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(Un)certain Skies? Drones in the World of Tomorrow

Corporate Partnership Board Report

OECD

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Foreword

The work for this report was carried out in the context of a project initiated and funded by the International Transport Forum's Corporate Partnership Board (CPB). CPB projects are designed to enrich policy discussion with a business perspective. They are launched in areas where CPB member companies identify an emerging issue in transport policy or an innovation challenge to the transport system. Led by the ITF, work is carried out in a collaborative fashion in working groups consisting of CPB member companies, external experts and ITF staff. Many thanks to the members of the Corporate Partnership Board companies involved in this work: Anheueser-Busch inBev, Google Inc., Toyota Motor Corporation, NXP, PTV, Uber.

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Executive summary

What we did

This report investigates the role of drones as part of the future transport mix. It specifically addresses the issues policy makers face in engaging with the emerging private drone sector. Drones for recreational purposes are not part of this study.

Drones are already deployed in the transport sector in surveying and monitoring the condition of infrastructure. They also promise to provide innovative services in freight delivery, passenger transport and disaster relief. With the sector developing at a rapid pace, regulators will want to create frameworks for drone use that allow innovation while ensuring positive overall outcomes.

The potential impacts of large commercial drone fleets are as yet not fully understood. Assessment of the potential impact on aviation has begun but appraisal is rarely addressed from a cross-sectoral perspective. Freight drones for urban goods deliveries and, eventually, drones for passenger travel, may have both positive impacts (e.g. improved connectivity in remote regions, traffic congestion alleviation, reduced travel times) and negative impacts (e.g. safety, privacy, noise, energy consumption, land use and visual amenity concerns). We explore how some of these impacts could be anticipated and included in appraisal guidelines to support the underlying policy goals of efficient, safe, sustainable and equitable transport.

The insights in this report build on expert interviews, a review of published research and a workshop with 37 international experts held in San Francisco in November 2017. Attendees included drone manufacturers, leaders of regulatory, humanitarian and economic organisations as well as representatives of companies that utilise drones as a central component of their businesses, or are planning to do so.

What we found

Drones, the technologies that enable them and their potential applications within the transport sector are already diverse and are evolving rapidly. Future use cases range from on-demand passenger drone services and fleets of freight delivery drones in urban areas to fully automated drones carrying large payloads and connecting continents in an airborne "conveyor belt". Drones also offer many promising support functions for transport systems. For instance, sensor-equipped drones can help to plan, maintain and manage transport infrastructure and traffic flows more effectively.

The current regulatory focus with regard to drones is on safety and interaction with manned aviation. Regulatory bodies have generally focused on the allocation of airspace for testing and on creating a framework for the licensing of commercial drone operations. The national and international civil aviation authorities driving this work currently prioritise the safe integration of drones with the existing manned aviation regulations.

The potential for disruption by drones extends beyond the aviation industry. The large-scale deployment of commercial drone fleets will challenge the transport system as a whole, for instance due to the potentially unlimited proliferation of "drone ports" for take-off and landing.

What role drones will play in future transport systems depends on the ability of this new "mode" to gain the social licence to grow. To build trust and public support, questions of safety will require answers together with a wide range of concerns traditionally associated with transport, including noise, emissions, energy consumption and social equity. However, novel challenges such as privacy and considerations about the visual amenity of cities and landscapes will also come to the fore. The aviation sector will provide significant input to tackle these questions, but experts from the wider transport policy community will also need to be engaged in the conversation.

The rise of drones provides regulators with an opportunity to foster an emerging market. Faced with disruptive technological change, regulators may support, hinder or act neutrally in the development of innovations. The key challenge is to test the suitability of existing regulatory frameworks for mitigating possible adverse impacts whilst allowing drone services to develop. Drone regulation will need to address the standard public concerns of efficiency, competition and sustainability.

What we recommend

Develop a vision for drone services integrated with the transport system as a whole

Drones could play an important part in creating an efficient, safe, sustainable and equitable transport system. The real value of passenger and freight drones is generated when and where they touch ground. Policy makers need to focus on the impact of the potentially millions of "drone ports" and their integration into the transport system, cities and society as a whole.

Include experts from outside aviation in the policy debate on drones

Several countries have established joint public-private discussion fora that bring together different parties interested in the development of a market for the use of civil, commercial drones. These "drone councils" are an excellent starting point for policy makers to develop a vision for drone services that are integrated with the transport system as a whole. They benefit from the inclusion of experts with a diverse set of backgrounds, including digitalisation specialists, transport economists and urban planners.

Explore the significant potential of drones for regional connectivity in thin markets

Many regions lack adequate surface access to potential markets. Particularly in developing and emerging countries, regional connectivity could be significantly improved for both for freight and passenger transport once reliable and efficient drone services are available. Such services could be a substitute for investment in infrastructure for surface transport networks. This could also benefit the connectivity of remote regions in developed countries to global markets.

Consider how drone services could become part of future urban transport

Drones present cities with a number of opportunities. They can alleviate pressure on ground transport and enhance emergency services. They can also make the work of different city departments safer and more cost efficient. Yet drones also present new challenges for cities, including questions of safety and security; the allocation, design and regulation of "drone ports"; the relation between drone services and existing ground transport services and questions of privacy, visual amenity and noise. Therefore city authorities should start to include drone transport into their urban development plans.

Mayors could use zoning powers to designate take-off and landing locations and set other operational criteria for drones. However, devolved regulatory authority could create fragmented and conflicting regulations.

Deploy drone services in a phased way that maximises public acceptance

Trials with drones have shown that public acceptance is high if the value proposition is clear to the public, e.g. for medical or humanitarian support. At the same time, increasing unease about safety, privacy and accountability can become a barrier to the introduction of drone services. Policy makers can alleviate these concerns by developing a vision for different use cases and a phased introduction supported by a progressive opening of markets for drones. The initial focus should be on use cases that provide clear value to society, such as emergency support or improved maintenance of transport infrastructure.

Mitigate innovation risk through coordinated research and development, tests and regulations

In order to create a market for efficient, safe and sustainable commercial drones, novel aircraft designs and air traffic management systems have to be developed. Significant public funds and large-scale test sites have been provided for drone development in many countries but further investment is needed and international coordination could save expenditure and accelerate progress.

Policy makers must also ensure that research programmes and funds will not look at technological questions in isolation but promote a more pro-active approach towards questions regarding the environmental, economic and social impacts of drones overall.

Introduction

Drones – a conceptual shift from military to civil applications

The public image of drones has undergone a surprisingly quick conceptual shift: while drones were solely the purview of the military just a few years ago, public discussion now focuses on drones for civil use in leisure and commercial applications.

