Transportation Research Part A 157 (2022) 40–58

Contents lists available at ScienceDirect

Transportation Research Part A

journal homepage: www.elsevier.com/locate/tra

Economic policy choices and trade-offs for Unmanned aircraft systems Traffic Management (UTM): Insights from Europe and the United States

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A R T I C L E I N F O

Keywords:
Unmanned aircraft systems Traffic Management (UTM)
Unmanned Aircraft Systems (UAS)
Drones
Air Traffic Management (ATM)
UTM concept
Economic regulation

A B S T R A C T

Despite expectations of substantial growth in Unmanned Aircraft Systems (UAS, also called drones) there is currently no large-scale system in place to manage UAS operating in shared airspace. Many countries are developing UAS Traffic Management (UTM) concepts which, unlike conventional air traffic management (ATM), seek to foster a competitive market involving many private actors and service providers and which rely on the cooperative and distributed management of UAS. This paper focusses on the economic policy dimensions of UTM. It describes the main participants, activities and commercial interactions of the emerging UTM concepts in the European Union and the United States. Building on these descriptions, we then consider some of the fundamental choices and trade-offs confronting policymakers when developing an economic policy framework for UTM such as: which activities should be competitive; how can access to scarce airspace be allocated in a safe, fair and efficient way; on what commercial terms will data be shared among participants; what infrastructure can cater for large scale UAS operations; and to what extent should the economic regulatory frameworks for UTM and ATM be aligned.

1. Introduction

Unmanned Aircraft Systems (UAS), commonly referred to as drones, are expected to transform aviation and in so doing yield substantial economic, social and development benefits (Giones and Brem, 2017; Magistretti and Dell'Era, 2019). In Europe, UAS are seen as a driving force for economic development with forecasts suggesting an economic impact exceeding €10 billion per year in the decades to come (SESAR, 2016). In the United States, the Federal Aviation Administration (FAA) has referred to the enormous opportunities for UAS particularly at low altitudes across a myriad of activities and sectors (FAA, 2020a). While the potential future uses of UAS are immense, the pace and scale of development of UAS will not be determined by technology alone. The economic and regulatory policy framework will also play a critical role in fostering the commercial incentives to develop and supply UAS services and to invest in the infrastructure necessary to cater to UAS operations. These frameworks can also help to promote societal acceptance that UAS can be safely managed in urban areas (Kopardekar et al., 2016; Aydin, 2019).

UAS Traffic Management (UTM) is seen as a critical enabler of UAS operations ranging from very low to very high altitudes (ICAO, 2019a). In general terms, UTM refers to a system and a set of services that provide the necessary information and procedures to enable

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https://doi.org/10.1016/j.tra.2022.01.006
Received 1 September 2020; Received in revised form 7 January 2022; Accepted 13 January 2022
Available online 31 January 2022
0965-8564/

safe flight for unmanned aircraft in shared and segregated airspace. UTM is a novel and rapidly evolving concept, and one where international and national policies are still being developed (Ali, 2019; McCarthy et al., 2020). Although there are important differences in the UTM concepts being developed around the world, a key unifying element is a reliance on a more distributed, competitive and automated traffic management system. This differs from the current more centralised, monopolistic and human-centric systems used for manned air traffic management (ATM).

Despite its central importance, only a limited number of studies have considered the commercial and economic policy aspects of UTM (Jiang et al., 2016; Kopardekar et al., 2016; Ali, 2019; McCarthy et al., 2020; Merkert et al., 2021; ITF, 2021). Most existing research on UTM tends to focus on technical design and interoperability issues (see Bijjahalli et al. (2020) or Otto et al. (2018) for recent reviews). Another stream of research investigates the importance of safety in the development of a UTM, for instance by mitigating the risks of collisions among UAS or with manned aircraft (Mott et al., 2020; Zhang et al., 2020) or by investigating the risks of intrusions in airports (Wang et al., 2019; Wendt et al., 2020). These contributions provide valuable insights about the safety, technical and operational design aspects of a UTM, but typically do not engage with important UTM economic policy issues.

Against this background, this paper has three aims. First, it starts by framing a UTM concept as a policy construct that involves a myriad of fundamental economic policy choices about: which services should be mandatory; which activities should be open to competition; what activities/services be provided by the state or alternatively be provided by private entities; how competing demands for airspace can be negotiated and resolved in an safe, efficient and fair way; what commercial terms should critical operational data be shared among different airspace users (both manned and unmanned) in real time; and what is the role for economic regulation in overseeing and managing UTM. In framing a UTM concept as a series of policy choices, we draw a direct comparison with the policy frameworks that apply to ATM for manned aircraft. Second, we describe the key attributes of the UTM concepts under development in the United States (US) and the European Union (EU), highlighting the main participants, activities, services and institutions of each concept. This reflects the fact that the UTM concepts are explained in considerable detail in policy documents, and also because a number of jurisdictions appear to be combining elements of the US and EU concepts in developing their own approaches. Third, the paper builds on this description of the main UTM concepts, actors and services to then identify and explore the main economic policy issues which are critical to the future deployment of UTM.

While the paper identifies key economic policy considerations and trade-offs it does not present a universal UTM economic policy framework that could be applied across all jurisdictions. In part, this reflects the nascent state of UTM and the fact that any policy framework will need to evolve and adapt to actual operational and market developments as they emerge (e.g., in terms of the pace and scale of operations; the types of commercial actors involved; the intensity of competition etc).[1] It also reflects the fact that the issues confronting policymakers differ across jurisdictions and reflect fundamental choices about factors such as the relative roles of the state vis-a-vis competitive market actors in providing services, the approach to managing and regulating shared airspace including the interaction between ATM and UTM policy frameworks, and the level of safety risk a jurisdiction is prepared to tolerate.[2] In addition, the analysis presented is largely qualitative in nature, reflecting the fact that there is currently no quantitative data or analysis available that we are aware of that presents estimates of the economic costs or benefits of developing and operating UTM.[3] Given that the focus of this paper is principally on the economic policy aspects of UTM, we have assumed that a certain baseline or target level of safety will be mandated or required. However, it is recognised that, in practice, there can be important interactions between economic and safety policies: higher safety standards (or lower levels of risk tolerance) typically entail higher costs and stricter regulatory requirements being placed on actors, which impact economic incentives (Oster et al., 2013). While we do not engage with the safety aspects of UTM in detail, we recognise that it is a critically important matter and in the concluding section set out some areas for further consideration to this end.

This paper comprises seven sections. Section 2 sets out the reasons why a dedicated UTM system is needed. Section 3 provides an overview of the main conceptual building blocks of the UTM concept, while section 4 describes how these key building blocks are being characterized and articulated the EU and the US. Section 5 discusses areas of apparent asymmetry in the policy frameworks for ATM and UTM. Section 6 then sets out and explores some fundamental economic policy issues likely to confront policymakers as UTM policy evolves. Section 7 presents conclusions.

2. The need for a dedicated UTM

The rationale for dedicated UTM systems is principally driven by three factors: forecasts of rapid growth in the number of UAS; the varying and complex nature of the UAS operations; and assessments that existing ATM systems are unable to ‘scale up’ to accommodate UAS operations.

[1] Connected Places Catapult (2021) describes this interaction as a “chicken and egg” problem of inter-dependencies amongst UTM technologies, standards, and regulations, which has prevented any one level from fully maturing.

[2] ICAO (2020) captures the diversity in key policy choices observing that “*States do not all share a common vision of how to organize and manage UTM Service Providers (USP), or even if or how to enable multiple USPs to operate together in the same airspace*” and that “*States are already providing UTM solutions with various levels of service (*e.g. *registration, identification and environment data), but the full capabilities, responsibilities and roles still need to be clarified and harmonized.*”

[3] A report by the US Government Accountability Office (2019) noted that the: “*FAA has not yet estimated the costs of developing or implementing this system because, according to FAA officials, the agency is still many steps away from developing the core infrastructure and regulatory requirements.*”

2.1. Expected rapid growth of UAS

According to ICAO (2019b), UAS operations are evolving at a fast pace, and in many parts of the world the predicted growth in the volume of UAS operations across both controlled and uncontrolled airspace could potentially soon be on a scale comparable, if not greater, to that of present-day manned air traffic. In the US, the Federal Aviation Administration (FAA, 2020a) estimates that the combined recreation and commercial UAS fleet is expected to reach 2 to 3 million by 2023 from less than 1.5 million in 2018. Europe is also expected to experience substantial growth in the use of commercial and recreational drones. According to SESAR (2016), in Europe, the number of recreational UAS is to increase from around 1 to 1.5 million in 2016 to some 7 million by 2035, while the number of UAS used for commercial and governmental missions should increase from 10,000 units to 395,000 units over the same time horizon.

Initially developed for military purposes in the 1960 s, UAS have gradually extended their scope and usage leading to the development of a "drone industry" (Giones and Brem, 2017). With the development of new technologies and the emergence of dedicated actors (manufacturers, operators, etc.), the UAS industry has rapidly evolved over the recent years leading to new applications. Some forecasts estimate that the global UAS market value will increase from 25 bn dollars in 2018 to 70 bn dollars in 2029 (BIS Research, 2019). Among the sectors where UAS are expected to feature prominently include: public sector services, health and education, agriculture and mining, gas and electricity and transport and logistics (PricewaterhouseCoopers, 2018). Ali (2019) lists the most popular applications of UAS including precision agriculture, fishery protection, package delivery, infrastructure monitoring, aerial photography and video, land surveying, environmental assessment, security surveillance, emergency response for medical services, forest fire detection, search and rescue, contamination measurement, recreation and many more applications to emerge in the near future. As the breadth of services delivered or performed by UAS increase over time (Magistretti and Dell'Era, 2019) so do the number of UAS in the sky that need to be managed.

