Trustworthy Airspaces of the Future: Hopes and concerns of experts regarding Uncrewed Traffic Management systems

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ABSTRACT

Uncrewed aerial systems (UAS) such as drones are an increasingly mundane part of our skies, and are expected as an industry to undergo exponential growth in the coming decade. In order to monitor and manage the airspace, Uncrewed Traffic Management (UTM) systems are being developed that will ensure UAS are able to interface with one another and with relevant forces on the ground. However, the remit of what UTM systems should incorporate is still in flux, leading to slow progress and lack of clarity in regulations that is already impacting the ability of the UAS industry to evolve. We present the findings of interviews with experts related to UAS, UTM, and general air traffic management in order to understand their concerns and hopes for the future of UTM. In particular, we examine how UTM should be shaped by questions around safety, trustworthiness, and fairness of our airspaces. We use these findings to present a roadmap for future UTM developments, including the introduction of scenario generation to embed these findings in tangible airspace models.

CCS CONCEPTS

• **Applied computing** → *Industry and manufacturing*; **Aerospace**; • **Social and professional topics** → **Computing / technology policy**.

KEYWORDS

Airspace, Management, Uncrewed, Traffic, Management, Drones, Unmanned, Aerial, Systems, Trustworthiness

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1 INTRODUCTION

Drones and other Uncrewed Aerial Systems (UAS) comprise a rapidly growing segment of airborne vehicles, one that is predicted to expand exponentially over the coming decade, with growth anticipated across a plethora of applications and opportunities. UAS not only offers new approaches with the potential to substantially change activities such as logistics, traffic management, commercial deliveries, and emergency response, but is already altering existing activities. For example, for better or worse, drones have undoubtedly changed the conduct and impact of warfare in the Ukraine conflict. Applications can also be imagined across a range of civilian sectors: drones may support medical deliveries across congested urban areas or stretches of water; the management of highway traffic and responses to incidents; and the support of fire and rescue services [19].

As noted, the UAS industry is already rapidly expanding. By April 2024, over 400,000 recreational drones and 360,000 commercial drones were registered with the United States Federal Aviation Authority (FAA) [12]. The growth of the drone economy is expected to further accelerate in the coming months, driven by technological advances catalysed by the Ukraine and Israel conflicts and by the growth in development of *autonomous* drones that use sensors, artificial intelligence (AI) and machine learning to be able to travel Beyond Visual Line of Sight (BVLOS), offering faster response to flight changes, broader application options, and improved GPS navigation [16]. Further growth is expected to stem from the rapid development of start-up companies in drone technologies, expansion in manufacturing in the West, and the entrepreneurial triggering of various drone services.

The anticipated growth in the drone economy raises pressing concerns about the management of low altitude airspace (~500ft) used by UAS. At this height conventional air traffic services do not operate, increasing security risks to the UAS and to conventional aviation [5]. Further, the density of expected interaction raises problems concerning in-flight encounters, the allocation of routes and the managing of dense traffic. This requires the development of new forms of aerial traffic management frameworks, strategies and regulations. However, the development of these frameworks, strategies, and regulations is outpaced due to the rapid speed at which UAS technologies evolve, and the unfamiliar paradigms of user needs [1]. Slow implementation of regulation is anticipated to have a knock-on effect on the trustworthiness and ultimate uptake of these systems, not just by government and organisations, but also by members of the general public whose opinion will dramatically impact the acceptance and integration of UAS. Further, drawn-out changes to regulations can delay vital innovation and expansion in this area.

In response, Uncrewed Aerial System Traffic Management (UTM) arose as part of research by the National Aeronautics and Space Administration (NASA) and was touted as an adaptation of the existing Air Traffic Management (ATM) system designed to meet the specific needs of UAS. The need for such a system came about to ensure that UAS were able to integrate safely within low altitude airspaces previously used almost exclusively by General Aviation (GA). It was anticipated that airspace regulators could create a UTM for their airspace according to their individual needs, but which were effective at collaborating with other UTM systems to allow UAS to use the airspace safely, efficiently, and equitably. However, it fast became clear that the proposed UTM ecosystem is a complex amalgamation of people, organisations and technology. Stakeholder networks involve an extensive population of users, operators, airspace controllers and regulators, and extend across services, supply chains, and geographic location. Technologies covers systems and services at dispatcher and recipient sites as well as communication networks both locally and globally. Organisations include manufacturers, operators, aviation authorities, legislators and airport authorities. Whilst some outcomes in such complex environments are predictable, more often behaviour is emergent and changing. To add even more complexity, the UTM landscape raises a wide range of ethical problems around privacy, security, autonomy, and artificial intelligence (AI). Drones operate within communities, both in dense urban environments and as a means to provide vital services to rural communities. The effect on those over whom the drones fly, the concerns of emergency services, first responders, of victims of accidents, of individuals who might end up dependent on drone services, all have ethical dimensions. Therefore, an ethics of drones will depend on a vast array of influences that have not yet been fully documented.

With all of this in mind, it becomes vital to understand the boundaries of what *should* fall within UTM systems, not simply what *could*. Further, investigation must be made into what is needed, and what is currently missing, that would ensure UTM systems are successful in guaranteeing low altitude airspace meets the social, legal, and ethical requirements of users. To begin to address this gap, we present the preliminary findings of a broader study investigating the goals and needs of UTM systems. We present insights from interviews with aviation experts, and unpack what opportunities, barriers, and potential risks there are in the ongoing development of UTM. In doing so, we answer the question:

How do stakeholders interpret concepts of trustworthiness, safety, and fairness and ways in which these can be manifest and embedded in UTM systems.

The findings of this paper are of high relevance to the communities of UTM researchers and practitioners. The paper provides important insights on social perceptions and constructions of some of the key concepts that will need to be covered if UTM is to be successfully deployed, from the perspectives of those involved. We anticipate that the success of UTM will not only require working technical solutions, but that these need to be acceptable to technology providers, service providers and end users. A sound understanding of the broader concepts of safety, trustworthiness and fairness based on empirical investigation is therefore called for.