Until the turn of the millennium, the use of drones had been largely restricted to military operations. The use of aircraft in a military combat theatre differs in significant ways from operating aircraft under peacetime conditions. The acceptability of risk is significantly higher, and there are very little, if any, non-military flight operations to take into consideration. Hence, the rules and procedures for separating aircraft from one another as well as the threats drones pose to people and objects on the ground are radically different from during civil flight operations.

The military has historically been a catalyst for the development of drone technology, absorbing many of the technological development costs but enabling technology transfer to civilian unmanned aircraft and operation systems. This has allowed drones to become cheaper, lighter, more sophisticated and easier to fly than a conventional aircraft, while at the same time paving the way for advanced integration of manned and unmanned air transport management. Most civilian drones are in fact part of a system that consists of the aircraft itself, guidance, navigation and control elements like radio transmitters, onboard sensors and software that together form the operation system and a human remote pilot or an Artificial Intelligence controller depending on the level of automation of the drone system and the data link communication architecture.

In some ways, the potential of drone transport was anticipated by the 1944 Chicago Convention, which states in Article 8: "No aircraft capable of being flown without a pilot shall be flown without a pilot over the territory of a contracting State without special authorization by that State and in accordance with the terms of such authorization. Each contracting State undertakes to insure that the flight of such aircraft without a pilot in regions open to civil aircraft shall be so controlled as to obviate danger to civil aircraft." (ICAO, 1944)

Recent market growth of commercial drones

Drone market forecasts vary considerably as they define the market boundaries differently e.g. military versus civil or commercial versus leisure use cases, but all agree that drones will be a multi-billion dollar market within the next five to ten years. A 2016 PriceWaterhouseCoopers (PwC) global report on the commercial applications of drone technology estimated a volume of USD 127 billion for a civil-drone powered solutions market for addressable industries (measured by cost of labour and services that have a high potential for replacement by drones) (PwC, 2016). Goldman Sachs projected a global market size of USD 100 billion for the period from 2016-2020, which included a USD 13 billion forecast for commercial/civil operations and an estimated total spending on drones (both military and civil) of USD 17.5 billion in the United States, USD 4.5 billion in China and about USD 3.5 billion in the United Kingdom (Goldman Sachs, 2016). A 2018 global survey by Blyenburgh, (2018) identified an expected three-fold increase in missions for the transport of goods between 2017-18 (albeit starting from a very low base). It also identified passenger drones as a growing, but miniscule market and projected the outlook for the use of drones for market sectors such as construction, maintenance and remote sensing as stable.

Regarding the number of drones, a 2016 report by Gartner projected that there will be ten times more commercial drones than manned aircraft by 2020. This would mean about 230 480 commercially operated drones around the globe in 2020, when compared with the statistics for manned aircraft fleets provided by

Boeing for 2016. These numbers are dwarfed by the projected global leisure drone fleet, which Gartner calculated at three million operative units in 2017. The firm also projected that the personal and commercial drone markets will increasingly overlap as technological breakthroughs allow the use of cheaper leisure drones for commercial applications.

Why now? The Fourth Industrial Revolution driving drone technologies.

The recent proliferation of drones is an early signifier of the impending "Fourth Industrial Revolution". This extension of the digital revolution involves the fusion of technologies, blurring the lines between the physical, digital, and biological sciences. It is generating the technological capabilities to conceptualise and manufacture radically different airborne vehicles, tailor them to very specific mission parameters, take advantage of the economies of scale from standardised building blocks and integrate drones with existing (air) transport systems. (Schwab, 2016) Suddenly, use cases that were either impossible or economically unsustainable for human-piloted aircraft are becoming technically possible and economically feasible.

While the Third Industrial Revolution (1980s until today) saw digitalisation permeate "just about everything", the Fourth Industrial Revolution is characterised by a fusion of technologies and accelerates its velocity, scope and systemic impact. This is particularly obvious with the accelerated development of drones and the development dynamics of related operating systems. The breakthroughs are more rapid than ever before, as reflected by the almost daily reports of new drones moving beyond concept stage and taking their first successful flights.

Concurrent advances in engineering and manufacturing technologies are pushing the pace of change and future drone capabilities and costs. These developments include sophisticated simulation models, new materials, dispersed battery storage, 3-D printing of large (metal) parts, biomimetic 4D printing methods for optimised elastic surfaces. They also include novel software tools and ICT technologies such as artificial intelligence, wireless 5G communication and the miniaturisation of electronics. All of these, and others still, have created opportunities for drones to vastly expand into the civil aviation sector with new use cases that are hard at present to anticipate.

Finally, the depth and breadth of simultaneous changes brought on by highly automated and autonomous forms of transport herald the disruption of entire systems of production, operation as well as the governance of transport infrastructure, vehicles and services. Overall developments of artificial intelligence (AI) and automation are at the core of the challenges posed by drone operations. Martini et al. (2016) gives a comparative review of the emerging drone laws, best practices and policies in this regard.

Looking at the long-term impact of the Third and Fourth Industrial Revolutions and plausible technology pathways, it seems likely that unmanned vehicles will partly address future mobility needs, replacing services on the ground, on rail, on water or in the air. The level of integration between the different types of vehicles involved and between these vehicles and their manned counterparts and with infrastructure is currently open for debate, but at a minimum, there will have to be some kind of integration between manned and unmanned vehicles in and across all modes.

Moving from science fiction to real world applications

The general population may not be ready yet to fly on a pilotless aircraft (though much of current flight is already automated), but as with technological advances in self-driving cars, buses and trucks, drone technologies are quickly moving from science fiction to providing services in the real world.

There is a growing interest in developing drones for a variety of mission types from start-ups to the largest global aircraft manufacturers. In experimental situations, drones can already carry packages, transport people, deliver humanitarian aid, inspect infrastructure and support a variety of other transport-related uses cases.

Eventually fully automated drones could replace manned aircraft, especially for the transport of passengers or freight along already established routes – much like airborne fixed-route shuttle services or aerial "conveyor belts". In other cases, they could provide new mobility options to serve remote areas, disaster-stricken zones and very thin markets that, to date, have not been economically feasible to serve. Finally, in addition to the ability to carry passengers or freight, unmanned aircraft operating as aerial sensor platforms will soon be able to support transport and other sectors by carrying out a wide variety of missions.

The rapid proliferation of drones for leisure use can serve as an early indicator for the readiness of markets to embrace drones for commercial transport services. However, it also serves as a reminder that large-scale deployment of drone fleets may be slowed down by growing public concerns.

Gaining social licence for the large-scale deployment of drones

Drones are already widely available for a broad variety of use-cases, ranging from leisure uses to commercial applications like precision farming. Indeed, the enthusiastic uptake of leisure drones across the globe point towards a growing acceptance of drones overall.

Alongside the proliferation of leisure drones has been a growing use of drones serving transport purposes. The latter are on the verge of scaling up from experimental use cases to potentially large, commercially viable fleets.