2.2. Different uses of airspace

UAS will likely utilise airspace in different ways to manned aircraft, with many flying at lower altitudes and operating in areas which hitherto have not been used for aircraft (Hassanalian and Abdelkefi, 2017). Commercial UAS in particular are expected to make extensive use of low altitude controlled airspace in densely populated urban areas. The presence of large numbers of small, undetectable UAS below this minimum height poses risks about the protection of persons and property on the ground, but also raises a challenge of how to safely integrate UASs and manned aircraft at this low level particularly in controlled shared airspace, for instance near airports (Zhang et al., 2020). Some UAS are also expected to operate at higher altitudes (above 600ft), which raises its own challenges insofar as they may have to adapt to a controlled air traffic management environment to avoid collisions with manned aircraft (Wang et al., 2019). For example, it has been suggested that Facebook, Google and others are looking at the use of high-altitude unmanned aircraft to provide a 4G network in remote areas around the world (EASA, 2018a). As these UAS will also have to descend into lower airspace on return from their operations, they will have to be safely integrated with users of that airspace. UAS will thus have to co-exist with manned aircraft which means that there must be a means for manned and unmanned aircraft to be able to identify, and respond to, the movements of one another particularly when UAS operate beyond the visual line of sight (BVLOS).

2.3. Limited ability of ATM to 'scale up' to accommodate UAS

Given forecasts of rapid UAS growth, policymakers in many parts of the world are confronting the question of how to effectively manage UAS operations, particularly in shared and segregated airspace. In principle, one option might be to expand and utilise the conventional air traffic management (ATM) systems used for manned aircraft. However, for a range of reasons, policymakers in most jurisdictions have concluded that ATM systems will not be able to 'scale up' to accommodate UAS operations, and that a new conceptual paradigm will need to be developed given the expected volume of UAS traffic and the diverse nature of UAS operations (Jiang et al., 2016). As ICAO (2020) notes: "*whilst segregated airspace has been an initial solution to accommodate a safe operating environment it does not enable future integration of manned and unmanned aviation, nor does it enable high density UAS operations*."

In the US, the FAA has noted that because the number of daily operations could reach into the millions this would stretch the National Airspace System beyond its current requirements, and that the number, type and durations of UAS operations cannot cost effectively be managed using the existing ATM system infrastructure (FAA, 2020a). In Europe, ATM systems are also considered to be reaching their limits, and as such, cannot be seen as the only appropriate means to safely and efficiently manage the upcoming UAS traffic (SESAR, 2018a; Vidović et al., 2019). There is also a perception that conventional ATM might not be well suited to UAS safety and management issues, particularly when it involves integrating UAS in urban areas where they are able to fly near people and buildings (Ali, 2019) and for which the social acceptance remains limited (Aydin, 2019; Clothier et al., 2015; Torija et al., 2020).

3. Laying the foundations of a dedicated UAS traffic management (UTM)

3.1. Different conceptions of UTM

While there is a broad agreement about the need to develop a dedicated UTM to cope with the expected exponential growth of UAS services, no common and precise definition of UTM is used across jurisdictions.

In the academic literature, most contributions on UTM have typically adopted a technological stance focusing on algorithms to facilitate the navigation of UAS or avoid conflict situations (see Bijjahalli et al. (2020) or Otto et al. (2018) for a recent review). As several institutions or governments around the globe began to tackle the question of the development of a UTM, some contributions have started to focus on identifying the main building blocks of what should comprise a UTM (Kopardekar et al., 2016; Jiang et al., 2016; Ali, 2019; McCarthy et al., 2020). Most contributions build on the broad and consensual definition of UTM provided by Kopardekar et al. (2016) which defines UTM as a system that aims to safely and efficiently enable UAS operations in the low altitude airspace by: allowing UAS operators to submit flight plans to execute a specific task; determining how to safely enable single or multiple UAS operations either within visual line-of-sight (VLOS) or beyond visual line-of-sight (BVLOS); and coordinating airspace services across many operators.

By contrast, perhaps reflecting the early and evolving stage of development, there does not appear to be a common notion of UTM adopted by policymakers. For example, as shown in Table 1, the term UTM can be used to refer to: a system; a set of services; particular functional attributes (automated and digital); as a subset of ATM; or in relation to other airspace and/or airspace users (e.g. manned airspace and users). The scope of UTM can also be defined as limited to traffic management for specific areas of segregated airspace (e.g.: below 500 feet) or more widely capturing traffic management of shared airspace as well.

Notwithstanding differences in the specific definitions of UTM applied across jurisdictions, it is possible to identify some common elements in the UTM concepts that are being developed.

3.2. Identifying the key elements of a UTM concept

A UTM concept is a representation of the different activities, roles, interactions and responsibilities among different entities and participants. The emerging nature of UTM means that different jurisdictions are developing UTM concepts to suit their particular conditions. However, in general terms, it is possible to identify a number of common elements or building blocks of all UTM concepts (Jiang et al., 2016; Ali, 2019). The building blocks can be categorised under three headings: UTM services; UTM participants; and local UTM networks.

To function effectively and safely all UTM concepts require that certain traffic management, navigation, data and coordination services be supplied to UAS operators. Table 2 identifies the typical services that will be supplied in most UTM concepts. While all of these broad types of services feature (albeit with different names) in UTM concepts, the precise boundaries between services will differ across UTM concepts. For example, in some jurisdictions UAS traffic management services might include the registration and validation of UAS operators, while in other jurisdictions it could be classified as a Common Information Service. Some services may also be combined or 'bundled' together, for example UTM traffic services could be combined with certain supporting or value-added services (such as weather services) in some UTM concepts.

Table 3 lists the activities undertaken by different UTM participants, including the typical services they provide and examples of entities that would provide such services. Three observations can be made about Table 3. First, UTM involves a wider range of participant types than conventional ATM where a single entity often undertakes many of these functions or activities. Second, participants providing similar commercial services will often be privately owned and directly compete with one another to attract UAS operators and other users. Third, while some form of Common Information Service features in all UTM concepts, how these services will be provided differs among UTM concepts. As discussed in section 6, some UTM concepts envisage provision by a centralised Common Information Services Provider, while other UTM concepts envisage these services as potentially being implemented as part of a distributed system.

The (simplified) interactions between these UTM participants are summarized in the Fig. 1 which shows how the different actors jointly create a UTM concept. As shown in Fig. 1, a notable feature of most UTM concepts is that there is no direct communication channel between an ATM Service Provider and a UAS Operator. Rather all of the information about ATM system operations is provided to a Common Information Services Provider or a UTMSP in the first instance, who then determines the constraints in which a UAS operator can safely operate. In addition, while in Fig. 1 a UAS Operator and UTM service provider are shown as distinct entities, in practice these activities could be integrated such that a single entity is both a UAS operator and a UTM Service Provider (e.g.: large logistics or package delivery UAS Operators may choose to act as their own UTM Service Provider).

Fig. 1 also highlights the fact that many UTM concepts envisage the development of a local UTM network where UTM Service Providers (UTMSPs) operating in the same airspace will cooperate to negotiate flight plans and maintain direct connections to one another to share data in real-time. As discussed in section 6, while local UTMSP networks are seen as a critical enabler of data sharing among overlapping UTMSPs, questions about the commercial terms and conditions on which UTMSPs will share data within a network have not yet been considered.

Table 1
Different UTM terms and conceptions.

Jurisdiction	Concept	Definition
International (ICAO, 2019a)	Unmanned aircraft system traffic management (UTM)	A specific aspect of air traffic management which manages UAS operations safely, economically and efficiently through the provision of facilities and a seamless set of services in collaboration with all parties and involving airborne and ground-based functions
	UTM system	A system that provides UTM through the collaborative integration of humans, information, technology, facilities and services, supported by air, ground or space-based communications, navigation and surveillance
European Union (EASA, 2018b)	U-Space	'U-space' means a set of services provided in an automated way through a digital system in a volume of airspace designated by a Member State.
	U-Space airspace	'U-space airspace' means the volumes of airspace designated by Member States, where U-space services are provided, or where certain capabilities from the unmanned aircraft and actions from the unmanned aircraft operators are required, or both.
United States (FAA, 2020a)	Unmanned Aircraft System Traffic Management (UTM)	The term 'UTM' refers to a set of federated services and an all-encompassing framework for managing multiple UAS operations. These services are separate, but complementary to those provided by the ATM system, and are based primarily on the sharing of information between Operators on flight intent and airspace constraints. UTM can offer services for flight planning, communications, separation, and weather, among others.

Table 2
Broad typology of UTM services.

Service	Functionality
UAS traffic management (UTM) services	• Allow a UAS Operator to plan and execute missions. • Ensure that flights do not conflict with other manned or unmanned flights. • Involve the relaying of any dynamic operating restrictions to UAS Operator. • Collect data during a UAS mission which is then shared with other parties.
Supporting or value-added services	• Can include weather services, geographical information services (terrain and obstacle data), surveillance data and a range of other enhanced connectivity or navigation services. • These services are typically not mandatory.
Common Information Services (CIS)	• At a minimum, include maintaining a central data repository (such as a Flight Notice Board or a Flight Information Management System) which a range of private and public participants can access, and include information about any flight restrictions and constraints. • Could also collect and distribute information about UAS operations, or encompass UAS registration and validation services to ensure that the UAS operator is authorized to fly. • Are expected to be provided digitally and communicated on a high-frequency basis.
ATM services	• Facilitate communication of information between a UTM system and the ATM system. • Enables the strategic de-confliction of manned and unmanned flights to potentially enact operating risk-mitigation procedures in-flight (i.e. tactical deconfliction).
UTM communications and navigation infrastructure services	• Allow constant digital transmission and broadcasting of data between participants such as UAS Operators, UAS traffic management services providers and Common Information Services.