The paper describes the research as follows. We start by providing a short review of existing literature related to key background concepts before outlining the methodology employed in collecting and analysing the data. We then present findings, broken down into the three main concepts of trustworthiness, safety, and fairness. The discussion then presents conceptual insights and theoretical and practical implications for regulation and technology development. The paper concludes by suggesting next steps that will help overcome the limitations of the current work.

2 BACKGROUND

Today the busiest airports in the world handle fewer than 300 operations per hour, but by 2035, large cities could see as many as 65,000 UAS operations per hour, a 200-fold increase [2, 22]. The rise of UTM systems therefore represents a pivotal development in the evolution of modern aviation. It is here we pitch our research that focuses on understanding what key elements should shape trustworthy UTM systems.

2.1 Trustworthiness, Transparency and Uncrewed Aerial Systems

Trustworthiness is a fundamental component in the deployment and operation of UTM systems and UAS [21]. Establishing trust among stakeholders including regulators, operators, and the public is considered crucial for the successful integration of UAS into public airspace. However, trust is complex and encompasses myriad aspects such as safety, reliability, transparency, equitability, security, risk, and ethics [15, 22]. Even once established, trust can be impacted by the implementation and behaviour of UAS [21]. Whilst there is no set definition to trust, we, inline with many others working in this field, subscribe to the definition of psychologists Mayer, Davis, and Schoorman: "The willingness of a party to be vulnerable to the actions of another party based on the expectation that the other will perform a particular action important to the trustor, irrespective of the ability to monitor or control that party" [20].

To improve trustworthiness, then, it is essential that UTM shines light on the ability, integrity, and benevolence of the operations carried out. This may mean, for example, ensuring that people can easily distinguish who is operating a drone (e.g., delivery provider), what the drone is doing (e.g., delivering goods), why (e.g. for a healthcare provider), and how (e.g., following a predictive flight path) [4, 6, 14]. Trustworthiness is further complicated by the factors such as developments in machine learning or AI, altering how aircraft are controlled and utilised [6, 11] and the anticipated number of UAS entering the skies. As the ratio of autonomous systems to operators increases, as is predicted in the UAS sector, overall system trust declines rapidly, particularly if the reliability of automated functions or control systems decreases [8]. As such, there are numerous areas of concern emerging in the literature regarding not only the importance of trustworthiness, but also the many risks involved in trying to build it. However, there is still little comprehensive investigation of the *boundaries* of trustworthiness, nor into the priorities of experts in the field as to which elements ought to be addressed sooner.

2.2 Practical and Ethical Concerns

In order to evaluate current and future UTM systems, we prioritise three, intertwining aspects. Trustworthiness, as demonstrated, is important to ensure uptake. Our other two aspects, fairness and safety, contribute to trustworthiness but are also core tenets of the airspace themselves, appearing in the strategic objectives of a number of aviation authorities such as the UK's Civil Aviation Authority [1] (CAA) and the FAA [2]. Safety in particular is a cornerstone of existing aviation management systems and subsequently will likely be considered a cornerstone in UTM. Within the applied definition of safety by aviation authorities, safety can be understood to mean the prevention of physical, economic, and social harm. As such, and building on existing systems, safety under UTM involves the development and implementation of fail-safe mechanisms and redundancy mechanisms including advanced collision avoidance systems, reliable communication protocols, and robust navigation technologies [17]. These systems must also be capable of managing and coordinating unprecedented numbers of vehicles without failures or significant delays [15]. The importance of successful, safe management of UAS is not only vital for the service users, but once again ties back to trustworthiness. For example, a collision between agents that results in societal harm – be that through debris falling on civilians, damage to property, or delays to other vital infrastructure - will affect perceived trustworthiness and subsequent reliance or tolerance of UAS.

An additional complexity to developing safe UTM is the requirement for accurate predictions of human and UAS' behaviour to carry out safety-focused, in-the-moment decisions, challenging due to the UAS proximity to humans. As such, UAS operators may find themselves in a position wherein they must make moral, spur of the moment decisions that may have a great impact on a wide array of stakeholders. In the future, this will also apply to autonomous UAS, leading to the considering of UAS operators and UAS as moral agents [23].

Equitability, as noted, is also a core tenet of existing airspace management systems. For this paper, we use the phrase 'fairness' to mean equitability, or equal opportunity to engage in, criticise, or benefit from the systems discussed. Fairness in UTM and UAS discussions is a critical consideration for the equitable and inclusive integration of these technologies into national airspace. For conceptual clarity we argue that fairness encompasses equitable access to national airspace, non-discrimination in terms of equitable access, accountability, and transparency in both policy and practice regarding the integration of UTM and UAS in shared spaces. Under the considerations for policy development, it is imperative to balance commercial interests with the needs of smaller operators, ensuring that all stakeholders have fair access to the benefits of UAS technology. This argument is already underpinned by accusations regarding the oversight of regulatory bodies being influenced by large companies [7, 18].

[1] https://www.caa.co.uk/Our-work/About-us/Our-role/
[2] https://www.faa.gov/about/initiatives/cp

2.3 Summary and a Note to Readers

This background segment has provided an overview of a number of existing concerns around trustworthiness in UTM, which are compounded by and in turn compound key concerns regarding safety and fairness of the airspace. Enabling transparency and consistency in a rapidly expanding industry that, in turn, enables accountability without compromising efficiency is not a new problem unique to UAS. However, the ways in which these concerns must be addressed *are* novel. Balancing the protection of life, goods, and infrastructure within an ecosystem of human and artificial moral agents provides an unprecedented challenge to stakeholders at all levels, from regulators, to pilots, to controllers, to people on the ground. At present, existing regulators are uncertain of how best to prioritise and tackle these issues, which is manifesting as stagnancy in developing a reliable, consistent UTM, and therefore stalling the UAS industry from, if you will excuse the turn of phrase, taking off. However, within this mire we also glimpse existing knowledge that, if drawn out and allowed to flourish, could provide the context needed to invigorate the development of a safe, trustworthy, and fair UTM. To begin to address these questions, we must first identify the system boundaries of UTM. As such, we turn to existing stakeholders and provide them a platform to express their concerns, questions, and indeed suggestions about the future of global UTM.

