 2021, from https://www.sesarju.eu/discover-sesar

Sickert, A. (2021, June 22). Expert interview with Ansgar Sickert from Fraport AG. (E. Pfister, Interviewer)

Stevens, M., & Atkins, E. (2020). Geofence Definition and Deconfliction for UAS Traffic Management. *IEEE Transactions on Intelligent Transportation Systems*. doi:10.1109/TITS.2020.3040595

Torens, C., Nikodem, F., Dauer, J. C., Schirmer, S., & Dittrich, J. S. (2020). Geofencing Requirements for Onboard Safe Operation Monitoring. *CEAS Aeronautical Journal, 11*(3), pp. 767-779. doi:10.1007/s13272-020-00451-0

Unifly. (2021). *About Us*. Retrieved September 14, 2021, from https://www.unifly.aero/company/about-us

von Reibnitz, U. (1992). *Szenario-Technik - Instrumente für die Unternehmerische und Persönliche Erfolgsplanung.* Wiebaden: Betriebswirtschaftlicher Verlag Dr. Th. Gabler GmbH.

VUL - Verband Unbemannte Luftfahrt. (2017). *Akzeptanzumfrage 2017.* Verband Unbemannte Luftfahrt.

VUL - Verband Unbemannte Luftfahrt. (2021a). *Analyse des deutschen Drohnenmarktes.* Verband Unbemannte Luftfahrt.

VUL - Verband Unbemannte Luftfahrt. (2021b). *Der Verband*. Retrieved September 14, 2021, from https://www.verband-unbemannte-luftfahrt.de/verband/

Wang, J., Liu, Y., & Song, H. (2021). Counter-Unmanned Aircraft System(s) (C-UAS): State of the Art, Challenges, and Future Trends. *IEEE Aerospace and Electronic Systems Magazine*, *3*(36), pp. 4-29. doi:10.1109/MAES.2020.3015537

Wingcopter. (2020). *Drone Delivery Solutions - For Humanitarian & Commercial Applications*. Retrieved September 14, 2021, from https://wingcopter.com/solutions

Wingcopter. (2021). *Wingcopter joins Flying Labs Network to support locally led drone delivery projects around the world*. Retrieved September 14, 2021, from https://wingcopter.com/flying-labs

Yamaha Motor Corporation. (2019). *Precision Agriculture: History of Yamaha Remotely Piloted Helicopters*. Retrieved 05 19, 2021, from https://www.yamahamotorsports.com/motorsports/pages/precision-agriculture-history

Zhong, C., Zhao, Z., Luo, C., Gursoy, C., Qiu, Q., Caicedo, C., . . . Solomon, A. (2020). A Cost-Benefit Analysis to Achieve Command and Control (C2) Link Connectivity for Beyond Visual Line of Sight (BVLOS) Operations. *2020 Integrated Communications Navigation and Surveillance Conference (ICNS).* IEEE Xplore. doi:10.1109/ICNS50378.2020.9222956

Ziegler, J. (2021, June 18). Expert interview with Jan Ziegler from Frequentis. (E. Pfister, Interviewer)

Appendices

Appendix A: Introduction of interview experts and their respective organisations

Richard Boden from Wingcopter

Wincopter GmbH is a German manufacturer and operator of UASs. Their business model revolves around the transport of cargo and goods. The four pillars of delivery are healthcare, parcel & e-commerce, groceries, and intersite logistics. With the W198 UAS, they are the first in the world to deploy a triple-drop system to conduct multiple deliveries in one mission (Wingcopter, 2020).

Richard Boden is head of certification at Wingcopter since July 2019. He studied Aerospace Engineering in Berlin and worked for the business jet cabin manufacturer F/List as Design Engineer. Now he is responsible for the Initial Airworthiness of the aircraft. This includes the type certification of the aircraft as well as the certification of the whole production chain (Boden, 2021).

Giancarlo Crivellaro from the European Commission

The European Commission is the executive branch of the European Union, responsible for developing and enforcing the compliance with legal frameworks. The Directorate General on Mobility and Transport (DG Move) is responsible for governing EU policy on transport via air, road, rail, maritime, and inland waterways (European Commission, n.d.).