4. UTM concepts and policy frameworks in the EU and the US

4.1. The UTM concept in the European Union: U-Space

Since 2018, European policymakers have been developing an institutional and regulatory framework to establish minimum rules and services for the immediate implementation of a UTM concept (known as U-Space) in all EU Member States.[4] An overarching aim of the U-Space policy framework is to create a competitive U-space services market that will ensure fair access to UAS Operators and attract business investment in the drone and U-space services markets (EASA, 2020).

EU Member States can designate a 'U-Space airspace' after making an airspace risk assessment which involves an evaluation of operational, safety and security risks, the type, complexity and density of the traffic, the location, altitudes or heights and the airspace classification. Accordingly, there can be multiple 'U-Space airspaces' in operation within a single country at any point in time, as well as cross-border U-Space airspaces. Where a U-space airspace is designated within controlled airspace then an ATM provider (ATMSP) will be responsible for manned aircraft, as well as for the dynamic reconfiguration of the airspace within the designated U-space airspace to ensure that manned and unmanned aircraft remain segregated. However, only UTM service providers (known as U-space

[4] In October 2019 the European Union Aviation Safety Agency (EASA) issued a consultation on a high-level regulatory framework for the U-Space (EASA, 2018a, 2018b). It received over 2,500 comments on the draft Opinion and in March 2020 issued a revised Opinion, draft Regulation proposal to the Commission, and an accompanying Impact Assessment (EASA 2020, European Comnmission 2020). A final Reguation was issued in April 2021 (European Commission, 2021a, 2021b).

Table 3
Typical UTM participants.

Participant	Core function and activity	Services provided	Examples of entities providing such services
UAS operator	• Individual or entity licensed to operate UAS.	• Current services include photography and videography; infrastructure inspection; transport and logistics; search and rescue missions; and organ delivery.[a]	• Individuals, commercial enterprises, public sector bodies, military or aid organizations.
UTM Service Provider (UTMSP)	• Offers certain UTM services which enable UAS operators to safely and efficiently integrate UASs into the national airspace.	• Provides core UTM services, such as communication and navigation services, network identification, geo-awareness etc. • Service coverage could vary significantly with some UTMSPs focused on particular regions or types of user.	• Known as U-Space service providers (USSPs) in the EU, and UAS Service Supplier (USS) in the US . • Examples of entities that provide or are developing UTM services include: Airbus UTM; Airmap; Altitude Angel; Google Wing OpenSky; Thales Ecosystem UTM; Terra Drone UTM; Unifly.
Supporting or value added service provider	• Provides additional services to support a UAS operator, UTMSP or other participants.	• Additional services can include weather, terrain and obstacle data along with tracking and conformance services and surveillance data.	• Providers of weather services (such as Meteorological offices), enhanced surveillance data or tracking and conformance services.
Common Information Services provider	• Facilitates the central collection or the exchange of data between relevant UTM participants to enable safe, fair and efficient access to airspace.	• At a minimum this could include operating a Flight Notice Board or Flight Information Management System (FIMS).	• In the US, the FAA will develop a Flight Information Management System (FIMS). • In the EU, Common Information Service (CIS) providers will provide certain common information services. Such CIS providers may be designated to provide services on an exclusive basis.
ATM Service Provider (ATMSP)	• Is responsible for traffic management in controlled airspace.	• ATMSP interfaces with UTMSPs and the Common Information Services provider to assure safe integration of manned and unmanned aircraft particularly within the vicinity of airports.	• Designated ATMSPs in different countries such as the FAA (US); DFS (Germany); Airservices Australia; Navcanada; NATS (UK).
UTM infrastructure service provider	• Owns and operates the infrastructure which facilitates communications and interactions between different participants.	• Infrastructure should allow for communications between UAS Operators and UTMSPs, and the infrastructure used by the Common Information Services provider.	• Mobile telecommunications companies. • Operators of existing ground-to-air infrastructures.
Public/local authorities	• Are expected to play necessary roles to coordinate access to airspace or potentially impact operations.	• Some public authorities may be required to dynamically manage low-level airspace in the case of emergencies or events. • Public authorities may also seek to manage airspace segregation, and put in place Temporary Flight Restrictions (TFR).	• Government departments, local authorities, the police, the military, and other agencies.
Regulator	• Is responsible for the regulation of aviation safety and determining policy for the use of airspace.	• Provides a regulatory and operational framework for UTM, this could include controlling airspace authorisation and defining airspace allocation and constraints. • May also have a role in licensing, setting standards or overseeing the quality and performance aspects of other participants in the space.	• Civil or Federal Aviation authorities in many countries.

[a] Negron (2019) identifies a wide range of other potential future UAS use cases.

service providers) will be responsible for the provision of U-space services to operators of unmanned aircraft in that U-Space.

There are two broad types of U-Space services: mandatory services and supporting services. Mandatory U-space services must be provided by UTMSPs to UAS operators. The four mandatory U-space services for all designated U-space airspaces are: network

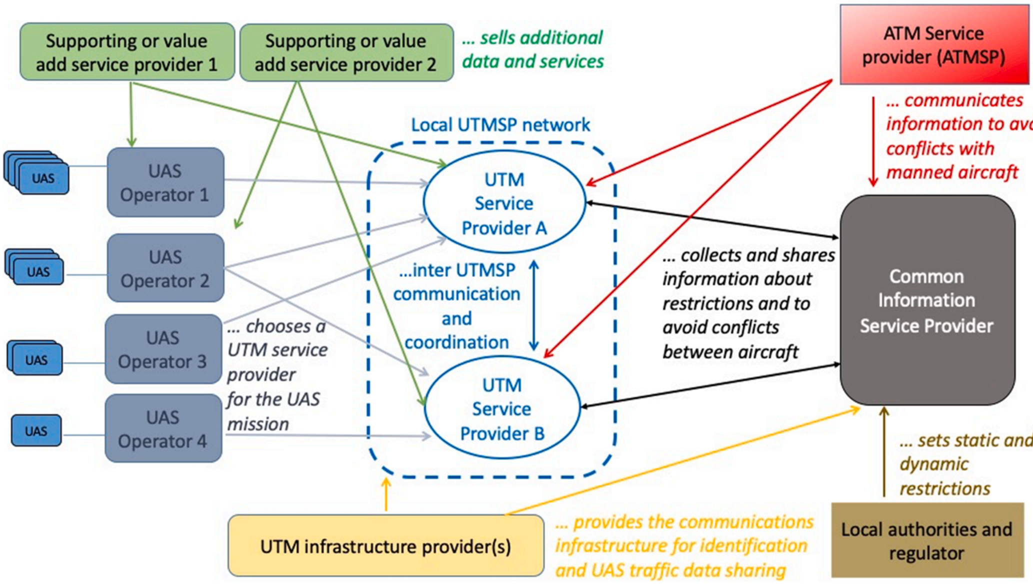

Fig. 1. Main participants and their (simplified) interactions within a UTM Concept.

identification service (which allows for continuous remote identification); geo-awareness (provides information about where a UAS is allowed to fly and where not); flight authorisation service (authorises the UAS to enter U-space airspace); and traffic information service (provides information on other known or observed air traffic which may be in proximity to the position or intended route). In addition to the mandatory U-Space services, the European Union has identified two supporting services including: a weather information service; and conformance monitoring service (which checks the current track of each UAS with respect to its planned mission considers the existence of new geo-fencing areas dynamically established).

All UAS Operators must utilise the necessary U-space services to exchange required information within the U-space airspace in which it is being flown. UAS Operators are therefore required to contract with a certified UTMSP or provide U-space services themselves (in which case they are considered to be a U-space service provider). UTMSPs, in turn, are responsible for providing at least the four mandatory services to UAS operators and to handle air traffic data without discrimination, restriction or interference, independently of its sender or receiver, content, application or service, or terminal equipment. UTMSPs are also required to exchange information, including air traffic information of the UAS, amongst themselves, and adhere to an open acceptable communication protocol.

Another critical element of the U-Space concept is the Common Information Function (CIF) that provides trusted information of sufficient quality, integrity and accuracy to UTMSPs and other users such as ATM/ANSPs. [5]The Common Information Function will be performed by Common Information Service (CIS) providers (noting that there can be more than one U-Space in a given Member State). The Regulation notes that Member States may be able to designate a single CIS provider on an exclusive basis for all of some or all of the U-space airspaces under their responsibility.[6]

As discussed in section 6, the possibility of CIS providers being privately owned and operated also appears to be allowed under the U-Space concept. However, while the draft Regulation included a requirement that the prices charged for the CIS service be subject to cost-based regulation overseen by a competent authority (on the basis that the CIS provider in a designated U-Space will be a monopoly), this is not a feature of the final Regulation. No regulatory oversight of the prices charged by CIS providers is required under the final Regulation notwithstanding the fact that some CIS services could be provided by a single entity on an exclusive basis.

Finally, it is expected that U-Space users will be directly charged for services they utilise by different providers to cover costs, and that the costs will depend on the types of UAS operations and quality of services provided. Although there are no estimates of the costs of U-Space in the public domain, the European Aviation Safety Agency has said that it expects that U-space costs will be lower than current ATM costs because it will be based around digitalised and automated services and will utilise existing infrastructure (EASA, 2019)

[5] Among the types of information that the CIS must make available include: horizontal and vertical limits of the U-space airspace; UAS capabilities and performance requirements set by the competent authorities for a given U-space airspace; a list of certified U-space providers offering services in the U-space airspace; adjacent U-space airspace(s); UAS geographical zones relevant to the U-space airspace; and static and dynamic airspace restrictions defined by the relevant authorities and permanently or temporarily limiting the volume of airspace within the U-space airspace where UAS operations can take place.