Before beginning, however, it seems prescient to note the underlying motivation of this work. The contentious nature of UAS and drones are a debate beyond the scope of this paper. Nevertheless, it should be acknowledged that the application of UAS, much like any technology, can be conducted for good or ill. Further, defining what is 'right' or 'wrong' in such scenarios is often done by those with vested interest in particular outcomes, and therefore may not align with the moral directorate of other individuals, groups, or nations. This paper does not seek to cast a value judgement on the merits of UAS uptake. Rather, as researchers we perceive the rapid growth of this sector and wish to draw attention to the lack of frameworks and regulations surrounding it as a matter of urgency. It is our intent that this work provokes important conversations and insights around how these technologies can be developed and integrated ethically and pave the way for future conversations to be had around ethical application.

3 METHODS

The study adopted a qualitative approach involving 13 interviews conducted with experts from fields related to UAS, UAV, and UTM between February and May 2024. We used a multifaceted approach to recruitment that included Academic Institutions, industry organisations, regulatory bodies and professional associations. Recruitment efforts also involved sending email invitations, posting on relevant online forums, and utilising social media platforms. Further participants were recruited through snowballing techniques and recommendations made by identified participants. Finally, the Trustworthy Autonomous Systems Hub posted a call for participants on their social media pages. Participants were asked to self-identify as 'experts' in their related field, and to have at least one year of experience in a role directly related to UTM, UAS, or UAV.

Semi-structured interviews were conducted online through Microsoft Teams and lasted between 30 – 45 minutes. Participants were

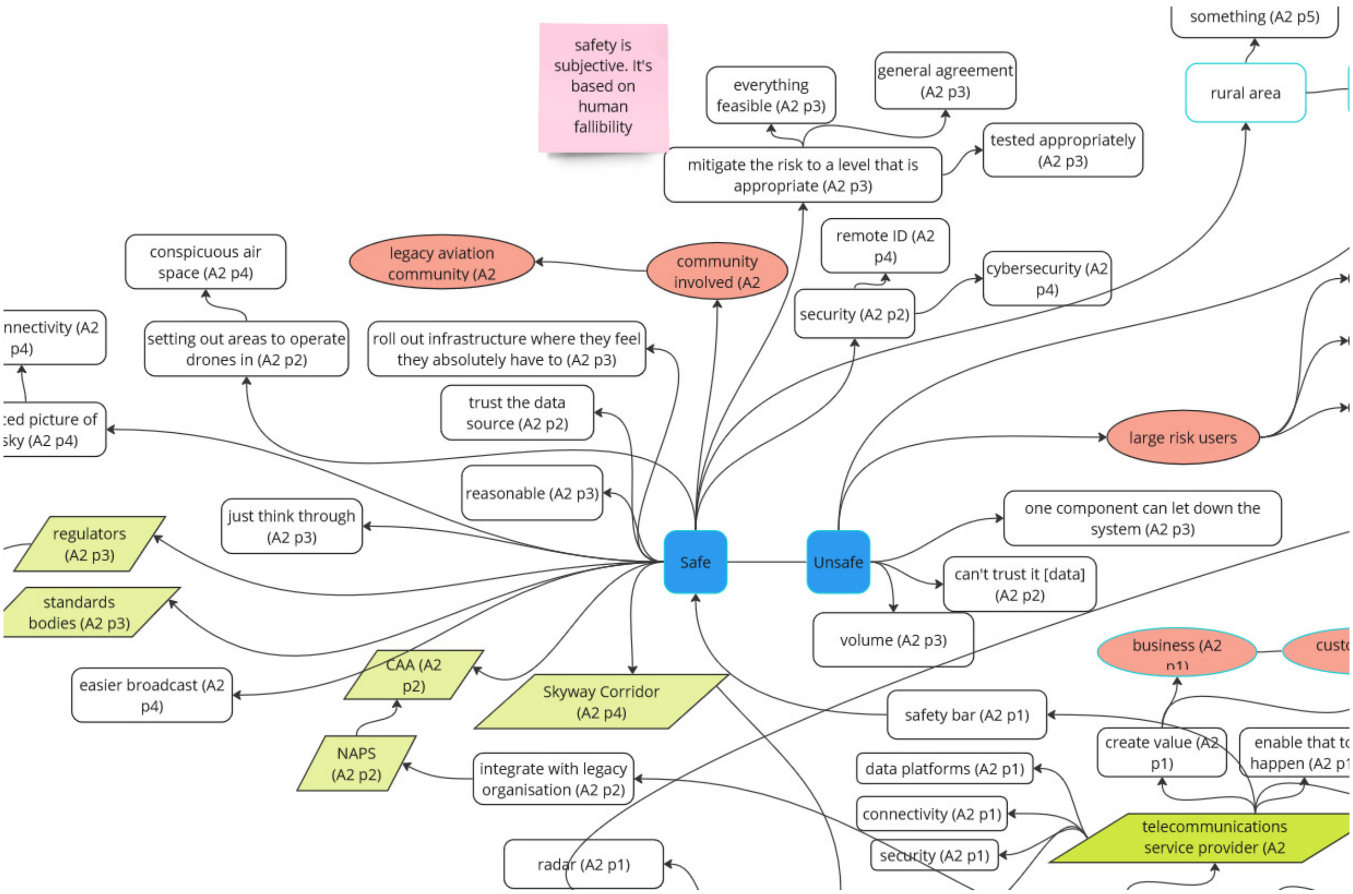

Figure 1: A cross section of the cognitive map of Participant A2. Uncoloured rounded squares represent concepts. Blue rounded squares represent pairs. Green parallelograms represent artefacts. Red circles represent stakeholders or actors. Sticky notes represent non-sequiturs or interpretation of the researcher(s). Arrows represent relationships or decisions.

provided with information sheet, consent form, and pre-screening questionnaire prior to the meeting, and consent was verbally confirmed at the outset of the call. Teams' inbuilt recording and transcription software was used to capture interviews, and transcripts were manually cleaned by the lead author. Ethics for these interviews was attained through the University of Nottingham Computer Science Research Ethics committee (CS-2023-R17).