Giancarlo Crivellaro joined the Commission in 2006 and worked in the Directorate General for Trade (DG Trade) on anti-dumping policies and trade defence instruments. He joined DG Move in 2012, first with Maritime Safety and since 2017, he works in the Aviation Safety unit. He works as a Policy Officer in charge of UAS aspects and is in charge of the preparation and adoption of the UAS regulations 2019/945 and 2019/947 (Crivellaro, 2021).

Dr. Jan Dirks from BMVI

The German Ministry of Transport and Digital Infrastructure, BMVI, is responsible for the mobility of people, goods, and data. Modes of transport include federal highways, railway, waterways, and airways. Besides the governance of this infrastructure, the BMVI is also in charge of security aspects regarding the respective transportation modes (BMVI, 2021).

Jan Dirks has been working for the BMVI for the past 17 years. He started out in Port Policy and transferred into the project group on Unmanned aviation in 2019. His tasks include the translation of EU legislation into national law, the promotion of research and development efforts, and the positioning of Germany as a leading market in the UAS economy. His focus in particular are all the regulatory aspects regarding U-Space (Dirks, 2021).

Jörg Dittrich from DLR/JARUS

The German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt), DLR, is a research centre for aeronautics and space. R&D efforts include aeronautics, space, energy, transport, security, and digitalisation (DLR, 2021).

JARUS, or the Joint Authorities for Rulemaking on Unmanned Systems, is a global group of experts gathering regulatory expertise. Their goal is to provide a comprehensive set of UAS requirements, regarding technical, safety, and operational aspects. JARUS developed the foundation on which EU regulation 2019/947 was developed (JARUS, n.d.).

Jörg Dittrich studied Aerospace Engineering at the Technical University in Braunschweig. In 2000, he continued his studies in the US, at the Georgia Institute of Technology, majoring in Helicopter Design and Electronics for UASs. Furthermore, he worked in a research facility specialised on UASs, where he helped design and build the flight electronics for a single-rotor UAS with a MTOW of 100 kg. Upon his return to Germany in 2002, he started working at the DLR at the Institute of Flight Systems. Dittrich started a Working Group on unmanned aviation, which turned into its own division in 2009 with him as department head. His experimental research on the boundaries of UAS regulation put him on JARUS' radar. Dittrich was appointed as a scientific consultant and helped develop and finalise the SORA principle. In 2020, he resigned from his job as head of department and now splits his time between the development of SORA for JARUS as part of the Leadership Team of the Working Group on Safety Risk Management, and the support of the German Federal Aviation Agency, LBA, with the implementation of the new regulatory framework (Dittrich, 2021).

Robin Garrity from SESAR JU

SESAR JU, or Single European Sky ATM Research Joint Undertaking, is an initiative by the EU and Eurocontrol to coordinate and concentrate European research activities on ATM infrastructure and harmonisation. It is part of the SESAR programme, which was established in 2004, and consists of 15 member institutions that represent various stakeholders in the industry (SESAR JU, 2021).

Robin Garrity served as Air Traffic Controller for 19 years, before working as the business manager for the ATM group at the British Science and Tech company Kinetic. He first started working with UAS in 2001. In 2012, he started working at SEASAR JU as an ATM expert and in 2015 he became the technical and operational lead on SESAR RPAS and UAS. Currently, Garrity works as the Senior External Affair Officer at SESAR JU. He has extensive experience with the European and international developments on RPAS and UAS, which qualifies him as the co-chair of the European Network of U-Space Demonstrators and as a member of ICAO's UAS Advisory Group. Additionally, Garrity fronts the SESAR RPAS interchange with European institutions, such as EASA, the European Commission, EDA, and Eurocontrol (Garrity, 2021).

Tamara Hartwich from BDL/VUL

The German Aviation Association (Bundesverband der Deutschen Luftverkehrswirtschaft), BDL, is a consolidation of stakeholders of the German aviation industry. Members include airlines, airports, air traffic control, and other service providers. Their mission is to position Germany as a site of sustainable air traffic growth, both economically and environmentally (BDL, n.d.).

The German Unmanned Aviation Association (Verband Unbemannte Luftfahrt), VUL, is a joint initiative from BDL and BDLI (German Aerospace Industries Association) with the objective to enable the sustainable and safe development of the German and European UAS market and to create a binding set of rules and standards for users and operators. They focus on the challenges of licensing commercial UASs and integrating them into existing air traffic structures. Besides the fair and safe co-existence of manned and unmanned aviation, VUL also deals with issues regarding the detection and interdiction of illegal UAS operations (VUL, 2021b).