[6] The draft Regulation included the more definitive statement that: "*For safety reasons, there can only be one common information service provider per designated U-Space airspace*". See European Commission (2020).

4.2. The UTM concept in the US: FAA NextGen UTM concept of operations

In the US, the FAA issued an overarching UTM Concept of Operations in 2018 which set out a vision, and associated operational and technical requirements, for a UTM system (FAA, 2018). The FAA's UTM Concept of Operations builds on work by NASA and the FAA on a UTM architecture needed to support a federated[7] set of services which are separate, but complementary to ATM services, and are based primarily on the sharing of information between UAS Operators on flight intent and airspace constraints (FAA, 2020a).

The FAA UTM Concept was originally focussed on UTM operations below 400 feet above ground level, but increasingly addresses more complex UAS operations within and across both uncontrolled and controlled airspace environments. As in the EU, the UTM concept does not seek to designate specific blocks of airspace as covered by UTM. Rather it requires that all UAS Operators that do not receive ATM separation services participate in UTM at some level using applicable services to meet the performance requirements of their operations. The applicable services required varies based on the type and location of the intended operation and the associated communication, navigation, and surveillance (CNS), and other operational needs. For example, UAS Operators that plan to fly beyond the visual line of sight (BVLOS) are required to share operation intent data with other operators/airspace users via a UTMSP (here called a UAS Service Supplier (USS)) network. At a minimum this data includes information about 'Operation Volume segments' of the intended flight path which are 4D blocks of airspace that have specified entry and exit times for the UAS Operator. These volumes may be stacked in sequence such that one volume's exit time coincides with the entry time of an adjacent volume along the flight path. UAS performance capabilities will typically determine the size of Operation Volume segments, with UAS of higher navigational performance being able to maintain flight within smaller volumes as compared to lower-performance UAS.

Three broad categories of service are identified in FAA's UTM Concept of Operations. The first set of services are mandatory and are required to be used by operators because of a FAA regulation and/or have a direct connection to FAA systems. The second set of services are those which may be used by an Operator to meet all or part of a FAA regulation. The third set of services are those which provide value-added assistance to an Operator, but are not used for regulatory compliance. UAS Operators have the option to self-supply all of these services or can choose to use a third party UTM service provider (i.e., a UAS Service Supplier (USS)) to support their operations.

In the FAA's UTM Concept, a UAS Operator is the person or entity responsible for the overall management of their operation.[8] This includes meeting regulatory responsibilities; planning flight/operations; sharing operation intent information; and safely conducting operations using all available information. USS are entities which assist UAS Operators with meeting UTM operational requirements, and ensure information sharing across the UTM community. Among the functions of a USS are: to act as a communications bridge between federated UTM actors; to provide the Operator with information about planned operations in and around a volume of airspace; to archive operations data in historical databases for analytics, regulatory, and Operator accountability purposes. USS are expected to be privately owned and operated. In addition to the services provided by USS, UAS Supplemental Data Service Providers will provide essential or enhanced services to Operators and USSs.

A key element of the FAA's UTM concept is the 'USS network' which is amalgamation of USSs connected to each other to facilitate inter-USS communication and coordination that will allow for the cooperative management of low altitude UAS operations without direct FAA involvement. Specifically, a USS Network will allow for the sharing of operational intent data, airspace constraint information, and other relevant details across the network to ensure shared situational awareness for UTM participants. The protocols will be based on a shared paradigm, with industry agreed upon methods for de-confliction and/ or negotiation, and standards for the efficient and effective transmission of intent and changes to intent.

Common Information Services in the FAA's UTM concept is provided through a Flight Information Management System (FIMS), which will support information exchanges and protocols between UTM participants and FAA systems, and other stakeholders (government agencies etc). Although the FAA will develop and manage the FIMS, it does not envisage itself as having an active operational role in UTM. Rather it sees it primary operational role as being to provide FAA-originated airspace constraint data through FIMS to airspace users (e.g., airspace restrictions, facility maps, active Special Activity Airspace). As such, the FAA does not foresee using FIMS to receive data – intent data or otherwise – from the USSs during nominal operations. During off-nominal situations, the USS notifies the FAA of an event via FIMS only if the situation meets the criteria for FAA/ATC attention. In other words, individual UAS Operators are responsible for managing their own operations safely within the real-time constraints established by the FAA. This allocation of responsibilities is seen as being consistent with the view that UTM should be a community-based, cooperative traffic management system, where the Operators and entities providing support services are primarily responsible for the coordination, execution, and management of operations, with 'rules of the road' established by the FAA (FAA, 2020a).

The costs of UTM development and operation are largely unknown and have not been quantified, although concern has been expressed that current funding levels for UAS integration efforts might be so large as to erode resources for activities related to manned aviation (GAO, 2019). In terms of charging and cost recovery, while the FAA's costs of providing ATM services are funded through a combination of excise taxes on airline tickets, aviation fuel, and cargo shipments, various options are being considered to cover the costs of the FAA's UAS activities, including the possibility of the introduction of user fees.

[7] The term federated is defined as: *"a group of systems and networks operating in a standard and connected environment"* (FAA, 2020a).

[8] A distinction is made between a 'UAS Operator' and a 'Operator'. The term 'Operator' includes all airspace users that elect to participate in UTM, which can include manned aircraft Operators

5. Differences between ATM and UTM concepts and policy frameworks

The long-term aspiration of the International Civil Aviation Organization (ICAO) is that current distinctions between specific airspace (controlled or uncontrolled), systems (such as ATM or UTM) or vehicles (manned, unmanned or autonomous) will become redundant, and as a result policy will converge to allow for the flexible accommodation of all types of operation at all altitudes (ICAO, 2019a). Some have suggested that this might involve the replacement of traditional ATM with more service-oriented UTM architecture (Evans et al. 2020). However, in the short-term, policy makers need to decide how to best integrate UAS operations within existing airspace policy, including the ATM policy framework. This section discusses five key areas of difference between current UTM and ATM policy frameworks.

5.1. Coordination structures: centralised vs decentralised

While UTM and ATM services are generally perceived as being complementary to one another, at least over the short term, there are a number of fundamental differences in the structures through which UTM and ATM services are provided. As noted, most UTM concepts are based on a decentralised or federated structure that relies on participants, particularly UTM service providers but also UAS operators, *cooperating* with one another to share information in a way that provides an ability to plan missions and to manage airspace in real-time. The need to share data gives rise to a need for mechanisms or protocols to facilitate the information exchanges, and most UTM concepts are based on open standard communication protocols that will allow services to be digitally provided in an automated way with minimal human involvement. This general approach differs from the more integrated and centralised nature of ATM service provision (e.g: *en route* air navigation services, or air navigation services in controlled airspace) where data and information is generally collected by a single central entity (an ATMSP), and which is still heavily reliant on humans to manage airspace (Kirwan, 2001; Metzger and Parasuraman, 2001). Initiatives such as NASA's ATM-X project and the EU's SESAR Joint Undertaking seek to advance human-machine teaming and collaboration in ATM operations.

5.2. Provision of air navigation services: monopoly vs competition

A corollary to the first difference is the focus in UTM on traffic management and navigation services being provided through a competitive industry structure. Like in other competitive markets, UAS Operators will be able to choose among privately owned UTM service providers in a specific area on the basis of their preferences, price and quality etc, and UTM service providers should be responsive to UAS operator needs. This competitive vision for the provision of navigation services for unmanned aircraft differs substantially from the dominant policy paradigm used for manned aircraft which is based around the monopoly provision of air traffic services (Arblaster, 2018). In most jurisdictions, ATM is characterized by a single provider of *en route* air traffic services, although there can sometimes be competition for the market (in the form of franchise competition) and for some air navigation services in lower airspace, such as for terminal control services (Cook, 2007; Kearney and Li, 2018). The different policy positions for ATM and UTM is perhaps most apparent in the US where the FAA is currently the monopoly provider of air navigation services to manned aircraft (Adler et al., 2020). In contrast, as described in section 4, the FAA's UTM Concept of Operations is focused on UTM being designed in a way to encourage an innovative, competitive open market of service suppliers, where the FAA's role in UTM is expected to be limited to setting the 'rules of the road' and becoming involved in off-nominal events (Evans et al., 2020). A similar policy position can be seen in the EU where the focus is on the development of a competitive U-space services market for unmanned aircraft, while air navigation services for manned activities are supplied through state-based monopolies in most EU member states (Bilotkach et al., 2015; Dempsey-Brench and Volta, 2018).

An important foundational question this raises is what is the policy rationale for allowing competition in UTM provision but not in ATM provision? In other words, what is it about conventional ATM for manned aircraft that means monopoly provision is preferred to a competitive structure. There are safety, technical, legal and economic issues to consider here.

Firstly, from a safety perspective, it would appear that navigation and traffic management failures in both activities could have serious consequences, particularly if, as expected, larger UAS operate transportation services (such as air buses and taxis) that are not dissimilar to services provided by smaller commercial manned aircraft (Straubinger et al., 2020). Moreover, because many UAS are expected to operate in densely populated urban areas the safety risks could be more significant than for larger manned commercial aircraft which use set flight corridors (Clothier et al., 2015; Lidynia et al., 2017). As such, there is no grounding from a safety perspective justifying the competitive structure of UTM compared to ATM.