Transcripts were subject to a process of cognitive mapping. Cognitive maps are a way to capture "one's internal representation of the surrounding world" [13]. These individualised maps rely on the concept of mental models [9, 10], the internal and external structures that individuals use to understand and engage with the world. Mental models allow people to infer and make assumptions from overwhelming amounts of information and data in any given scenario, without having to actively process each piece of data individually, thus freeing up the cognitive capacity necessary to function in the world [24]. Cognitive mapping captures mental models in various, diagram-based formats to allow cross-examination between the individual cognitive maps of a single person, and broader themes that emerge across the maps of multiple people. Generating these maps enables the researchers to process and understand large amounts of messy or complex qualitative data regarding a 'problem' or concept by manually noting down the connections and links. Cognitive map styles may focus on drawing decision analysis mental models, concept maps, or semantic webs [24]. In this paper, we draw on a simplified form of decision analysis cognitive mapping, which captures "an implicit social agreement between those that create risk (e.g., government planners, industry, natural resource managers) and those that bear risk (e.g., laypersons, plan implementers)" [24] (p. 1336). Participants were asked to broadly define UTM, and to explore what their key concerns were around safety, fairness, and trustworthiness within UTM, for example by answering what a 'safe' airspace might look like, and what needs to be implemented to achieve that definition. From transcripts of each interview, stakeholders, artefacts, concepts, and decisions were identified and mapped around pairings (safe and unsafe, fair and unfair, trustworthy and untrustworthy) and connected by directional lines to showcase the mental model of the participant, an example segment of which can be seen in Figure 1.

Cognitive maps are exceptionally useful to interpret messy, complex, and evolving mental models/system models. However, cognitive maps can never be 'completed' as mental models shift and adapt continuously. Further, mapping the sum total of an individual's mind as it relates to a topic is an impossibility for any method. Rather, our maps capture an overview of a moment in time, and whilst unable to offer incontrovertible truths about the universe or individual experience, they do offer insights into how systems are experienced, understood, and interpreted within that spatio-temporal context.

Full, separate cognitive maps were made of the first four interviews conducted. From these maps, key themes and sub themes were identified. All 13 interview transcripts were then subject to thematic analysis, shaped by themes identified from cognitive maps, to create a broad overview of the conflicts, consistencies, dilemmas, and feedback loops that emerged. The identified themes form the structure of the findings section presented in this paper. This process was done in Lumivero NVivo 14's Collaboration Cloud.

4 FINDINGS

13 Participants represented a broad range of sectors, roles, experience types, and experience levels. For anonymity, these details are left unassigned, however, generalised information can be seen in Table 1, where the response is shown in the left cell of each column, and the number of participants who answered with that response in the right cell. If participants self-described as fitting more than one category, they have been counted in all of the responses they gave, e.g. if someone lived in both Belgium and France, they would be counted in both responses. All participants were male.

Questions asked of participants were organised by three key themes – safety, fairness, and trustworthiness. These three themes are used to structure the bulk of this section. However, throughout the interviews it became increasingly clear that there was no generally accepted definition of what UTM was. As such, we begin by presenting an overview of the varying conceptualisations of UTM.

UTM was used as an acronym for 'Uncrewed Traffic Management', 'Unmanned Traffic Management', and 'Unified Traffic Management'. The goals and remit of UTM was contested. For some, it is a form of traffic management specifically designed to prioritise UAS. For others, it is a system that builds on and advances traditional, manned ATM to integrate UAS in the airspace alongside other users. For others still, it is a fully automated ATM system that completely removes the need for human involvement in UAS traffic management, with the ultimate intention of replacing ATM as well.

The purpose and priorities of UTM was also contested, whether it be about ensuring safe entrance to the airspace, controlling who accesses the airspace, or preventing misuse of the airspace. One key suggestion was that UTM should focus on enabling BVLOS operations, wherein the UAS is able to be flown beyond where the operator can physically see it. This achievement was highly prized by participants as it would then further diversify potential use cases of UAS, e.g., connecting rural communities (A11), allowing access to uncontrolled airspace (A12), and "*[increasing] safety for people on the ground as well as the safety for the entire geography*" (A13). These goals were implicitly assumed to then improve trustworthiness, fairness, and safety for all stakeholders including regulators, service providers, and the general public.

Despite the general consensus that UTMs would have overwhelmingly positive effects, there was also some scepticism of the ability for the industry to implement "*interconnected*" (A10), functional systems in the foreseeable future. Most participants put a minimum timeframe of 10 years for when UTMs could be expected to be functional, as "*I've been in the industry seven years and having the same conversations that I started out with*" (A12). "*They're talking a lot, but not solving the problems*" (A10). The necessity of UTM in the short-term at all also garnered passionate responses, as "*there's a whole load of very bombastic, what I'd say slightly bullshitty, announcements about how prevalent, how big this market is and how soon it's going to happen, none of which I personally believe in*" (A10). Instead, some participants argued that focus should be placed on ensuring the peripheral details such as UAS technology and regulations were well developed:

> "*If you think about it in two parts, you've got the need for traffic management at the moment, which is well, there's nobody flying drones. So what do we need it for? (. . .) The bigger argument is your safety case. So very few operators in the UK can make an effective safety argument why they're safe to fly because they are unable to quantify the risk that's involved in different areas*" (A11).