Tamara Hartwich is the head of flight operations, technology, and safety in BDL since August 2020. She also acts as the specialist point of contact for the VUL (Hartwich , 2021).

Ralf Heidger from DFS

DFS – Deutsche Flugsicherung GmbH is the German ANSP. They steer civil and military aircraft through German airspace, process the air traffic at German airports, and collect, consolidate, and distribute aeronautical information. Within the UAS industry, they are tasked with the detection and identification of UASs around German airports to prevent safety and security threats to manned aviation (DFS, n.d.).

Ralf Heidger has been with DFS since 2001, when he began working as the department head of tower and special systems in the technical solutions division. Over the course of 15 years, he was responsible for the conception, development, and provision of the radar data processing system PHOENIX as well as other systems. In 2016, Heidger transferred into the strategy division and started implementing the UAS division together with Angela Kies and head of corporate development, Oliver Pulcher. After restructuring within the company, he ended up back with technical solutions as program manager for UTM. Now, Heidger is the lead expert on the development and/or purchasing of systems relating to UAS issues (Heidger, 2021).

Berkay Inan from Austro Control

Austro Control is responsible for the safe coordination of Austrian air traffic. The organisation is split into two main divisions. For one, they act as the Austrian ANSP and pendant to the German DFS. Additionally, they take on inspection and governing responsibilities as the Austrian Aviation Authority (Austro Control, 2019).

Berkay Inan has been working in the Aviation Authority division in the department of the Drone Competence Center since 2019. He deals with flight authorisations in the specific category and acts as project manager for national research projects, Further tasks of the Drone Competence Center include safety management measures, research and development efforts, and strategic projects. Additionally, Inan deals with customer service requests, such as questions on UAS operations and co-operations with industry partners and businesses (Inan, 2021).

Angela Kies from DFS

DFS – Deutsche Flugsicherung GmbH is the German ANSP. They steer civil and military aircraft through German airspace, process the air traffic at German airports, and collect, consolidate, and distribute aeronautical information. Within the UAS industry, they are tasked with the detection and identification of UASs around German airports to prevent safety and security threats to manned aviation (DFS, n.d.).

Angela Kies has been working for DFS since 2001, primarily in the areas of corporate-, strategic-, and business development. For the past 6 years, she shas been involved with UAS and now acts as the head of Unmanned Aircraft Systems within the department of corporate strategy. Her main objective is the safe and fair integration of UASs into the national airspace system. This also includes related issues, such as Urban Air Mobility, UAS detection at German airports, and U-Space and UTM development (Kies, 2021).

Carsten Konzock from LBA

The German Aviation Authority (Luftfahrt-Bundesamt), LBA, is responsible for the supervision of the aviation industry. This includes both public transportation and General Aviation. The LBA investigates the economic capacity, maintenance and flight operations, as well as security measures of commercial aircraft operators. Additionally, they are responsible for the licensing of pilots, training, and examination. With regard to UAS operations, LBA is tasked with the licensing of remote pilots and the supervision of the examination agencies, the issuance of LUC licences, and the audit of these certificates (LBA, 2019).

Carsten Konzock has been with the LBA since 1996. Previously, he had studied Aerospace Engineering at the Technical University Berlin. He started out in the LBA in the maintenance division for approximately 18 years. Then he worked for the President of the LBA for 5 years, and 2 years ago he was appointed to lead the department on UAS operations. His main area of responsibility is the implementation of European and national legislation (Konzock, 2021).

Ronald Liebsch from DIN/DJI

The German Institute for Standardisation (Deutsches Institut für Normung), DIN, is an independent platform for defining industrial and societal standards. They participate in research studies and help innovations reach the market in areas such as digital economy or society. DIN supports the German legislation in the implementation of European regulation. Some of the projects regarding UASs deal with the management of geodata in UTM infrastructure, the authorisation processes of UAS operations, or the detection and interdiction of UASs (DIN, 2021b).

DJI, or Da-Jiang Innovations Science and Technology Co., Ltd, is a tech company that has specialised on the manufacture of UASs in the consumer and prosumer market segment. DJI has revolutionised the hobby UAS market by providing affordable and easy-to-use quadrocopters with integrated cameras. Now they offer a broad product portfolio, ranging from a small Phantom quadrocopter for photography to the large agricultural octocopter Agras MG-1 (DJI, 2021).