A second technical rationale for not introducing competition for ATM services is to ensure high levels of interoperability and the transmission of only trusted and reliable information. However, as discussed above, the expectation is that UTM will require a similar, if not more complex (given the volume and nature of UAS missions), need for high levels of interoperability. In other words, the competitive structure does not appear to be justified on the basis that interoperability is less critical.[9]

[9] A need to ensure that information on UAS operations comes from trusted sources and is of sufficient quality, integrity, accuracy and security appear to underpin the focus on a single information gateway (the Common Information Function) in the EU's U-Space concept. See EASA (2020).

The legal framework has also shaped the existing ATM institutional structure including the fact that governments have historically delegated responsibility for their airspace to a single ATM provider under international conventions.[10] While the issue of how responsibility to provide air navigation services is delegated or assigned in the context of UTM has not been explicitly addressed to date, one option is that such responsibility could be delegated to Common Information Services providers (e.g.: the FAA who will operate the Flight Information System in the USA and designated Common Information Service (CIS) providers in the EU) who could perform a role similar to that currently performed by ATM providers for manned aircraft to comply with international conventions. Regarding the management of cross-border UAS movements, international bodies are currently focused on efforts to harmonize UTM systems and make them interoperable across international boundaries (ICAO, 2020; ITF, 2021). This will require the development and adoption of common rules, standards and processes for strategic deconfliction, situational awareness, flight planning and authorization of UAS operations in the respective airspaces. It will also require the development of rules to ensure the cross-border collaboration between UAS Operators, UTM Service Providers and Common Information Service providers.

A final rationale for why ATM has historically been provided through monopoly is economic, and based on the argument that given the characteristics of costs and demand in the supply of ATM services it is most efficient for there to be only a single supplier in a specific region (i.e.: to exploit any potential economies of scale, scope or density)[11]. This raises a question about whether such cost and demand conditions will also apply for UTM? Recall from the discussion above that a key aspect of the UTM architecture is the separation (or unbundling) of UTM service provision (which will be competitively provided by privately owned UTMSPs) from Common Information Services provision (which will typically be provided by a single monopolistic supplier in a designated region).

Although not articulated in any policy document, the underlying economic rationale for allowing competition in UTM service provision appears to be based on the expectation that only moderate levels of fixed costs will be incurred and that multiple providers can be sustained given expected demand. For example, if, as described above, UTMSPs utilise the equipment and infrastructure of existing communications companies, then the capital investments that UTMSPs need to make in communications equipment will likely be moderate; in effect, they will be just be another customer of the telecommunications companies. While some larger UTMSPs may choose to invest in their own communication infrastructure which could result in higher capital costs being incurred, presumably such investments will only be undertaken if the UTMSP believes that the level of demand it can attract from its competitors is such that it can recover its fixed costs. However, the extent of competition between UTMSPs might not be universal in scope and coverage: in some areas there may be many competing UTMSPs (e.g.: densely populated rural areas) while in other areas there could be potentially no UTMSP offering a service. In areas where there are no UTMSPs there may be a need for public subsidy, or the appointment of a default provider to ensure full coverage[12].

In contrast, most UTM concepts envisage a single monopoly provider of Common Information Services in a given region. As described in section 4, in the US, the Federal Aviation Authority will develop and manage a single FIMS across the country, while in the EU Member States may be able to designate a single CIS provider per U-Space airspace. Again while a rationale for this monopoly structure has not been clearly articulated in policy documents, it appears that the reasons are similar to that which applies to ATM. That is, there is an expectation that there could be significant fixed costs associated with the investments needed to provide the Common Information Services (e.g.: in communications equipment, IT hardware and software), which could give rise to economies of scale and scope at certain levels of demand, or economies of density such that it may be efficient for a single provider to service a particular geographic area. In addition, as discussed in section 6.1 below, Common Information Service providers might also be given a statutory monopoly to ensure that system wide information comes from trusted sources and is of sufficient quality, integrity and accuracy.

5.3. Activities subject to economic regulation

As noted above, the dominant policy paradigm used for ATM is based around the monopoly provision of air traffic services and as such is subject to various forms of economic regulation and oversight including price regulation, which places restrictions on the level of charges that can be levied on airspace users, and quality regulation to ensure certain performance standards are met.

Although the form and extent of economic regulation of UTM has not yet been clearly articulated in many jurisdictions, as noted above, the expectation is that competition will play a bigger role than for ATM and as a consequence the need for economic regulation of prices and quality will be more focussed than it is for ATM. In particular, UTMSPs are expected to operate in a competitive market and as such competition is expected to be the main constraint on ability of any single UTMSP to set high prices or reduce quality. In areas where competition is not working effectively and there is a single dominant or monopoly UTMSP, there may be a need for some form of economic regulation of prices and quality. A tendency towards a small number of dominant or monopoly UTMSPs might arise because of network effects: the more Operators that use a particular UTMSP, the more attractive that UTMSP will be to other users. This

[10] Article 28(a) of the Chicago Convention entrusts each state with responsibility to provide air navigation services above its land and territories. In addition, Article 6 explicitly forbids all international scheduled services except with the special permission of the state that the flight overflies or has as its destination

[11] While historically it may have been the case that there were large fixed costs associated with ATM communications and navigation infrastructure (such as ground stations and radars etc) which meant that a single provider would be most efficient in a specific region, the enduring relevance of this rationale may change as a result of the emergence of space-based communications infrastructure and/or the use of alternative communications infrastructure such as that used for mobile communications.

[12] This could involve competition *for* the market as occurs in other sectors such as railways. See Nash et al. (2019).

raises the potential for a first-mover advantage which could lead to the market 'tipping' in favour of one or a small number of large UTMSP. Such concerns about the early monopolization of UTM services by large private entities have recently been identified in the US (White House, 2021).

While the expectation is that competition will replace the need for economic regulation of UTM service provision in most circumstances, there is likely still a role for economic regulation of the prices charged by Common Information Services providers which, as noted above, will operate as monopolies in specific designated areas. In the US, a state-owned entity the FAA will develop and manage a single FIMS across the country and, as such, to the extent that any charges are levied on users they will be directly regulated. In the EU, as noted above, there is no longer a requirement that Common Information Service (CIS) providers be subject to price regulation or oversight notwithstanding the fact that some CIS providers will operate as monopolies in all or some U-spaces under their responsibility. This approach differs from that applied to ATM which requires that air navigation service charges are set or approved by a National Supervisory Authority and that a common charging scheme is applied in all EU Member States.

5.4. Communication, navigation and surveillance infrastructure: ground-based vs space-based

Another area where there does not appear to be full policy alignment for UTM and ATM relates to policy initiatives involving a gradual shift away from ATM being based on ground-based communication, navigation and surveillance (CNS) towards space-based (or satellite) CNS (Ali, 2019).[13] Space-based (or satellite) air traffic management for manned aircraft is seen to provide benefits in terms of more comprehensive coverage including in challenging terrain or in areas where there is currently minimal supporting infrastructure. Over the longer term, space-based CNS can allow for the optimisation and replacement of more expensive ground equipment and assets with the remaining radar-based infrastructure only providing the primary contingency in case of a Global Navigation Satellite Systems (GNSS) failure. In Europe, the vision is for navigation to become based solely on GNSS (with the exception of contingency operations) by 2030 (SESAR, 2018b). In the US, a switch to a satellite-enabled navigation system is a key element of the FAA's NextGen modernisation programme. According to the FAA, satellite-based navigation is more precise than traditional ground-based navigation aids and allows for the creation of optimum routes anywhere in the National Airspace System (FAA, 2020b; Novak and Jurkovac, 2017).

While at the international level the possibility of using space-based CNS for UTM has been acknowledged (ICAO, 2019b), the UTM concepts being developed in different jurisdictions appear to be firmly based around the use of ground-based CNS (including existing mobile communications and wifi networks) for the foreseeable future (Jiang et al., 2016). This policy position may reflect current limitations in the availability, and practical feasibility, of using space-based CNS for UTM. However, this may change in the future if as expected a constellation of low Earth orbit satellites, or pseudo-satellites, could provide low-latency, high-speed global internet connectivity particularly to those UAS which fly at higher levels and in more challenging terrain.

5.5. Remote identification and electronic conspicuity policies

A critical element of integrating UAS into airspace and addressing safety and security concerns involves policies about how manned aircraft and UAS will be made identifiable to one another and to other participants. These policies, known as remote identification, network identification or electronic conspicuity in different jurisdictions, aim to ensure that UAS and other airborne vehicles can be electronically identified and monitored at all stages of a flight through use of a unique identifier and the constant transmission of electronic information and data. For ATM, since 2020 it has been mandatory for many commercial and general aviation manned aircraft operating in the EU and in the US to be equipped with a transmission system (ADS-B Out) via which an aircraft broadcasts identity and other operational information periodically at a high rate from an onboard system.[14]

Although all UTM concepts incorporate a need to achieve remote identification of UAS, most concepts are not specific about what technologies can be used to achieve such an outcome (Kang et al., 2019). Some studies have shown that the use of ADS-B by large numbers of UAS could interfere with ground station reception and raise serious safety concerns for aircraft operating in the same airspace (Maiolla, 2019). In the US, the FAA explicitly rejected the requirement for UAS to be mandatorily fitted with ADS-B Out capability (FAA, 2019), in favour of a policy requirement based around remote identification (RID) which can use a combination of technology and services. In the EU, it will be mandatory for UAS operating in all U-space airspaces to utilise a network identification service. However, there is currently no specific requirement about the technology that should be used to facilitate network UAS e-identification.