However, the general attitude to UTM was positive, with participants strongly advocating that working towards building reliable, interconnected UTMs is not only necessary, but beneficial for the industry as "*we are building today all the system, all the community, the manufacturer, the airspace, the authority, we are building a lot of nice things for the future*" (A5).

4.1 Trustworthiness

Trustworthiness was discussed by participants in one of three ways; trust in the technology, trust in the regulators, and trust in the users. This was further broken down as to how to improve trustworthiness in each of these aspects for the user, the regulators, and the general public. Trust in the technology was typically very high, whereas trust in the users and regulators was much lower.

4.1.1 The Technology. There was a high level of trust in UAS technologies to be developed and deployed safely and quickly. However, there was also an awareness that being seen as trustworthy by the general public was a prominent challenge, particularly for the use of UAS by private companies where expectations around integrity and benevolence were low: "*most of the people will be against, not just only because of the noise, it's also because they don't understand the need for private company to have it*" (A5). Being seen as trustworthy by the public was considered important as it would make or break the concept of using drones for daily public services like deliveries, transportation, and emergency uses. Subsequently, it was considered vital that UTM should incorporate considerations around public trust within its design and implementation:

> "*OK, let's look how it works with acceptance. It will be in 10 years and probably then we will face major issues that will have been too late to tackle because we didn't take those ten years to try to convince the population of the interest of going through there to show them that is not just because 1% of the rich side of the population that will use it. We have to show that it's an innovation,*

Table 1: Participant Backgrounds

Country of Work		Sector		Role		Experience Type		Years in Sector	
Belgium	1	Academia	1	Airline Pilot	1	Commercial	4	1-2	1
France	2	Industry	5	CEO	1	Funding	1	3-5	2
Germany	1	Policy or Regulatory	4	Consultant	2	Infrastructure	2	6-10	1
Ireland	1	Software	2	Director or Managing Director	6	Policy	4	11-12	5
UK	6	Telecoms	1	Head of Drones	3	Platform Developer	1	21-30	1
USA	3			Research Fellow	1	Regulation	2	31+	3
		Vice President	1	Research and Development	2				
						Training	1		

> *it will help, it will promote some new kind of traffic of connection or delivery. This is, let's say the future of innovation*" (A5)

Trustworthiness was not only seen to be affected by how UAS are used, but also in the motivation behind it such as ensuring people did not feel spied on or monitored and making sure that the usage of drones in warzones was not just representative of imminent danger, but also for rescue, supplies, and other forms of support. It was further expected that UTM should have fail-safes built in for unforeseen events, such as navigating through adverse weather, natural disasters, and drones going "*rogue*" (A1).

Other concerns expressed by participants regarding the technology behind UTM were related to the trustworthiness of data collection and use. These concerns were particularly around ensuring clear and accessible data, a clear demarcation of data rights for non-users, and having safeguards built in to protect all possible actors, especially as some organisations already adopting UAS are perceived as "*data hungry*" (A6).

4.1.2 The Users. Building on concerns around the technology behind UTM systems, we saw that some industries or organisations begin with higher levels of trust than others. In part, this correlates with the expected usage of organisations. For instance, organisations who are understood to be, as A6 said, "*data hungry*" bring with them higher concerns of being 'spied' on. As A6 went on to say, "*no-one owns the airspace above their dwellings, but they do own a right to privacy*" (A6). The Chicago Convention, signed into United Nations law in 1947, declares that the state owns all airspace above its territory. As of time of writing, there are no clear delineations on the altitude at which the airspace above privately owned land becomes state owned. As such, it was a pressing concern for many of the participants that UTM should be conscientious of grey areas in the law, particularly, again, when incursions may affect public perception of UAS.

Further, the user was at the heart of much of the debate around trustworthiness, as they were deemed to be the "*lynchpin*" (A1) of the UTM debate. UAS users were seen to cover a wide range of sectors and motivations including large scale commercial deliveries, small scale real estate surveying, or individual recreational users. Many of the experts noted that the behaviour of users was as instrumental to the trustworthiness of UAS and future UTM systems as the motivation behind their usage. For instance, bad behaviour was typically understood as being down to thoughtlessness (A1) as the UAS community do not "*[take] it seriously enough*" (A4). However, some of the participants also expressed that they had witnessed deliberately poor or even "*malicious*" (A1) behaviour from users. There were mixed opinions on why this may be, as some participants argued that most UAS users are coming from an aviation background and therefore do not have the "*maturity*" (A13) as an industry to know how to behave, where others argued that most UAS users were coming from a technological background and therefore don't have the conventional aviation knowledge to properly utilise the airspace.

4.1.3 The Regulators. The regulatory bodies surrounding UTM are currently fractured and oblique. Many countries are opting to allow their aviation authority to develop regulations around UTM and UAS. However, participants highlighted myriad problems that this approach presents. For instance, aviation authorities were recognised to already be stretched and struggling to keep up with the demands of traditional aviation, leading participants to question whether they would have the capacity to regulate the emerging UTM services: "*I think this is the problem with the CAA, that people don't trust it because they don't, they come up with contradictions that people aren't good enough, they're overworked. All this sort of stuff*" (A10). Further, it was suggested that lack of oversight had led to a swathe of alternative organisations and thinktanks emerging, all competing to achieve their goals and subsequently preventing each other from making progress, and each with their own opaque agendas. For instance, a multi-million pound research fund that aimed to enable innovation in the UK's aviation airspace was questioned by A11: "*if you look at what [fund] reports to, it reports to something called the Aviation Council, now if you look at who sits on the Aviation Council; [list of four popular airlines] - all manned airlines*" - suggesting that the needs of UAS might not be being represented to an accepted degree.