With the private sector driving the development of new technologies to manufacture and operate drones and experimenting with novel service applications, public authorities face the question of how to best support the emerging drone market such that society benefits as a whole.

What is a "drone" in the context of this report?

The term drones is used in public discussion as an umbrella term for airborne vehicles without a pilot on board. Other, more technical terms are also used to discuss drones in many countries and in aviation. The most frequently used terms are Remotely-Piloted Aircraft Systems (RPAS) and Unmanned Aircraft Systems (UAS). Literature also refers to Unmanned Aerial Vehicles (UAV), Autonomous Aerial Vehicle (AAV), Remotely Piloted Aerial Vehicle (RPAV) etc.

In this report, the term "drone" encompasses all flying vehicles without a human operator on board.

Unless otherwise specified, a distinction is not made between the different levels of automation. These levels range from a drone remotely piloted from the ground (within or beyond the visual line of sight [VLOS and BVLOS]) to a fully autonomous drone requiring no human intervention in carrying out its mission.

This less technical definition is used in order to

- encompass a wide variety of current and emerging concepts,
- encourage a view of drones as a new part of the transport system, rather than an extension of existing air traffic system; and
- be more readily understandable for the general public.

Furthermore this report addresses drones:

- Irrespective of their size and weight. This includes drones small enough to just be equipped with a sensor e.g. for construction site monitoring up to full sized airplanes that carry hundreds of passengers or many tons of freight.
- Irrespective of the altitude at which they are able to operate. This includes all classes of navigable airspace excluding space travel.

- Irrespective of their design layout or engine type. This includes drones with a varying number of rotors, e.g. quadcopters with four individual rotors to tilt and fixed-wing drones or combinations thereof and powered by different engines ranging from electric to combustion and hybrid engines.
- That are used to either transport a) passengers, b) freight or c) supports the performance of the transport system. While the use of passenger and freight drones as part of the overall transport system is clear, support drones can be used for a wide variety of use cases for the transport sector, e.g. drones to collect data for the better planning and maintenance of transport infrastructures, to monitor construction sites and traffic flows as well as to guide emergency operations and other emerging (cross)-sectoral support functions.
- When employed in a commercial context. Policy and regulatory concerns for leisure drones are also important questions and can inform guidelines for the commercial use of drones. In this report we will focus exclusively on the commercial use of drones.
- As part of a larger operational system. The term drones thus refers to both the aircraft itself and the systems required to operate it.

This report outlines the principal policy considerations associated with the large-scale deployment of drones, with a focus on the next five to twenty years.

Current state of play

Drone design, airspace management and service models

Drone designs vary widely depending on the missions for which they are intended. They include, but are not limited to, quadcopter drones able to carry small payloads such as the heavily publicised pizza delivery drones of recent years. Hassanalian and Abdelkefi (2017) present an extensive overview of drones and various current categorisation methods. Most common among these are categorisations based on the weight, wingspan, payload capacity or flight range and flight endurance as well as classifications based on rotor, wing , fan or hybrid design, the selected propulsion system or mission capabilities, e.g. whether they are capable of vertical take-off and landing (VTOL) or horizontal/conventional take-off and landing (HTOL/CTOL). Other classifications look at the type of application a drone might be used for, e.g. military vs. civil, or passenger vs. delivery drones.

The heterogeneity of drone designs is driven by the large variety of potential drone use cases. Specific use cases serve to specify drone mission parameters. These include at a minimum the intended payload (weight and dimensions), range, altitude and speed, but may be much more detailed in order to tailor drone design to a specific use case, e.g. a 4-6 passenger drone operating in a dense, quiet urban area with a large proportion of high rises and constant high temperatures.

Drones are one part of the airspace management system. The defining quality of drones, regardless of their vehicle design or mission, is that there is no human operator on board. Accordingly, the operating system must be able to perform all necessary tasks to fulfil a mission. The operating system includes on-board systems and ground based control systems, ranging from a pilot within the visual line of sight of a drone to fully automated drone control systems integrated in an artificial intelligence (AI) based air traffic control centre with little to no human oversight. The technological advances of recent years had a significant impact on the guidance, navigation and control (GNC) systems of drones (see Kendoul, 2012).

A major technological challenge in every day operations of unmanned aircraft will be air traffic management (ATM). A recent Single European Sky ATM Research Joint Undertaking (SESAR JU) "Roadmap for the safe integration of drones into all classes of airspace" (SESAR JU, 2018) expects that large drones using ATM services will be piloted remotely in a one to one relationship, while drones using U-Space services will be highly automated and supervised. U-space is a European concept for "a set of new services relying on a high level of digitalisation and automation of functions and specific procedures designed to support safe, efficient and secure access to airspace for large numbers of drones. As such, U-Space is an enabling framework designed to facilitate any kind of routine mission, in all classes of airspace and all types of environment - even the most congested – while addressing an appropriate interface with manned aviation and air traffic control" *(SESAR JU, 2018).* Similarly, in the USA the National Aeronautics and Space Administration (NASA), Federal Aviation Authority (FAA) and industry are working on technologies that will enable a UAS Traffic Management system (UTM). They envision UTM as an air traffic management ecosystem for eventually fully automated drone operations that is separate but complementary to the FAA's Air Traffic Management (ATM) system. The current research and development efforts will ultimately identify services, roles/responsibilities, information architecture, data exchange protocols, software functions, infrastructure, and performance requirements for all kinds of drones services. In China there are already UTM/U-Space systems operational on regional and national levels, which will be further strengthened according to the China Civil Aviation Administration (CAAC) which has developed two cloud computing systems — U-cloud and U-care — for UAV flight registration and monitoring (Zhang, 2016).

The integration of current ATM systems with drones will be an iterative process: the regulatory framework and the operational parameters allowing unmanned traffic management systems to coordinate with conventional air traffic management will ideally continue to co-evolve progressively.

Service models and business models

The business models that will drive drone deployment and widespread up-scaling are in flux and this complicates the regulatory task. As with any new technology deployment, the initial focus is often on how technologies can beneficially replace current ones – e.g. what can drones do that is *already* being done? An immediate and related focus is how well new technologies can do *better* what is already being done. These two uses are relatively easy to anticipate, but not always. For example, drone inspection of infrastructure and the built environment is one way in which drones can be used to substitute existing practices. Arguably, because of the characteristics of drones, these inspections can be more thorough, faster and less expensive to carry out. Nonetheless, when advanced sensors, including cameras, are deployed in places where they were never expected (e.g. over private property, at the level of upper-storey windows), and the sensor platform allows persistent storage of the sensor input, new privacy-related challenges emerge.