Given the expected increasing interaction between manned and unmanned aircraft, there may be synergies in ATM and UTM policy alignment on remote identification and/or electronic conspicuity (Holcombe, 2018). In the short term, this could ensure that all aerial vehicles use a common and interoperable technology which, in principle, could minimise the risk of mid-air-collisions (Wallace et al., 2018; Wendt et al., 2020). Over the long-term the use of consistent identification technology for manned and unmanned vehicles could reduce equipment costs and encourage investment in the necessary ground-to-air (or air-to-air, space-based) infrastructure, which

[13] This involves ADS-B signals being broadcast from aircraft and then being received by a constellation of low-earth orbit satellites. An example of a space-based ADS-B service currently being deployed on a commercial basis is offered by Aireon.

[14] ADS-B involves the automatic broadcast of Global Navigation Satellite System (GNSS) position data/information from an aircraft once per second without the need for an external interrogation. Moreover, the information that is broadcast using ADS-B can include a range of data including aircraft identification, altitude, speed, velocity, projected path and other useful operational information.

Table 4
Economic, operational and safety differences between ATM and UTM.

Dimension	ATM	UTM
Number of traffic management providers	• Typically a single service provider in a given designated airspace.	• Generally presented as multiple competing providers of UTM services to UAS Operators.
Overlapping or exclusive provision in a specific region	• Generally involves a sole provider having the exclusive ability to offer services in a particular region.	• Expectation of overlapping provision of UTM services such that multiple UTM service providers can provide services within the same area/region.
Single or multiple service provision	• Traditional ATM service provision is based on a single 'bundled' set of communication, navigation and other services (e.g.: weather) being provided by a single ATM provider.	• Generally based around the 'unbundled' provision of services; such as 'core' or 'mandatory' UTM services provided by UTMSPs, and other 'additional' or 'supplementary' services provided by SDSPs.
Competition or monopoly provision	• Dominant policy paradigm for ATM is based around the monopoly provision of air traffic services.	• Many UTM concepts based around competitive UTM service provision which is market driven and responsive to user needs. • However, Common Information Services will typically be provided by a single entity in a given region.
Extent of economic regulation of prices and quality	• ATMSPs are generally either state-owned and thus directly regulated, or subject to price and quality regulation	• If UTMSP markets are effectively competitive there should not be a need for separate economic regulation of prices or quality, as competition should constrain the ability of any single UTMSP to exercise any market power they may have. • However, because Common Information Services will typically be provided by a single monopoly in a given region, it could be state owned and subject to direct regulation, or potentially subject to cost-based regulation by an external regulator.
Data and information sharing	• Based around centralized collection and distribution of data and information by a single entity.	• Based around more disaggregated, less centralized sharing of data and information among a wide range of participants.
Coordination and management of airspace	• Responsibility for coordination and management of airspace rests with the ATM service provider in specific region, and is still ultimately reliant on humans (to different degrees) to manage airspace in real time.	• UTM participants, particularly UTMSPs, are expected to cooperate with one another to manage airspace in real-time. This is expected to be facilitated through open standard communication protocols provided in an automated way through a digital system.
Communication, navigation and surveillance systems	• ATM is based on ground-based communication, navigation and surveillance (CNS) although there is expected to be a shift towards space-based (or satellite) CNS in many jurisdictions in the future.	• Many UTM concepts appear to be based around the use of ground-based CNS (including existing mobile communications, bluetooth and wifi networks) for the foreseeable future.
Remote identification and conspicuity policies	• Most commercial and general aviation aircrafts in the EU and US must now be equipped with ADS-B Out to facilitate identification.	• Most UTM concepts are not specific about what technologies for remote identification. ADS-B Out capability (FAA, 2019) has been rejected in the US, while in the EU there is no specific requirement about the technology to be used.
Safety and segregation of airspace	• Based around the proactive and advanced strategic management of airspace, often on a first come-first served basis. • Airspace separated into different classes, with fixed rules about who can enter some airspace classes, where they can fly (e.g.: restrictions) and requirements to follow air traffic control instructions. • Commercial users operating in controlled airspace tend to use predictable flight paths using segregated corridors. • Flight plans are typically submitted to ATM service providers which determines the flow of traffic . • Tactical management of airspace focusses on safety through maintaining appropriate separation of aircraft. • Typically only the Civil Aviation Authority (CAA) can introduce Temporary Flight Restrictions (TFRs).	• The highly automated nature of UTM operations means that the current airspace classification scheme may not accommodate UAS operations. • Most UTM operations expected to occur in the tactical timeframe (i.e.: not be scheduled) which means that separation management could be applied pre-departure (Evans et al. 2020). • Most UTM concepts based on cooperation between UAS/UTMSPs to ensure separation and deconfliction. It is anticipated that deconfliction and separation will need to be managed through an automated system using algorithms (ICAO (2020). • Flight (mission) plans submitted by UTMSPs to a Flight Notice Board which can be accessed by other stakeholders (including other UTMSPs) to facilitate planning, strategic deconfliction and flight approvals. • In addition to Civil Aviation Authority providing TFRs, some public authorities may be permitted to dynamically manage low-level airspace by putting in place Temporary Flight Restrictions (TFR).

could improve coverage and spread costs over a wider customer base.

A related policy issue where there is a need for greater UTM and ATM alignment is the altitude and height measurement systems used by manned and unmanned aircraft. Conventional manned aviation measure pressure altitude from barometric readings, while UAS often use other systems such as satellite-derived altitudes (EASA, 2018c). This can give rise to discrepancies in the height and altitude readings, and conflicts can potentially arise if aircraft use different measurement technologies in shared airspace (Zhang et al., 2020). In Europe, recognition of this problem has led to development of a Common Altitude Reference System (CARS) that will use a common technology and datum to determine the height or altitude.

Building on the discussion above, Table 4 summarises some of the principal economic, operational and safety differences between ATM and the UTM concepts described in this paper.

6. Fundamental UTM economic policy choices and trade-offs

As noted in Section 1, UTM is a policy construct which involves a range of fundamental choices about factors such as what rules and institutions should be established, how will information be shared and interoperability achieved, and where competition should be allowed to develop. This section identifies some of the most important policy choices, and the various trade-offs, which need to be considered.

6.1. To what degree should the UTM architecture be centralised or distributed?

As discussed, UTM concepts will be more decentralised than conventional ATM and will rely on the cooperative sharing of data and information among a wider range of participants (Jiang et al., 2016; Ali, 2019). However, an important design choice is exactly how decentralised a UTM architecture should be, and, in particular, whether it should include a centralised entity or be based on a highly distributed architecture of information sharing with no, or very little, central coordination.

Centralised UTM concepts involve a single entity being responsible for managing and supplying a wider range of Common Information Services in a particular geographic area. At the extreme, this entity could perform some management and operational functions that are broadly analogous to the systems operation function in conventional ATM. In contrast, more distributed UTM concepts are based around a range of participants sharing data among themselves using a series of common data sharing protocols, standardisation and automation with no, or very little, central coordination. In effect this is based on the idea that if all UTMSPs operating in a UTMSP network use compatible protocols and standards when interacting then this should, in theory, achieve the same benefits as a single centralised entity that adopted common standards and protocols.

Three factors appear to be important in determining the relative balance between a more centralised or distributed UTM concept. First, there is the issue of how interoperability (i.e., the way data is exchanged and interpreted by different participants) and coordination among UAS, both in the planning phase but also during a mission, is best achieved. Centralised UTM concepts rely on a single entity (e.g.: Common Information Service Provider) receiving and supplying relevant common data and information to all UTM participants in a particular region. In contrast, in a distributed UTM concept, interoperability is achieved through individual entities exchanging data and information using common standards and protocols at different stages of a mission (pre-flight, during mission, post-flight), with no centralised entity responsible for collecting and disseminating information. The feasibility of a distributed approach therefore depends on the universal adoption of common standards and protocols and on the development of policies relating to remote or network identification. While a distributed approach can achieve high levels of interoperability if standards and protocols are well designed and adopted by all participants, it may be necessary to establish a body to consider and assess changes to protocols or standards to deal with new volumes or forms of traffic.

Secondly, the decision about how centralised a UTM concept should be influenced by concerns about safety and, in particular, the degree of trust and reliability in the information and data shared among UTM participants. The EU's decision to require that the provision of the necessary UTM information is done in a centralised manner through one single gateway (the Common Information Function) in a U-Space airspace, appears in part, to be motivated by a desire to increase safety by ensuring that essential flight information *"comes from trusted sources"* and is of *"sufficient quality, integrity and accuracy as well as security so that the USSPs and other users such as ASNPs can use this information with full reliability when providing their services."* (EASA, 2020).

A third factor is who bears the costs of the sharing of information. In more centralised approaches, such as the EU's U-Space concept, the costs will include the initial investment costs and any on-going operational costs associated with establishing and supplying Common Information services in each U-Space. These costs will then have to be recovered (either in full or partially) through charges levied on UTM service providers (and ultimately UAS Operators) and potentially other participants who utilise the Common Information services. In more distributed UTM concepts, many of the costs of information sharing will likely be incurred by individual UTM participants such as UAS operators or UTMSPs. UASs and other participants will incur the costs of the equipment and other costs of the processes and protocols needed to achieve the required level of interoperability and allow the UASs to interact with one another. From an economic perspective, a key factor relevant to the degree of centralisation of activities is whether there are likely to be economies of scale or scope in information collection and sharing, such that a single entity incurring those costs for a particular geographic region would be more cost efficient than multiple entities collecting and sharing information.

6.2. Should the common information function be publicly or privately owned and run?

Another fundamental policy choice is whether the provider of Common Information Services or flight information management services should be owned and operated by private entities or under public control and oversight. Although the EU's U-space concept is not explicit on this issue it appears to contemplate that Common Information Service (CIS) providers in a designated U-Space could be privately owned and operated.[15] In contrast, in the United States, the Flight Information Management Systems (FIMS) will be developed and operated by the FAA, however, as noted in section 4, the FAA's envisages its role in UTM as being very limited relative to its role in operating the conventional ATM system.