4.2 Safety

Safety was commonly considered the "*core of aviation*" (A13) and the most immediately important of the three aspects. Participants frequently argued that UTM would, and indeed must, improve safety, as airspace management is "*always about safety*" (A4). Despite this, what constituted as a 'safe' airspace and how this could be achieved was heavily disputed. For instance, safety could mean the reliability of the UAS technology itself, the effectiveness of supporting infrastructure, not doing physical harm to people, or even protecting the environment. However, safety was not seen as a priority for all stakeholders. The GA community (non-commercial aviation such as gliders, hot air balloons, weather balloons, police helicopters, aerial surveyors etc.) were generally understood to have a much higher risk tolerance than commercial aviation. This higher tolerance for risk was also understood to be starting to be replicated in the existing UAS industry and was something that participants were keen to reduce through the application of UTM.

4.2.1 Re-using Existing Frameworks. Where other industries, such as commercial aviation, have had time to develop safeguarding procedures and regulation, UTM as a concept is still so juvenile that this is not yet the case, meaning "*the risk [surrounding UAS] is still high because there we don't have any control*" (A5). For some participants, the obvious – and fastest - route to developing a safe UTM is therefore to draw on pre-existing frameworks, particularly commercial ATM: "*if we look far from here, UTM will be something like a digitalised ATM*" (A5). Indeed, one participant even recommended that UTM and ATM should not be considered distinct from one another:

> "*Actually do you reverse the challenge and actually you say we already have known things in the sky, commercial aviation, how much of that are we looking to fully automate and how do we deal with existing aviation, make that into a fully automated system, and then bring new aviation once we've actually shown it works with existing aviation constructs rather than trying to create a new upstart industry*" (A11)

However, for others, the idea of basing UTM on ATM principles raised more concerns than it solved, as they saw UAS as having such different needs from existing aviation technologies, that they could not see how overlapping the two would progress safety, instead fearing that relying on traditional aviation would hinder development:

> "*If you want to hold drones, to hold them back from operating until they can figure all this stuff out, it would be about the same as going back to 1926 and telling Mr Boeing hat he can't fly in United Airlines without TCAS. You know, because eventually, you know, you're going to have to have it! And you know then we'd never have commercial aviation if that was the case*" (A7)

Further, the development of UAS and UTM related technology was also contentious, as whilst several participants claimed confidence that the technology was close to, or indeed already, capable of deploying 'safe' UAS, others felt that the technology still had a long way to go to be as safe as they wanted: "*I'm confident of the technology. I'm confident that drones are about as safe as cars. I'm absolutely sure drones are not as safe as aircraft*" (A10). The division between these two opinions correlated to the sector that the expert worked within. The technical side of things was considered by experts who came from a more social angle (such as researchers and regulators) to be 'easier' to deal with, heavily relying on the assumption that technological advances would solve most technical problems quickly and efficiently. However, experts who came from the more technical side (e.g. practitioners and engineers) believed that the technical problems were a far more pressing concern than any social issues that could 'easily' be dealt with at policy level.

4.2.2 Regulators and Regulation. For some, the lack of clear existing regulation highlighted the need for UTM even more than the other points raised so far. However, this lapse also highlighted the need for a specific regulatory body responsible for enforcing those regulations. Currently, most countries appear to assume that their respective airspace authority would take on this mantle e.g. the CAA in the UK, the European Union Aviation Safety Agency in Europe (EASA), and the FAA in the USA. Most participants were fairly confident in the ability of these authorities to integrate UAS, however, some believed that a new regulatory body is needed that is specific to the creation, implementation, and regulation of UTM compliance in low altitude airspace.

Another suggestion was that other existing bodies, such as telecommunication regulators, may also be able to contribute to the creation of a safety-conscious UTM, depending on the element under scrutiny: "*There's some interesting debates to come because the technical standards will come from a regulator, an aviation regulator, but they might also come from an Ofcom regulator. You know, they may come from others, they may come from the (. . .) Information Commissioner's Office to define the, you know, the surveillance standards*" (A6). Telecommunication regulators were suggested as a possibility as they already have infrastructure in place that could support UAS to be utilised safely, for instance by drawing on mobile phone networks' datasets to not only provide a back up to a "*brittle*" (A10) GPS-based location system, but also to provide useful data regarding the environment the UAS are operating in.

4.2.3 Cybersecurity. The potential use of existing infrastructure and data sources to fully automate UTM, however, also brought with it additional safety concerns around cybersecurity: "*a highly automated system, it has the potential to be much safer, but in making it highly automated, you're introducing these sort of single point vulnerabilities where one well positioned hack and suddenly 10,000 aircraft are out of control in the same air space*" (A6). This was discussed as extremely high risk, particularly as recent activity in warzones around Ukraine and the Middle East show the ease with drones can be disabled through spoofed GPS signals and signal jamming.

4.3 Fairness

Fairness was the facet that participants struggled to engage with most. Definitions of 'fairness' regarding UTM were broad, but typically required 'equitable' access, as "*the airspace is for everybody*" (A5) and so people should be "*able to do what they wanted at that particular place and time*" (A8). However, for some, fairness was beyond the remit of UTM, at least for now, as "*the sky's not dark with drones, you know? So you know, this is not a huge issue, and if, there are so many issues that that we need to resolve eventually, that if we hold people to resolving them before they do any flying, they'll* *never fly because it'd just be too, it'd take too long, it'd cost too much, they'd run out of money and it's over*" (A7). For others, fairness was a key tenet on which they thought UTM should be based, with multiple participants citing the mantra of air traffic control that a fair airspace is one that is 'safe, orderly, and expeditious'.