The third category of use cases is more problematic. This is the broad category of new uses that emerge that simply were not thought possible or feasible before. By their very nature, these uses are hard to anticipate and, when they are deployed, their potential for disruption may be high as is the uncertainty around their staying power.

Two examples of these potential use cases outline the type of challenges that may emerge as new uses become possible.

While the use of drones for freight and parcel delivery, especially for the last-kilometre, is foreseeable (and is currently being trialled in a number of instances) the potential for direct-to-consumer delivery, wherever that may be, are use cases that will prove to be highly problematic from a policy perspective. If windows, rooftops, yards or public space like sidewalks all become potential droneports, zoning, construction, building regulations, property law (including air rights), private contract law regarding the use of shared spaces of collective dwellings, and laws regarding noise and visual amenity will all come under pressure. The risk of unwanted outcomes through poor, or inexistent, coordination across these regulatory spheres is high.

Large-scale, persistent, and ubiquitous surveillance is a task that military drones already routinely undertake in conflict zones. These create high-definition, multi-spectral, nearly complete records of “reality” that are useful for both incident prevention and post-incident forensic investigation (e.g. tracking movements of people and vehicles backwards in time). These surveillance capabilities are starting to be deployed by law enforcement agencies for event-related use or, more broadly, for persistent surveillance on the basis of existing laws relating to video surveillance. It may be that commercial operators soon leverage such capabilities to provide new services based on (even more) ubiquitous location and tracking-based capabilities to public authorities and, ultimately, to consumers. Combined with new data analytical capacities, like vehicle, facial, gait or audio recognition or with motion pattern recognition (e.g. remote identification of pedestrians, cyclists, older or younger people, etc.), a raft of new services become possible - as do a range of potentially privacy-abusive practices. (see section “Safety and Security first”)

The intrinsic and unplannable nature of these, and other, hard-to-anticipate use cases, make it even more important to agree robust principles to frame drone deployment going forward. No general classification of drones and operating systems exist due to rapidly evolving technologies and missions.

Due to the rapidly evolving technologies and expanding scope of missions, there is currently no internationally agreed categorisation method for drones available. Despite the ongoing work e.g. at Joint Authorities for Rulemaking on Unmanned Systems (JARUS) and the Aviation Safety Agency (EASA) it seems likely that a definitive, all-encompassing, globally accepted categorisation method may not emerge for quite some time, posing additional challenges for regulating authorities and standardisation bodies.

For this report we included a wide variety of drone designs and mission types when analysing which policy areas could potentially be affected by the large-scale deployment of drones. Some more detailed examples of current and future drone designs and service models and the questions raised when envisioning their large scale deployment are described in the section "Scaling up".

Regulations for drones

The commercial use of drones represents one of emerging challenges for regulators linked to disruptive technological changes. As a critical tool in the hands of government to influence behaviour, regulation may support, hinder or act neutrally in the adoption and development of new technology. When new products and technologies emerge, the adaptability and suitability of existing regulatory frameworks is put to the test. The twin challenge for regulators is to ensure that innovation can flourish while at the same time mitigating potentially adverse economic and societal impacts that arise from disruptions

Current and emerging challenges

As drones are the latest addition to objects flying in regulated airspace, existing regulatory frameworks for the aviation sector tend to apply to commercial drones (Jones, 2017). However, regulatory regimes designed for different and older technologies are in many instances not adapted to many drone use cases, e.g. leveraging the safety benefits of being able to let a drone in distress crash in a safe place as there is no crew to protect. In some cases, drones may be in a regulatory void with very little control over their particular conduct. As a result, aviation standards, laws and regulatory approaches require constant updating (Clarke and Bennett Moses, 2014).

At the national level, the rationale for updating and even introducing regulations when dealing with commercial drones is mainly underpinned by public safety and security concerns (Stöcker et al., 2017). Similarly to existing aircraft, drones can pose threats to people and property in the case of technical failures, collisions or hijacking. However, in contrast with manned aircraft, drone activity is more heterogeneous and is therefore harder to anticipate. In addition, the costs of detecting drones violating rules and related investigations are higher (Clarke and Bennet Moses, 2014).

National regulations have to date displayed a wide range in their level of restrictiveness of drone activity, going from effectively banning commercial drones licensing to promoting very permissive regimes. Despite this diversity, meta-reviews (Jones, 2017; Stöcker et al., 2017) of recently approved drone regulations identify some common elements across most jurisdictions:

- Administrative rules (e.g. pilot's licence and training, aircraft registration, insurance requirements)
- Operational limitations (e.g. maximum weight, flight altitude restrictions, VLOS)
- Airspace management rules (e.g. flight authorisation, restricted flying zones, maximum altitude).

Flexibility is also an important characteristic of emerging drone regulation, in two ways. First, requirements across administrative, operational and airspace rules are modulated based on the different characteristics of commercial drones. These encompass size (weight), flight altitude, the role of the pilot (if any), the degree of autonomy and the purpose of the drone operation. The pervasive growth of commercial drones also leads to a blurring of the traditional administrative boundaries. Michel (2017) found that 133 communities, home to 30 million inhabitants in 31 US States have some kind of regulation pertaining to unmanned aircraft.

At international level, this translates into the need to develop international standards and principles for the use of drones as advocated by the ICAO, the UN agency for aviation. In addition JARUS (Joint Authorities for Rulemaking on Unmanned Systems), a group of experts from the national aviation authorities in charge of designing a set of common technical and operational requirements for the integration of drones in the airspace and at aerodromes, has been set up. Efforts in this area are ongoing at the time of writing and are not included in the review.

A second challenge linked to the blurring of administrative boundaries at subnational level deserves further attention. When drones are allowed to operate in urban areas, the higher the number of permitted movements and/or deliveries is, the higher their operational benefits and competitive advantage will be (SESAR JU, 2016). At the same time, public safety concerns are most prominent in cities. Hence, with urban operations the trade-offs between more permissive and more restrictive rules become most apparent. A more detailed analysis of urban questions can be found in the chapter "Challenges for policy makers"

Therefore, our report identifies the development of commercial drone operations in and around urban areas as one of the greatest challenges for regulators and policy makers over the coming years. Regulatory issues are inevitably linked to infrastructure development questions in this realm: Whose responsibility is it to develop 'safe' landing zones for drones? Should these designated aerodromes be regulated differently from existing airports? Heavily preoccupied with airspace interactions (and rightly so) regulators may be overlooking the question of land-use interactions.

Emerging national regulatory frameworks for commercial drones

The regulation of commercial drones at national level has typically begun with the extension of existing regulatory frameworks for the aviation sector to commercial drone operations, given the similarities between manned and unmanned aircraft.