Ronald Liebsch has worked for DJI between 2018 and 2021. He was responsible for the technological standardisation and the support of the policy team regarding regulatory questions. He acted as an interface between regulatory working groups, the European DJI division, and the head office in China, to assess regulatory and technological developments and their implementation into the production lines. Liebsch now works as a senior expert on aviation regulation and is also involved with DIN standardisation projects (Liebsch, 2021).

Dr.-Ing. Nora Metzner from Droniq

Droniq is a joint venture between the German ANSP DFS and telecommunications provider Deutsche Telekom that was established in 2019. Their objective is the provision, distribution, and marketing of services for UASs in Europe. Droniq pursues the utilisation of mobile networks to establish a connection between the UAS and its ground station and to provide electronic visibility (Droniq, 2021).

Nora Metzner has been working in production management at Droniq since 2020. Previously, she studied engineering and got her PhD in airport infrastructure. Now, she is deeply involved in the design and implementation of a safe and integrative U-Space infrastructure (Metzner, 2021).

Koen Meuleman from Unifly

Unifly was founded in 2015 in Belgium, starting off as a spin-off from the Flemish Institute for Technological Research VITO. They provide technical solutions regarding UTM infrastructure with the objective to integrate UASs safely and efficiently into airspace structures and provide tools for managing and visualising traffic volumes. Their three pillars focus on traffic management, operations management, and security management (Unifly, 2021).

Koen Meuleman is one of the founders of Unifly and currently acts as the expert on regulatory affairs. Previously he was involved in the founding of the Belgian Drone Association and subsequently became its president. Meuleman and his colleagues founded Unifly because they saw a need to integrate UASs into airspace structures and provide a comprehensive regulatory framework for them (Meuleman, 2021).

Ansgar Sickert from Fraport

Fraport AG is one of the leading international companies in the airport business. Their core business is managing the operation at Frankfurt International Airport. Within the UAS market, they act as a UAS operator for missions within the airport infrastructure. They also play a crucial role in the integration of UTM and ATM as the two systems converge and UASs become more likely to operate to and from airports. Furthermore, the detection of illegal UAS flight around airports is an important factor for Fraport's operations (Fraport, 2021).

Ansgar Sickert has been working for Fraport since 2001. He has studied Politics and International Relations in Great Britain. Sickert worked for Fraport in India and spent four years at the embassy in Tokyo. Since 2017 he is the airport's representative at the Airports Council International, a European airport association. He oversees all activities concerning UASs and Urban Air Mobility at the airport as well as the regulatory aspects governing UAS operations (Sickert, 2021).

Jan Ziegler from Frequentis

Frequentis is a Vienna-based company specialised in communication and information systems for control centres with safety critical tasks. They supply software solutions to customers in ATM (civil and military) and Public Safety & Transport. Their objective regarding the UAS industry is to ensure interoperability of ATM and UTM systems and to adapt ATM standards for the UTM ecosystem (Frequentis, n.d.).

Jan Ziegler joined Frequentis in 2014 when it was still called Comsoft. He worked as Teamlead on Surveillance Technologies, such as ADS-B and multilateration. In 2017 he started to work for a consultancy firm and was called back to what was now Frequentis Comsoft in 2018. Since then, he was charged with building up the UTM division within the company and has been working in the field ever since (Ziegler, 2021).

Appendix B: Open category 2019/947

UAS		*Operation*		*Operator/pilot*	
Class	*MTOW*	*Subcategory*	*Restrictions*	*Registration*	*Competence*
C0	< 250 g	A1	-avoid flying over uninvolved people if possible -no flying over assemblies of people	Only if equipped with camera/sensor	-read user manual
C1	< 900 g	A1	-minimise flying over uninvolved people -no flying over assemblies of people	Yes	-read user manual -online training Online theoretical exam
C2	< 4 kg	A2	-not over uninvolved people (30 m distance)	Yes	-read user manual -online training Online theoretical exam -self-practical training -written exam at CAA
C3 *C4*	< 25 kg	A3	-not near people -outside of urban areas (150m distance)	Yes	-read user manual -online training Online theoretical exam