4.3.1 Accessing the Airspace. As noted, one idea that was circulated was that UTM should be based on, or equivocal to, ATM, as it had achieved fairness of airspace for traditional aviation, and so could be reconstituted to do the same for UAS. To ensure fairness of access to the airspace, a common query was whether airspace should be segregated or unsegregated. These questions were contentious, and evoked strong opinions on both sides of the debate. Restricting, or segregating, airspace was more often considered to be unfair, although some saw it as a necessary evil, and most acknowledged that certain situations would require some restrictions to be put in place "*on behalf of society at large*" (A1) e.g. to enable emergency services or prevent access to dangerous areas. However, for other participants, failing to segregate the airspace through UTM would inevitably lead to a "*wild west*" (A4) scenario in which smaller users would likely be bullied out of the space and larger users would work toward monopolising it.

One interesting facet of this debate was in the conceptualisation of the airspace. For those who argued that segregated airspace was the fairest way to ensure equitable access, they usually saw the airspace as a limited resource, and worried that there was not enough to go around. Those that argued that airspace should be unsegregated typically considered the amount of airspace to be vast and big enough for everyone. Despite these differences, all agreed that everyone who wanted to should be able to access the airspace, and that there needed to be a hierarchy of who had more "*legitimate*" (A2) access to airspace.

Despite this, not everyone agreed that fairness should be, or even could be, embedded in UTM, arguing that "*we don't have equal access to airspace now with manned aircraft, you know, we have the concept of better equipped, better served*" (A7). Equipage is the equipment needed for a UAS to be flown in airspace and varies across jurisdictions. Typically, most UAS must be equipped with an electronic cooperative system, or electronic conspicuity systems; navigation; and anti-collision lighting. This allows for the rule of aviation to shift from see and avoid to "*see, be seen, and avoid*" [3]. This development, whilst considered good for safety, was seen to contradict fairness doctrine as "*a fair approach to the airspace basically means that to the extent possible, you don't want to impose equipment that is not required and you want to allow different systems to take as much space as they need to accommodate for their use case*" (A9). This attitude towards adopting mandated equipage was particularly divisive when discussing the General Aviation (GA) community. Indeed, the GA community garnered some very tongue-in-cheek criticism regarding their perceived stubbornness: "*but you've got a bunch of dinosaurs who fly light aircraft who go well, no, I don't want to change what I'm doing and I don't want to put a transponder on my aircraft because I don't need to and you guys have to work around me*" (A10). The GA community in general were seen to be very vocal and "*trick[y] to deal with*" (A12) as they were perceived to not want to have to change how they currently access and use airspace, nor to feel like they were being surveilled via equipage. However, GA are still separated in the zeitgeist from UAS, precluding their involvement in formal discussions regarding the development of UTM, preventing peaceful harmonisation of the two communities.

4.3.2 Regulating the Airspace. Further questions around fair access were raised regarding the user behind the UAS, and how equitable access could be managed in such a way as to prevent larger operations from dominating resources. Current regulations (based on ATM) limit access to airspace based on a 'risk budget' model wherein only x amount of vehicles are allowed through an airspace in a given period of time. Further complicating risk management, there is no universal way to measure safety in aviation. Most common are systems that measure accidents per number of flights and departures, flight hours, and/or passenger miles [20]. These metrics are inappropriate for UAS as number of flights are still low, and most UAS do not yet have passengers on board. Further, a risk budget model is at risk of enabling larger or more resource affluent organisations to dominate the airspace and prevent smaller organisations or startups from being able to enter. This concern is further compounded by the inability for small operations to prove their safety without appropriate metrics, creating a vicious cycle that stops UAS operators from conducting flight hours needed to gain approval, meaning that they cannot access the space they need in order to prove that they should be allowed to access it: "*we found it was easier to get permission to do a whole load of innovative testing of drones on the main runway at Heathrow, which we did overnight, not during the day, than it was in the middle of Cape Ness in Scotland, where there are like 2 sheep and no people*" (A10). Furthering these concerns, small organisations have also been excluded from policy discussions as they cannot spare the resources to participate in regulatory meetings or trials (A8), making it seem to regulators like smaller operations were not invested in shaping policy, subsequently leading to already over-stretched regulators re-allocating resources away from hosting round tables in which small organisations may have their needs heard.

The sluggishness and inability of regulators to adapt to UAS needs was an issue for many of the participants, who expressed frustration that "*the regs are all currently designed about what I would call traditional aviation*" (A12) as it means that "*the aviation authorities are not, I don't know, they're not designed and they're not built to deal with, and they don't really have the mindset to deal with this kind of technology push. You know, they're all around traditional aviation, things take 5 to 20 years to happen*" (A12). These frustrations extended beyond just fairness of access for flying, and into other elements of UTM such as ensuring consistency across different jurisdictions and enabling further developments.

5 DISCUSSION

Our findings highlight key concerns, criticisms, and opportunities presented by expert UTM stakeholders. From these findings, we uncover three avenues within which progress would improve the trustworthiness, safety, and fairness of UTM, and thereby ensure the UAS industry is given opportunity to grow and evolve. First, by defining the system boundaries of UTM with clear definitions, roles, and jurisdictions. Second, by making clear who the appropriate, accountable regulatory body (or bodies) are and their specific roles.

Finally, providing platforms for more stakeholders to share their concerns, criticisms, and hopes for UTM – even outside of the UAS community – at all levels of the development process.

5.0.1 Defining UTM. Throughout this project, it has become increasingly difficult to fully delineate between trustworthiness, safety, and fairness as the concepts have overlapped and intersected. Further still, on several occasions, the concepts were seen to contradict and interfere with one another. For instance, where it was widely believed that implementing mandatory electronic conspicuity would improve safety, it was also understood to potentially reduce fairness if an operator could not afford the expensive kit. Even more complicated, electronic conspicuity would simultaneously improve and threaten trustworthiness, as it would make UTM data more reliable, unless the system was compromised. As such, it becomes clear why stagnancy is threatening this emerging industry, and why regulators may be so reticent to commit to one approach over another. However, based on the input of our participants, we contend that lack of decisive, definitive evolution of UTM will be a deciding factor as to whether the UAS industry succeeds or fails. As such, deciding what falls within the confines of 'UTM' becomes potentially the most pressing issue for the community to address to prove safety and fairness, and build trustworthiness.