An example (Masutti, 2016) is offered by the Italian Navigation Code, which extended the definition of aircraft to include drones. In 2005 and 2006, the Italian legislature proposed a new definition of aircraft and, as a consequence of this decision, Article 743 of the Navigation Code now states: "Also considered aircraft are remotely piloted aircraft systems, as defined by specific laws and regulations issued by the CAA and for those military ones as defined from the decrees issued by the Ministry of Defence" (Navigation Code, 2006). The consequence of this decision is that all rules established by the Code for manned aircraft are, as far as is possible, applicable to unmanned aircraft.

Similarly, insurance and liability requirements have been extended to commercial drones across the EU based on the existing framework of Regulation 785/2004 which defines third-party liability insurance requirements for aircraft based on their mass. However, applying Regulation 785/2004 to drones has required a number of clarifications and may need further adjustments. For instance, the European Commission clarified that rules do not apply to model aircraft and hobbyist drones; national legislators (e.g. the House of Lords in the United Kingdom) called for the minimum amount of liability to be raised; independent studies (Steer Davies Gleave, 2014) raised warnings about the costs of enforcement and the risk of accidents involving uninsured drones. Hand in hand with these issues, the certification procedures of safety-critical products and systems will bring significant challenges to both suppliers and regulators to enable commercial services.

While they represent a good starting point, existing regulatory frameworks may be insufficient to deal with the complex and specific challenges raised by commercial drones, and further technological developments such as collision avoidance systems could soon render them obsolete. There are parallels here with the need to update regulatory frameworks ahead of the introduction of automated vehicles such as driverless trucks on public roads (See Box 1 "The regulation of self-driving trucks").

Disparate national regulations

The proliferation of national rules and laws in recent years also highlights one of the main issues that regulators are grappling with while they try to promote the safe use of commercial drones: that the potential damage of incidents involving drones is also largely unknown given the absence of historical records. The weight of commercial drones may be only one of the criteria determining their potential damage and hence appropriate insurance requirements, for example; other factors such as speed, the material and characteristics of the airframe and the presence of parachutes also play a role.

This diversity also reflects the reality that there are various categories of commercial drones, differing in size (weight), flight altitude, the role of the pilot (if any), the degree of autonomy and the purpose of the drone operation. The requirements across administrative, operational and airspace rules are modulated based on the different characteristics of commercial drones in most national regulations. A crowd-sourced, constantly updated "Global Drone Regulations Database" can be found online (UAViators, 2014). An overview of the detailed provision in the United States, the European Union and China is provided in the Annex.

For a global summary, the most comprehensive review of national regulations carried out to date (Jones, 2017) identifies a handful of countries where outright bans (e.g. Argentina, India, Morocco) or effective bans due to very restrictive regulations (e.g. Chile, Colombia, Nigeria) are in place and no commercial flights have been approved. Next, around 20 countries permit drone use for commercial purposes under the requirement of VLOS and a limit of one drone per pilot. Population restrictions often accompany VLOS and experimental BVLOS operations – these are allowed in 11 countries, including the United States, on a case-by-case basis. In France, Canada and Poland drones cannot fly over heavily populated areas and are only allowed in certain zones. Towards the more permissive end of the spectrum, in China, administrative rules vary significantly depending on the mass and type of drones but operations including BVLOS are authorised once all requirements are complied with. Drone delivery is explicitly banned, however. National regulations are in constant flux, resulting in most recent changes across the whole spectrum from abolishing flight bans (e.g. in India) to establishing procedures to allow flights over heavily populated areas, e.g. for France.

Box 1. The regulation of self-driving trucks.

Driverless vehicles already operate in controlled environments like ports or mines, and trials on public roads are under way in many regions including the United States and the European Union. Within the next ten years, vehicle operators and fleet managers will likely accelerate the adoption of these vehicles due to the considerable labour cost reductions that they bring. Other benefits of automation to society include lower emissions due to more efficient routing and better safety by reducing the incidence of human error. At the same time, the transition to automation presents a number of political and regulatory challenges that the governments will have to address. The adoption of driverless vehicles in freight transport will carry profound impacts on employment. There will be job losses among drivers while other jobs will be created, especially linked to the support and maintenance of new vehicles in operation. Potentially, some on-board tasks will also be required. The challenge for policy makers is to mitigate the negative social impacts of driver job losses, whilst balancing the social status of the newly created jobs with the efficiency opportunities of the road transport industry.

The current regulatory framework in road transport (which in the European Union includes e.g. EC Regulation No 561/2006 on working time, EC Directive 96/53/EC amended by Directive 2015/719/EC on the weights and dimensions of vehicles) has been developed and implemented for a situation in which the driver is present in the cabin of the vehicle. To reach the underlying policy goals of economic efficiency, equity and sustainability, all road transport legislation will need to be adapted to support the implementation of driverless vehicles. In order to ensure the highest safety standards during the introduction of driverless vehicles on public roads, standardisation of vehicle technical characteristics at the international level will also be required, and work is ongoing at the UNECE World Forum for Harmonization of Vehicle Regulations (WP.29).

The lack of drivers on board automated road vehicles presents an enforcement challenge too, because the current paper-based control procedures cannot be carried out in the absence of personnel on board. This calls for the development of completely new data-driven enforcement procedures, which would enable checks and inspections to be carried out without hindering the flow of goods and undermining the efficiency gains of driverless vehicles, possibly even without stopping the vehicles.

All of these challenges will require new and enhanced approaches for data collection, sharing and analysis. Further cooperation will be necessary between public authorities, transport operators and vehicle manufacturers. Data-driven regulation based on live feeds and digital inspections should therefore become the norm. Greater data needs will also raise challenges with respect to issues of ownership, storage and dissemination of data.

Sources: ITF (2017a), ITF (2017b)

Cloud technology to monitor drone operation in China

To better monitor whether or not unmanned aircraft violate these regulations, China has created an unmanned aircraft cloud that monitors the activities of all unmanned aircraft in that country (Wei et al., 2016). The cloud is usually passive, collecting data on location, speed and altitude. However, China has geofenced certain areas where unmanned aircraft operations are prohibited. Unmanned aircraft weighing more than 4 kg empty or more than 7 kg with payload are also required to have "geofencing" software on board that would sound an alarm to the operator should the unmanned aircraft enter a prohibited area.

The unmanned aircraft cloud is a cornerstone of how China intends to manage the operation of the over 20 000 unmanned aircraft currently flying there. The cloud is not intended to be a monopoly as multiple providers can each offer their own version of the cloud. Chinese regulations specify the requirements of a cloud provider, who must meet the requirements of the civil aviation authority of China as well as local authorities and the military. Cloud providers are also required to supervise, record, and monitor the pilots and operators of unmanned aircraft and must report the following to the civil aviation authority every six months: number of unmanned aircraft using their systems, number of operators, technology improvements, difficulties, accidents and incidents.