From a policy perspective a key question this raises is why some jurisdictions seem willing to allow for private ownership and operation of all, or most, UTM activities, but still wish to maintain a policy of state ownership and control over ATM service provision and associated activities. While a range of political, historical and other reasons can underlie the state ownership and operation of ATM providers (Cook, 2007; Lehiany et al., 2015), one rationale is that a supplier in state control is not expected to be motivated by private gain.[16] Accordingly, a public ATM provider should, *in principle*, be directed to act in a socially desirable way: for example, to promote efficient and fair use of airspace by not setting prices in excess of costs, and by making efficient and timely investment decisions. Whether these aspirations are fulfilled in practice is subject to considerable debate, but assuming that this is, at least in part, the reasoning underlying the policy of maintaining ATM provision in state ownership and operation, a question it raises is why the same reasoning does not apply to UTM provision? Put differently, why is there a presumption that private providers of UTM services can be appropriately controlled through a mix of competition and price regulation, while private providers of ATM services could not be controlled through such mechanisms and need to be under more direct state control?

6.3. What should the interconnection terms for data sharing be in local UTM networks?

A key aspect of the more disaggregated, less centralised UTM concept is that it relies on the sharing of data and information among a wide range of participants, including between UTM service providers through local UTM networks (ICAO, 2020). In the US, a key element of the UTM concept are UTM local networks (called 'USS networks') while the EU's U-Space concept anticipates a form of inter-UTMSP sharing arrangement will develop to facilitate data exchanges among UTMSPs. The need for UTMSPs to share data raises a question about the (wholesale) terms and conditions that will be struck between UTMSPs. These terms and conditions might include any prices/charges levied for sharing data, and other conditions or commercial protocols introduced for sharing information and engaging in de-confliction actions.

Interconnection terms and conditions for sharing data can potentially be cooperatively or non-cooperatively determined. Non-cooperative determination might involve competing UTMSPs setting prices and other terms independently from each other, and as such UTMSPs will engage in direct bargaining over charges and other conditions. Experience from other sectors where data is shared among competing service providers (such as communications) suggests that there may be circumstances in which each UTMSP has incentives to set prices for sharing data at inefficiently high levels (Laffont and Tirole, 2000; Armstrong, 2002). Specifically, if UTMSPs compete for subscribers, there may be intense competition *for* subscribers to a UTMSP, however once a subscriber is signed up to a provider, it will effectively hold a monopoly position in providing access *to* operational data and information from that subscriber which other UTMSPs will need to access.[17] Larger UTMSPs with market power might also have incentives to discriminate against smaller competitors (e.g., by offering worse terms and conditions). This could result in a series of closed local UTM networks emerging in a given area. Perhaps for this reason, under the EU's U-Space concept, UTMSPs are required to handle air traffic data without discrimination, restriction or interference, irrespective of their sender or receiver, content, application or service, or terminal equipment.

This concern might also underlie recent policy initiatives in the US to promote competition and ensure that air traffic control is not monopolized (White House, 2021).

The cooperative determination of data sharing interconnection terms and conditions would involve competing UTMSPs in a local network negotiating interconnection prices and conditions. This approach addresses concerns about each UTMSP individually seeking to exploit its monopoly position, however it raises the possibility of competitors coordinating on the setting of prices which raises a risk that UTMSPs will collectively have an incentive to set high interconnection charges for sharing data or use of their systems, which is then passed through to charges levied on UAS Operators (i.e. there is the risk of collusion). One variant of cooperative determination are so-called peering or 'bill and keep' arrangements where UTMSPs would agree not to 'bill' each other for sharing data, and where as a result the interconnection price is set at zero or effectively below cost (Cambini and Valletti, 2003; Shrimali and Kumar; 2008). In practice, the viability of this approach may depend on the expected degree of symmetry in the amount of traffic information shared

[15] Although removed from the final Regulation the draft EU Regulation included a restriction on ownership such that the CIS provider shall not be related or connected in any manner or form to any U-space service provider in the airspace for which it has been designated and shall not provide any U-space services itself in that airspace. This provision was not derived necessarily from a safety point of view but more from a competition and market perspective, and is necessary to ensure that there is no conflict of interest when the common information is made available to the different USSPs and to ensure fair competition in the U-space services market. See European Commission (2020) and (2021).

[16] The incentives created under different forms of ownership have been examined at length in the economic literature (Vickers and Yarrow, 1988; Decker, 2014). Taken as a whole, this literature suggests that ownership structure can affect the incentives of management, and therefore the performance of the entities subject to state ownership.

[17] In mobile communications this is sometimes referred to as the 'termination monopoly problem' and arises where mobile telephone companies compete actively to get subscribers to join their network, but once a subscriber is signed up to their network *all* calls received will need to be terminated using their network, for which in some jurisdictions, they will charge other networks a termination charge.

among different UTMSPs.

In short, the need for multiple competing UTMSPs to share data may require that interconnection principles and conditions be established and subject to regulatory oversight. These principles and conditions for data sharing should aim to limit individual and collective incentives for UTMSPs to set high interconnection charges for sharing data or establish other non-price terms and conditions which limit interconnectivity between networks – i.e., leading to a series of closed networks. In addition, such terms and conditions should ensure that the terms and conditions by UTMSPs who are monopolies or have significant market power do not discriminate or hinder access and utilisation of airspace.

6.4. How should UAS access to airspace be allocated safely, fairly and efficiently?

The UTM concepts considered in section 4 require that access to airspace for UAS Operators be safe, fair and efficient. In the US, the FAA's UTM concept seeks to ensure that there is no assumption of priority that would diminish equity of access for UAS to operate in the airspace (FAA, 2020a). The EU's U-Space UTM concept focusses on the need for an effective and enforceable regulatory framework that provides fair access to all airspace users (EASA, 2020). Such requirements for fair and efficient access give rise to a question of how airspace capacity is allocated among UAS, particularly in locations where airspace is congested and scarce and there are potentially conflicting demands for its use (Rule, 2015). While the concept of 'fairness' is multifaceted, in the current context it is generally used to refer to allocations where all operators (including new entrants and smaller operators) are not unduly impeded in their ability to access airspace, and where airspace is not just allocated to first-movers or the largest operators (Evans et al., 2020). The need to allocate (and re-allocate) airspace access both *strategically* (prior to the flight) and *tactically* (immediately prior to, or during, flight) gives rise to fundamental questions about how access should be allocated and re-allocated among UAS Operators, and on what criteria. Chin et al (2020) note that there are multiple reasonable definitions and associated metrics of fairness in the context of UTM.

There are a number of possible airspace allocation approaches that could be applied including: administrative or rules-based methods; standard bilateral or multilateral negotiations; and electronic auctions or real-time open market allocation mechanisms conducted at high speed without human intervention (Skorup, 2019; Evans et al., 2020; see Jovanović et al. (2014) for an application of such market measures for ATM). Drawing on the experience of the application of such approaches in other sectors, Table 5 presents a high-level summary of some of the, in-principle, benefits and limitations of each allocation approaches.

In addition to these standard allocation approaches some UTM concepts have proposed that airspace might be allocated through some form of de-confliction algorithm (see Tan et al. (2019), Evans et al (2020) and Sacharny et al (2020) for recent examples). This appears to envisage that conflicting demand could be resolved through technological processes which seek to fully optimise the use of scarce airspace given competing demands (Balampanis et al., 2017). Such an approach could, in principle, substantially improve the safety and efficiency of airspace use by allowing for competing airspace demands to be accommodated (Ong and Kochenderfer, 2017). However, there are still likely to be situations where airspace is heavily congested and there will be competing demands for the use of the same airspace, in which case some allocation decision rule or process will need to be incorporated into the algorithm. In these situations, such an approach becomes a variant of an administrative or rules-based approach where the algorithm is coded to allocate access according to certain decision rules (e.g.: first-come, first-served). Evans et al (2020) simulate scenarios for first come-first served strategic deconfliction in terms of fairness based on when operators file their flight plans. Developing policy for allocating access among competing UAS operators is likely to be one of the most challenging issues associated with UTM systems across the world. In the US, it is proposed that UAS operator collaboration be the principal means of achieving equitable access where there is a moderate airspace demand. When UTM demand/capacity imbalances arise, and operators have already planned and shared their intent with the network, then a negotiation process should occur between UTMSPs and operators. The industry will be expected to agree upon methods and standards for de-confliction and/or negotiation, which might include requirements to alter spatial or temporal elements of the operation intent and/or operator collaboration/negotiation through the use of de-confliction algorithms. However, in the event that these processes are not successful and demand for a volume of airspace becomes '*too great*', then the FAA may be required to provide demand management of access to maintain the safety of flights and support all types of operations (FAA, 2020a). The EU's U-Space concept also relies on UTMSP and Operator collaboration to airspace access in the first instance, and does not set out any formal priority access rules (except for UAS conducting special operations). [18]However, in circumstances where two flight authorization requests have the same priority, they shall be processed on a first-come-first-served basis (i.e.: an administrative allocation).

Any airspace allocation mechanism will also need to take account of how airspace is shared with manned aircraft that operate in non-segregated areas. The EU's U-Space concept sets out the expectation that manned aircraft operators flying in U-space airspace which is uncontrolled will continuously make themselves electronically conspicuous to the U-space service providers. In the US, although manned aircraft Operators are *not* required to participate in UTM they are encouraged to voluntarily to do so to obtain the safety benefits.