Whilst further work to concretely address the boundaries of UTM must take place, our initial findings suggest that it should be a *safety-focussed system that lays out clear, concise requirements for all air traffic flying at low-altitude range.* These requirements should focus on enabling collision avoidance, communication, and navigation. Part of this should be in the required sharing of data regarding who, what, why, and how a UAS operation is being flown. This information should be easily understood, and easily accessible. For instance, emergency services could rely on established brand identity through coloured markings and lights. Further to this, for-profit organisations of all sizes who may start with lower levels of trust should be given the same opportunity to prove their ability, integrity, and benevolence through structured testing and the development of metrics specific to monitoring UAS safety. Finally, UTM should also offer a framework to govern prioritisation of access, as well as a moral and ethical framework for piloted and autonomous UAS to rely on.

5.0.2 Regulating UTM. Currently, any policies or regulations developed are not clearly or coherently enforced by any one regulatory body. Indeed, the majority of interviewed experts believed that no existing regulatory body was currently both suitable and able to adopt the mantle. However, it is vital that an appropriate regulatory body is identified and implemented for each jurisdiction as soon as possible, to allow it to grow with the industry and establish itself over time. Whether this body emerges from existing aviation authorities or is appointed from one of the thinktanks or organisations that have developed to try and drive progress is a topic for debate. Nevertheless, it is vital that whoever the body is, they have specialised knowledge in UAS, UAV, GA, and low altitude airspace; as well as the capacity to make individual and flexible decisions in moments of crisis or emergency. The body should be both accountable and hold UTM users accountable. It should define what is fair and listen to all stakeholders to make sure that definition holds true in practice. Importantly, this means that it has resources dedicated to managing and implementing UTM, as well as to progress it in the future as the UAS industry evolves. Finally, it should be designed to integrate and co-exist with similar bodies in other jurisdictions, all of whom should be applying similar principles and definitions of UTM.

5.0.3 Community Interoperability. UTM is not currently considering a broad enough range of stakeholders in its development. This reduces trustworthiness of the system before it even exists and further prevents principles of trustworthiness, safety, and fairness from ever being embedded in it. This must be addressed by actively including, not passively excluding, people in policymaking who fall outside of traditional aviation or large corporations including startup organisations, the GA community, and the general public. Problematic isolationism is already beginning to pervade UTM and must be addressed soon; it even emerged during the interviews, where participants involved in UAS were very disparaging, albeit often with some cheek to their tone, about the GA community, despite both having similar needs in terms of safe and fair access to low altitude airspace. Further still, the isolationism could even be seen within the UAS community, where participants focused on more social elements of UTM thought the technological work was an easy fix and vice versa. Until a more universal understanding of what the airspace is, who uses it, why, and how can be achieved, UTM will be inefficient in addressing any one of those concerns. This will subsequently lead to issues in the future including lack of uptake, reduced safety, and loss of innovation. Further, it was shown that an additional benefit of ensuring different communities are involved in UTM discussions is the idea of novel interoperability. For example, by including the expertise of telecom and infrastructural engineers, it was expected that UTM could integrate existing infrastructure and data packets to faster, and more reliably, introduce UAS to the airspace. As such, community interoperability and exchange should be facilitated as part of the successful development and long-term maintenance of UTM.

5.1 Limitations and Future Research

This work presents the first stages of a broader investigation into the trustworthy, safe, and fair development of UTM systems. As such, our findings represent a relatively small data pool that will be expanded in the future. All participants were male, and all were based in the USA, UK, or Europe (although some also had experience or expertise in other countries). All researchers who contributed to this paper were also based in these countries. As such, our findings are likely skewed to a western perspective. Concerted effort should be made in future research to understand cultural and geographical differences across other continents.

As per our discussion, it emerged as an important part of this research that different perspectives with different priorities are given opportunity to contribute to this kind of research. As well as building on this by bringing these voices directly to one another, future work should also look to gather the perspectives of other stakeholders affected by UTM including GA and traditional aviation.

Further, whilst the aviation and novel technology industries do skew heavily male, future research should endeavour to gather perspectives from women or other minority genders in addition.

Finally, we acknowledge that UAS and UTM are rapidly evolving fields. Best efforts have been made to ensure technological and policy-related information is up to date at time of writing, however, changes are constantly coming into effect that may render parts of this publication less relevant.

6 CONCLUSIONS

This paper presents the findings of interviews with experts involved in multiple facets of UTM. Through a focus on trustworthiness, safety, and fairness, we investigated concerns and opportunities around the implementation of UTM that impact the uptake and longevity of the UAS industry. We showcased the many inconsistencies and contradictions within UTM principles that contribute to the complexity and also the necessity of progress in this area. To this end, we provide three areas of focus that represent the priorities of stakeholders; defining UTM, regulating UTM, and enabling community interoperability. We posit that the continued development of UTM systems *without* explicit consideration of these elements will fail to elicit a long-term, efficient UTM ecosystem. Rather, by incorporating these concerns into the development of UTM, an ecosystem will be generated that is long-lasting, flexible and reliable to meets the needs of all stakeholders, and which will encourage the UAS industry to thrive.

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A GLOSSARY

- AI – Artificial Intelligence
- ATM – Air Traffic Management
- BVLOS – Beyond Visual Line of Sight
- CAA - Civil Aviation Authority
- EASA - European Union Aviation Safety Agency
- EVTOL – Electric, Vertical, Take Off and Landing Vehicle FAA - Federal Aviation Authority
- GA – General Aviation
- NASA - National Aeronautics and Space Administration
- UAS – Uncrewed/unmanned/unpiloted Aerial System
- UAV - Uncrewed/unmanned/unpiloted Aerial Vehicle
- UK – United Kingdom
- USA – United States of America
- UTM - Uncrewed/unmanned/unpiloted Traffic Management

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