Several countries including Sweden and the United Arab Emirates have adopted the most permissive approach to drones and have designed licensing regimes to accompany the use of experimental BVLOS operations.

The potential for international harmonisation

Currently aviation is built on the development of international standards, translated into national laws that enable such a global industry to operate in a very similar fashion around the world. The fragmentation of national regulations clearly reflects different sensitivities to the public safety risks posed by drones. However, it may also slow down the uptake of drone technologies in countries with the most restrictive regimes and could render operations economically unviable in countries with very high regulatory requirements.

The benefits of an international regulatory approach to commercial drones may not be as clear as for the manned aviation sector (since commercial drone operations are not yet international in nature) but there are multiple benefits of international regulatory cooperation in this field too, not least the ability to update safety standards at the global level based on the most recent evidence. First examples of governmental international co-operation for cross-border drone operations in Europe are trials by the European Maritime Safety Agency (EMSA) and FRONTEX, the European Border and Coast Guard Agency to surveil maritime borders. Moreover with introduction of large, long haul freight drones the need for internationally harmonised regulation will become even more apparent.

Global players driving the commercial drone industry

The industrial configuration of the commercial drone sector is increasingly international. Existing multinational companies active in digital, aviation, distribution and delivery services already operating in several countries are entering the market. Both drone manufacturing and ancillary services (e.g. software development, insurance) are carried out by global companies. In addition, the sector is consolidating through a number of mergers and acquisitions as well as the rise of system operators similar to Uber that operate under a 'Drone as a Service' model striking contractual arrangements with individual operators.

For all these companies working across national boundaries, greater harmonisation translates into lower administrative barriers and costs when entering new markets. Therefore the industry itself is likely to put continued pressure on harmonisation and will certainly continue to provide insights to regulators in order to streamline new rules and laws. Most future scenarios also foresee the rise of international drone operations.

The prospects for international harmonisation are highest in the field of technical and safety standards, and cooperation in R&D for technologies also looks promising. Cooperation is likely to intensify in the field of airspace management too, building on the increased success of joint airspace management initiatives for manned aviation and the need to integrate larger drones with existing air carriers. In this field, concepts such as low-level dedicated airspace for small commercial drones may also be adopted in a relatively uniform way internationally, should trials lead to positive outcomes.

ICAO will play a key role for international regulatory harmonisation. It is currently backing the creation of a single global drone registry, as part of broader efforts to come up with common rules for flying and tracking unmanned aircraft. The single registry would eschew multiple databases in favour of a one-stop-shop that would allow law enforcement to remotely identify and track unmanned aircraft, along with their operator and owner (Creamer, 2017). ICAO has also been working with its member countries, industry and stakeholders to develop single registry standards. It issued the Unmanned Aircraft Systems circular (ICAO, 2011) which sought information on the application and usefulness of unmanned aircraft in order to develop a regulatory framework and guidance material that would enable unmanned operations to take place in a similar fashion around the world. ICAO is also working on amending 18 of the 19 annexes of the Chicago Convention in order to account for unmanned aircraft.

At the European level, member states are cooperating on the issue of drone standards and regulations with a view to establishing a comprehensive regulatory framework for all drones operating in the European Union in 2018. The European Commission’s efforts are supported by the Aviation Safety Agency (EASA) and build on the work of JARUS, a group of experts from the National Aviation Authorities in charge of designing a set of common technical and operational requirements for the integration of drones in the airspace and at aerodromes, as well as ICAO.

However, harmonisation of operational and administrative rules is a much greater challenge. In the space of a few years, the different national regulations adopted across the world have shown considerable divergence as discussed above. The main areas of dissent have emerged around:

- *BVLOS operations*: “Beyond visual line of sight” means flying an unmanned aircraft without the pilot having to keep the unmanned aircraft in visual line of sight at all times. This means that the drone’s remote pilot must be able to respond to or avoid other airspace users by visual means as the safest way to reduce the risk of collisions and other accidents. The number of countries offering derogations and allowing BVLOS under special permits has increased in recent years, but the basic requirement of VLOS has remained in place in most countries.
- *Flying over populated areas*: the second most common restriction to commercial drones is the operational ban over populated areas, usually cities and large public events. While it is not difficult to understand why such restrictions are in place, they also limit drone operations where their benefits may be highest: in urban settings.

A more detailed discussion about drones in urban environments follows in the section in “Challenges for transport policy makers”.

Scaling up

How far citizens are willing to go to accept the deployment of drone fleets will depend on their understanding of the balance of benefits and disbenefits that may result from scaled-up use of drones. It will also depend on the successful mitigation of potentially adverse effects via the development of appropriate regulations.

Looking at the many different designs of drones and emerging specialised use-cases, it is intuitively obvious that a framework to assess the benefits and challenges for the overall transport system must be introduced.

At the same time, it is essential to understand that new players are entering the "aviation market", e.g. electronic retail companies, new emerging B2B and B2C service providers, telcos and other advanced system providers who perceive new business opportunities. Different business and operational cultures between those new players and the established aviation community – particularly their contrasting business time frames between 5-10 years for the former and 20-40 years for the latter – need to be understood, addressed and balanced by the involved communities and the regulators. Moreover as regulators are faced with similar, digitally driven disruptions for surface transport modes (e.g. automated ground vehicles, shared an/or on demand transport options, etc) the large scale introduction of drones will benefit from close interactions between all involved transport policy makers to create more systemic and co-operative multi-modal transport solutions.

Three different use cases are presented below. They examine drones used for a) passenger transport, b) freight transport and c) drones to support the better management of the overall transport system.

Future visions for scaled up drone fleets are analysed vis-à-vis the technology currently available, service models, regulatory status and the envisioned benefits and challenges. Finally, drones to support humanitarian missions are examined to understand a possible pathway for the introduction of drones for specific missions and how drones can gain social licence to grow.

Passenger drones

Imagine travelling downtown from an airport in San Francisco, Tokyo or Dubai in a convenient 5-seater passenger drone in a matter of minutes instead of being stuck in traffic for hours. Imagine reducing your average commuting time by 80% facilitated by a flying taxi service operating in your region. Imagine travelling from Seoul to Paris in an airplane carrying hundreds of passengers without a pilot on board.

Why passenger drones?

Since the 1950s, civil helicopters have been flown over (peri-)urban areas and many cities have dedicated places at which helicopters can land. Commercial passenger-carrying operations have largely been confined to the corporate or charter markets, however, transporting just small numbers of passengers.

There are five major arguments put forward to invest in passenger drones capable of ferrying from a single traveller up to hundreds of passengers: First, drones provide enhanced connectivity to remote regions. Second, scheduling and routing becomes more flexible. Third, drones may contribute to congestion reduction. Forth, drone services reduce infrastructure investment costs and, lastly, they address the potential shortage of pilots.