6.5. What type of communications infrastructure should UTM use?

The issue of the infrastructure used to facilitate communications between different UTM participants, in particular communications between UTMSPs and UAS Operators and inter-UAS communications has received relatively limited attention. However, consideration

[18] In contrast, the draft Regulation established out seven priority access rules including that manned aircraft had priority over unmanned aircraft.

Table 5
Comparison of different airspace allocation approaches.

Allocation approach	May be suitable in which settings	Potential benefits	Potential limitations
Administrative allocation (e.g.: first come-first served)	• Where airspace is not scarce, there is no congestion and demand is not growing.	• Avoids the complexity and transaction costs associated with other allocation methods. • Provides a predictable rule for airspace allocation (e.g.: first come-first served).	• Does not typically take account of market signals (such as willingness to pay) when determining how airspace capacity is allocated. • May lead to the crowding-out of UAS Operators who have a high value for access but are unable to obtain access rights. • Can stifle development in related markets if a small number of large UTMSPs or UAS Operators have enduring rights to access, and there are no liquid secondary markets.
Bilateral or multilateral negotiations	• Where airspace is scarce and there is a need for bespoke or complex arrangements that provide a degree of certainty to both parties. • Allows for individual negotiation of parties to provide bespoke access requirements.	• Can allow users who value access most to negotiate to access to it on specific, bespoke terms. • Can allow UAS Operators to make long-term plans on the basis of commitments tailored to their needs complemented through short-term secondary trading of access rights on platforms to address conflicts/scarcity as and when it arises.	• Can raise issues about discrimination and unfair treatment in the allocation of primary access rights • Negotiation process can be non-transparent. • Long-term arrangements can act as barrier to access/entry. • May be insufficient access to scarce capacity available in short-term to address congested airspace.
Auctions or real-time open market allocation mechanism	• Where airspace capacity is constrained and there is a sufficient number of bidders.	• Potentially a non-discriminatory and efficient airspace allocation mechanism, such that those who value it the most will acquire rights. • Could provide signals about the need for additional airspace capacity in specific areas.	• To be effective as an allocation mechanism it is necessary that there is sufficient competition among UTMSPs for capacity. • Could be complex to implement and operate. • May not result in fair access if hoarding, or largest UAS Operators, are the only ones who can afford access. • Can give rise to over or under recovery of revenues for the auction operator.

of this issue is important as there is a close connection between the nature and magnitude of infrastructure costs and the scale of charges faced by UAS operators which will affect their incentives to enter. A recent survey of existing active recreational and hobby drone users in Australia found that current drone registration charges are substantially below of what drone flyers would be willing to pay (Merkert et al., 2021).

In the short term a number of existing communications infrastructures could be used to facilitate UTM communications. One possibility is to use the existing ground-based equipment of mobile communication companies and non-aviation spectrum to transmit and receive signals to/from UAS Operators in real time (Zhu et al., 2019). In Germany a joint initiative between Deutsche Telekom and Deutsche Flugsicherung (DFS) – called Droniq – will use the mobile telecommunications network and spectrum to track UASs. Effectively, UTMSPs and UAS operators that utilise these services will just be another customer of the telecommunications companies and will 'share' the infrastructure (and spectrum) with other communication users. A reliance on mobile communications infrastructure in the short-term is part of the EU's U-Space concept. Another possibility is to provide UTM connectivity through existing ground-to-air communications infrastructure used for conventional ATM. This might involve the use of existing assets (such as satellites, ADS-B and radar ground stations and receivers) and aviation spectrum to communicate. The use of existing ground-to-air infrastructures, alongside mobile communications and internet networks, is part of the initial UTM concept implementation in the US. Over the long term, specialist provider(s) of UTM equipment and infrastructure could emerge which can provide UTM communications services. Such infrastructure providers might utilise different technologies to provide connectivity which could involve a mix of assets including the assets of communications companies and low earth orbit satellites that will provide low-latency, high-speed global internet connectivity. Some larger UTMSP or UAS operators may decide to invest (either on their own or as part of a joint venture) in their own dedicated communication assets and equipment using a specific technology. This could allow them to differentiate themselves from their competitors by having a high level of quality, security and reliability in that area.

A number of economic considerations are relevant to the decision about which infrastructure should be used to underpin UTM communications. First, the different infrastructure options involve different levels of costs, which will ultimately need to be recovered through charges levied directly or indirectly on UAS operators. While existing mobile communications infrastructure may involve the lowest cost outlay in the short-term, it may leave UTMSPs and UAS operators heavily reliant on the performance and operational aspects (e.g., coverage) of existing mobile communications companies. Second, it may be the case that in the initial stages UTMSPs will utilise the infrastructure of existing mobile communications providers but over time, as demand increases, policy is focussed on new investments in UTM-specific ground-to-air (or air-to-air, space-based) infrastructure and technologies which offer services tailored to UTMSPs and the UTM environment. Third, the product and service quality attributes of the different infrastructure options may vary. For example, existing mobile communications infrastructure may not be universal in coverage and could suffer from quality of service issues such as congestion and latency. Finally, there are also important questions about spectrum availability and security in some jurisdictions. Conventional manned ATM surveillance systems (such as ADS, TCAS/ACAS and SSR/MLAT) operate on the 1030/1090 MHz frequency which has been adopted as the world aviation standard and is used in most countries which is reserved for aviation. However, the growing volume of data required to facilitate the evolution of airspace management may in the coming years place greater pressure on the available aviation spectrum (Maiolla, 2019). While non-aviation spectrum offers an alternative, there are some concerns that this may not offer the same level of reliability, coverage and security as aviation spectrum (i.e., it is not a full substitute).

6.6. Can operators choose, or substitute, between UTM and ATM?

Finally, there is a policy choice about the extent to which some manned and unmanned users can choose between using UTM services and ATM services. In the US, UTM services are currently seen as being separate from, but complementary to, the services provided by the ATM system (Perez-Castan et al., 2020). However, the policy envisages that some manned aircraft operators might elect to participate in UTM and, indeed, are encouraged to do so to obtain the safety benefits (FAA, 2020a). The EU's UTM concept does not appear to allow manned users to utilise UTM, although it is envisaged that a conventional ATM operator could assume responsibility to ensure that manned and unmanned aircraft remain segregated in designated controlled airspace.

Looking ahead, there may be a greater potential substitutability between UTM and ATM for some UAS operations. For example, unmanned air taxis, or larger forms of unmanned cargo transportation, may come to follow flight patterns and paths similar to those currently used by light aircraft or helicopters which in controlled airspace utilise traditional ATM services (Al Haddad et al., 2020). Because of the nature of these operations in segregated and designated airspace, these UTM operators may often fall under the responsibility of traditional ATM operators. Conversely, manned helicopters who operate in urban areas might wish to have a choice between using the UTM system or the ATM system (and traditional services provided by ANSPs) as is being proposed in the US. To the extent to which UTM and ATM become potential substitutes this again raises a question about the alignment of the policy frameworks for UTM and ATM, and whether over time such frameworks need to converge so as to not distort the incentives of participants. This would avoid the risks of 'regulatory arbitrage', where some participants would choose to utilise the traffic services which impose lower levels of obligation or are provided at lower cost.

7. Conclusion

Although technological developments for unmanned aircraft are arriving at a much faster pace than for manned aviation, there is currently no universal system in place to manage unmanned aircraft. Conventional air traffic management which relies on communication between air traffic controllers and pilots and on radar detection is unsuited to unmanned aircraft, and for this reason many jurisdictions are currently grappling with a need to quickly develop a UTM concept and policy framework. This task is made challenging by the novel characteristics of UAS and expectations of substantial and rapid growth which require a new UTM policy paradigm. This new UTM approach differs in important ways from conventional ATM policy which has gradually evolved over the past century. Notably, unlike ATM, UTM concepts are typically based around automated, decentralised, community based system of traffic management where UTM operators and other supporting participants cooperate with one another to coordinate and manage UAS, and where there is limited direct operational involvement of civil aviation authorities or centralised traffic management bodies.

In framing UTM as a policy construct this paper has sought to identify and explore some of the key building blocks, economic choices and trade-offs that policymakers confront when developing a UTM concept. Different choices on some these aspects can be observed in the UTM concepts already being developed in the US, Europe and elsewhere in the world. Many of these issues are also relevant to the longer-term aspiration of bodies like ICAO to see policy frameworks for different airspace, systems and vehicles converge to allow for the flexible accommodation of all types of operation at all altitudes. By setting out some of the key economic policy considerations and trade-offs involved in constructing a UTM economic policy framework, we see this paper as a first step in focusing attention on how the economic, regulatory and commercial aspects of UTM can impact on the pace and scale of future deployment.

However, we recognise a number of limitations of our analysis which require further research and consideration. Firstly, our focus has been on the UTM concepts being developed in the US and the Europe, and it would be useful for further work to understand the different approaches being adopted for UTM concepts in other jurisdictions. Secondly, we have assumed that the economic policy framework for UTM will always ensure that a certain baseline or target level of safety is maintained. However, as noted in the introduction, in practice the economic and safety policy frameworks are often interconnected (Oster et al., 2013), and further research is needed to better understand how safety targets and regulations interact with the economic and commercial incentives of different UTM participants. Thirdly, we have not presented a quantitative analysis of costs or benefits of different policy choices. This reflects the fact that there is a dearth of data and quantitative information in the public domain about how much UTM will cost to develop and operate. Finally, we have not set out to present a universal template of an economic policy framework for UTM. Rather, our approach has been to focus on the important policy choices and associated trade-offs on the assumption that these can only be appropriately addressed within a jurisdiction's specific institutional, economic and regulatory policy context. As UTM concepts evolve and become operational at a large scale there is likely to be considerable value in quantifying the costs and benefits of different choices and drawing comparative insights as to which policy approaches seem to have been most effective across jurisdictions.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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