Appendix C: Consistency matrix

	Regulation								UTM						Econ.				Technology						Security						PA					
	D1		D2		D3		D4		D1		D2		D		D1		D2		D1		D2		D3		D1		D2		D3		D1		D2		D3	
	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
Regulation D2 A	3	3																																		
Regulation D2 B	3	3																																		
Regulation D3 A	3	3	4	2																																
Regulation D3 B	3	3	4	3																																
Regulation D4 A	4	2	3	3	4	2																														
Regulation D4 B	2	4	3	3	2	4																														
UTM D1 A	3	3	3	3	3	3	4	3																												
UTM D1 B	3	4	2	4	3	3	3	3																												
UTM D2 A	4	3	3	3	3	3	4	3	3	4																										
UTM D2 B	2	3	3	3	3	3	2	3	3	3																										
UTM D3 A	4	3	3	3	4	3	3	3	3	2	3	3																								
UTM D3 B	2	4	3	4	3	3	4	3	3	3	3	4																								
Econ. D1 A	3	3	5	1	5	1	4	2	3	3	3	3	3	3																						
Econ. D1 B	3	3	2	4	2	4	2	3	3	3	3	3	3	3																						
Econ. D2 A	3	3	4	4	3	3	3	3	3	3	3	2	3	4	3	3																				
Econ. D2 B	3	3	2	4	3	3	2	3	3	3	3	3	3	4	2	3																				
Technology D1 A	5	2	3	3	3	3	4	3	4	3	3	3	3	3	3	3	3	3																		
Technology D1 B	2	3	3	3	3	3	2	3	3	3	3	3	3	3	3	3	3	3																		
Technology D2 A	5	2	3	3	3	3	5	1	3	3	3	3	3	3	3	3	3	3	4	2																
Technology D2 B	1	4	3	3	3	3	1	5	3	3	3	3	3	3	3	3	3	3	3	4																
Technology D3 A	3	3	3	3	4	3	3	3	3	3	3	3	3	3	3	3	3	3	4	3	3	3														
Technology D3 B	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	3														
Security D1 A	3	3	3	3	3	3	4	3	4	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3												
Security D1 B	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3												
Security D2 A	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	5	1										
Security D2 B	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	4										
Security D3 A	3	3	3	3	3	3	4	3	3	3	3	3	3	3	4	3	3	3	4	3	3	3	3	3	3	3	2	3								
Security D3 B	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	3	3	3	3	3	3	3	3	3	3	3	4	3								
Public acceptance D1 A	3	3	3	3	3	4	3	3	3	3	3	3	3	3	2	4	3	3	3	3	3	3	3	3	3	3	3	3	3	3						
Public acceptance D1 B	3	3	4	3	4	2	3	3	3	3	3	3	3	3	4	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3						
Public acceptance D2 A	3	3	2	4	3	3	2	3	3	3	3	3	3	3	1	5	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3				
Public acceptance D2 B	3	3	4	3	3	3	3	3	4	3	3	3	3	4	4	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3				
Public acceptance D3 A	3	2	4	3	4	3	4	3	3	3	3	3	4	3	3	3	4	3	4	3	4	3	3	3	5	1	5	1	5	1	3	3	3	3		
Public acceptance D3 B	3	3	1	3	3	4	3	3	3	3	3	3	3	3	2	4	3	3	3	3	3	3	3	3	2	5	2	5	2	5	3	3	3	3		
Public acceptance D4 A	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	4	3	3	3	3	3	3	3	3	3	3	3	3	3	3	4	2	3	3	3	3
Public acceptance D4 B	3	3	4	2	4	2	3	3	3	3	3	3	3	3	4	2	3	3	3	3	3	3	3	4	3	3	3	3	3	3	2	4	2	3	3	3

- 5 coherent and correlated
- 4 coherent
- 3 neutral
- 2 slightly inchoerent
- 1 incoherent
- ☐ conflict potential

Appendix D: Scenario bundles

		Scenario A	Scenario B
Area	Driver	Alternative	Alternative
Regulation	D1	A	B
	D2	A	B
	D3	A	B
	D4	A	B
UTM	D1	A	B
	D2	A	B
	D3	A	B
Econ	D1	A	B
	D2	A	B
Tech	D1	A	B
	D2	A	B
	D3	A	B
Security	D1	A	B
	D2	A	B
	D3	A	B
PA	D1	B	A
	D2	B	A
	D3	A	B
	D4	B	A