Apart from high volume passenger transport with rail, light rail or metro lines, a large share of passenger urban and inter-urban transport today relies on an extensive road network in combination with cars or bus services and is often subject to significant congestion at peak periods. A 2014 INRIX study calculated that Americans spend 6.9 billion hours per year stuck on congested roads. It also put the total economy-wide cost in France, Germany, the United Kingdom and the United States combined, at USD 200.7 billion in 2013, and expected it to increase by 46% by 2030.

Shortening intra-urban and intra-regional commuting times and relieving some people from the daily stop-and-go traffic of (sub-)urban transportation is therefore one of the most cited reasons for starting to invest in the development of a passenger drone service.

Moreover, as traffic growth is outpacing investment in infrastructure building and maintenance, congestion could become an even bigger drain on further economic growth. Even more so in countries that currently lack adequate surface transport networks and regional connectivity. The Asian Development Bank in a 2017 study projected that USD 8.3 trillion would be needed for transport infrastructure investments in Asia's developing countries alone from 2016-2030 to enable continued economic growth. That is an annual average of USD 520 billion needed to mostly maintain existing transport infrastructure and continue to connect to yet inaccessible regions. Passenger drone services might help to connect to remote, often indigenous communities, with reduced impact on the existing habitats.

Opening up another, less congested travel path in the air that is currently either entirely unused or served by only a few helicopter companies by introducing passenger drone services seems a compelling proposal to a) connect underserved regions and cities, b) alleviate surface transport congestion and c) significantly reduce transport infrastructure investments.

From the service operator point of view two major factors drive the business viability of passenger drones compared to the already available helicopter services. First, cutting the pilot and crew staffing cost to almost zero (depending on the degree of automation of take-off/landing and cruise) and, secondly, the reduced per vehicle manufacturing, maintenance and operation cost due to novel designs and economies of scale.

When discussing regional or long distance drone travel the already high automation level of existing passenger aircraft is often cited as an excellent starting point for a fairly quick transition to remotely piloted or fully automated distance air travel. Referencing the imminent introduction of automated surface vehicle automation and the simpler navigation demands in the relatively less crowded navigation space, at least during cruise, SESAR JU (2016) suggests that long distance passenger transportation without pilots on board could be introduced from 2030 onwards. This is also an increasingly attractive prospect for an industry facing a dearth of pilots, underlined by the 2017 Boeing pilot study that projects that the commercial aviation industry will need 637 000 new airline pilots worldwide between now and 2036. That is an average of 87 new pilots graduating per day, or almost four pilots every hour.

For the congestion mitigation potential of passenger drone services to be realised, travellers must feel that the safety, accessibility, quality and affordability of the services provided are sufficient for them to forego the use of cars for certain trips – especially during peak hours. To significantly decrease infrastructure investment spending the long-term reliability, availability and affordability of drone services between sparsely connected regions must be guaranteed. There are important equity considerations to address from a public policy perspective, however.

One of these is the degree to which drone passenger traffic will truly alleviate congestion for the overall system (and thus benefit all) or simply enable some, more affluent, travellers to avoid personally experiencing congestion. These considerations should not influence whether or not such a use case makes sense – it may very well be a commercially attractive proposition – but it will impact the extent to which public authorities should go out of their way to facilitate it via investments or permissive regulatory treatment.

Another fundamental point to consider for passenger (and freight) transport drone use cases that are predicated on congestion alleviation (or travel time savings) is that drone technology deployment is only one of a set of co-mingled and co-evolving technology changes within and outside of the transport sector. Where these are likely to have an impact on congestion or travel times, they will also have an impact on the viability of or benefits from specific drone use cases. For instance, a city that moves to a unified traffic system based on self-driving fleets and high-capacity public transport may not experience congestion thus eliminating one of the principal selling points for drone services. From a public policy perspective, it is important to keep in mind that system-wide efficiency improvements remain a fundamental policy objective even as the system itself changes.

Moreover, the energy consumption and emission profiles per passenger kilometre travelled and thus the effect of the introduction of drones to the Paris Agreement, reached at the 21st United Nations Framework Convention on Climate Change (UNFCCC) COP 21 remain yet unclear.

Passenger drones today

No regular passenger drone service operates at present. In 2017/18, a variety of passenger drones have made maiden flights, however, operating under experimental licences in several countries, and many more prototypes have been tested at various global test sites or showed their capabilities at trade shows.

New helicopter-sized vehicles have been under development since the 1980s, with a focus on developing aircrafts that are capable of vertical take-off and landing, so called VTOLs. A VTOL is a vehicle that does not require a runway because it takes off, hovers, and lands vertically thus being better suited for urban transportation where runways are not available or could only be built at prohibitive cost. Design proposals are suggesting various numbers of rotors or a combination of rotors and propellers, sometimes attached to short fixed wings, mainly to improve steering capabilities and forward thrust during cruise. Recognizing the energy inefficiency and high noise profiles of traditional helicopter engines, a large number of the newly proposed vehicles include an electric or hybrid-electric engine. The range of helicopter-sized passenger drones will be about 100 kilometres, according to a study by Deloitte (Lineberger et al., 2018).

The following paragraphs highlight a few examples of the current state of the art for different deployment scenarios:

Single passenger drone in an urban, sub-tropical scenario

The EHang 184 was developed by Chinese drone manufacturer EHang, based in Guangzhou. Its multi-rotor design uses an electric engine and is capable of carrying up to 100 kg or one individual passenger with baggage. It made its first public flight in China in February 2018. It was announced that it could fly at a maximum of 160 km/h for 23 minutes at sea level, or ten minutes at 100 km/h at a higher altitude. The manufacturer claims to have conducted over 1 000 test flights with a human on board, including special tests such as a 300-metre vertical climb, a weight test with an over 230 kg payload, a routed test flight covering 15 kilometres, and a high-speed cruising test that reached 130 km/h. The EHang 184 was also flown in a variety of weather conditions including fog, heat and gale-force winds of up to 50 km/h and at night.

In 2016, EHang, Nevada's Governor's Office of Economic Development and the Nevada Institute for Autonomous Systems agreed on a collaboration that would have paved the way for test flights at Nevada's FAA UAS Test Site, but so far FAA approval for testing has not been granted.

In 2017, EHang obtained the Special Flight Permit for civil aerial vehicles issued by Civil Aviation Administration of China (CAAC). The CAAC continues to work with EHang and other Chinese drone manufacturers to jointly establish relevant airworthiness standards for drones in its UAV Technical Experts Committee to create systematic industry polices and standards (EHang, 2018).

Two-passenger drone in an urban, high heat scenario

As part of the "Smart Dubai" strategy that also includes a driverless metro, Dubai has been inviting several passenger drone companies to help achieve the target of 25% of "autonomous journeys" of all trips by 2030.

In September 2017, the first actual test flight with a passenger on board a drone in Dubai took place with the Volocopter, an 18-rotor drone created by a German start-up of the same name and funded by Daimler. The Volocopter is powered by an electric engine; the diameter of the rotor rim including propellers measures just over seven metres. The Volocopter carries a maximum payload of 160 kg, has a maximum flight time of approximately 30 minutes, a range of 30 kilometres and a maximum airspeed of 70 km/h. It takes two hours to recharge (Ong, 2017).

Dubai announced that the trial of drone taxi services would be continued for five years. During this time the Dubai's Road and Transport Authority will cooperate with the UAE General Civil Aviation Authority and the Dubai Civil Aviation Authority in order to develop requirements for regulations, standards, and certification requirements (PWC, 2017).

Two-passenger drone for regional service in a temperate climate zone

In New Zealand, a start-up called Kitty Hawk launched its two-person drone *Cora* for testing in March 2018. Funded by Google co-founder Larry Page, Cora has a wingspan of 11 metres, but can take off vertically, then using a propeller at the back for propulsion. Powered by an electric engine, it flies at a maximum airspeed of 180 km/h for around 160 kilometres at a time up to an altitude of 915 metres (Kitty Hawk, 2018a).

Kitty Hawk was originally launched in California but found it difficult to get approval from US regulators for an official certification and the launch of a commercial service. Therefore, it moved its operations to New Zealand, where the regulatory authorities committed to devise a certification process for a drone-taxi service within the next three years (Sorkin, 2018).

A statement published at the launch in March 2018, by New Zealand Ministry of Business, Innovation and Employment GM Science, Innovation & International said: "We saw Cora's potential as a sustainable, efficient and transformative technology that can enrich people's lives, not only in New Zealand, but ultimately the whole world." (Kitty Hawk, 2018b)

Other passenger drones at advanced concept stage

Beyond the above examples, many other start-ups and leading aircraft manufacturers are working on passenger drones. Some have been presented at trade shows, including the Consumer Electronics Show (CES) in Las Vegas.

Airbus's *Vahana* drone, built by the company's Silicon Valley outpost A^3, completed a first test flight at Oregon's Pendleton Unmanned Arial Systems Test Range in February 2018. The Vahana is another VTOL single-passenger drone, but with wings and tail sections that rotate from vertical to horizontal as the aircraft lands and takes off. The battery-powered drone is six metres long and 5.7 metres wide, with a projected range of 100 kilometres. Airbus's goal is to bring the Vahana to market in the United States by 2020 (Collins, 2018).

Boeing has not publicised civic passenger drone tests yet. In 2017, however, it bought the Aurora Flight Sciences, a company whose projects include a flying taxi developed with Uber Technologies' Elevate project (Hawkins, 2017). Aurora's main line of business is the military aircraft sector, where it has won several contracts from NASA and DARPA, including for a VTOL aircraft. It is unclear whether Aurora will continue to work on civil passenger drones with or without partnership with Uber. While Uber itself is not developing any drones, the firm is working on design requirements for aerial passenger vehicles and co-operates with several drone manufacturers, with a view to launching an aerial taxi service for five to six passengers and a small amount of luggage with pilots on board in Dubai, Dallas and Los Angeles by 2020. The company says it expects to transition to autonomous drone transport by 2030 (Uber, 2016).

Lilium, a German start-up that attracted USD 90 million from investors led by Chinese internet giant Tencent, is proposing a different aircraft design: The Lilium Jet has a rigid winged body with 12 flaps carrying three electric jet engines each. Depending on the flight mode, the flaps tilt from a vertical into a horizontal position. The drone can carry five passengers. Lilium says that wing-borne, electric-powered drones can travel five or six times the distance of drone designs with rotors (Auchard, 2017).

Workhorse, a US-based manufacturer of electric vans who partners with logistics firm United Parcel Service (UPS) is proposing a drone powered by an electric-gasoline hybrid engine. The vehicle named *SureFly* accommodates two passengers and is said to have a range of 113 km. Workhorse plans Surefly to function autonomously within the near future (Zart, 2018). The company received permission to fly by US regulators in January 2018; the SureFly's maiden flight, planned for the 2018 CES in Las Vegas, had to be postponed due to rainy weather (Lee, 2018).

Passenger drone service models

Currently passenger drones aim mostly at providing unmanned aerial taxi services. These services directly target an existing (and expensive) niche market currently dependent on manned helicopter-based services that link airports and central business districts or different parts of highly congested urban areas. These are regulated services that are part of the broad offer of licensed commercial transport operations in cities, but, because of their limited scope and the small niche market they serve, are typically not part of broader strategic transport policy, including aspects relating to investment or fare regulation.

Open questions for transport policy makers include: will taking the pilot out of the aircraft change this? Will enhanced and unmanned aerial taxis form an integral part of broader transport policy and objectives? Will passenger drones soon evolve towards larger-capacity shared aircraft that can move a significant number of people at peak hours in ways that contribute to congestion reduction while meeting other noise, environmental and equity imperatives?

Aerial passenger drone services will certainly find a market. Yet the extra regulatory space given to such services will have to be guided by broader transport policy objectives.

Major policy concerns with regards to passenger drones

The main policy concerns regarding passenger drones are the safety and security of vehicles and of airspace management systems. Other future challenges centre around the air/ground interfaces and the impact of future drone ports on noise levels, emission exposures and the visual amenity as well as on the social equity.

Freight drones

Imagine getting your pizza delivered right through the window of your skyscraper apartment by a small delivery drone. Imagine receiving your weekly supplies needed to run your business in a remote region by a drone that can carry a payload of up to 25 kg - which will also pick up your products and shuttle them to market when ready. Imagine large cargo drones delivering tons of freight like an intercontinental conveyor belt made of drones.

Why freight drones?

Drones for freight transport have four advantages:

- They avoid surface congestion and delays.
- They allow faster, customised delivery.
- They enable low-cost air cargo services as drones are cheap to operate.
- Freight drones improve market access for remote places.

Airfreight currently accounts for about 1% of world trade calculated by tonnage, but roughly 35% of world trade when calculated by the value of shipped goods. Unmanned freight transport - especially when looking at drones the size of regional or intercontinental cargo aircraft - may lower the cost per ton significantly. Hoeben (2014) describes the reasons for cost reduction: lower personnel cost due to a switch to ground based crews (e.g. remote pilots or controllers), increased flexibility of flight schedules and lower fuel costs. Heerkens (2017) expects that the majority of advantages will stem from the efficient transport of relatively small loads, flexibility in scheduling and thus increased productivity for large-scale unmanned freight transport. The spectrum of drones ranges from those with a 300 kg payload and 500 km range to drones with a 15 000 kg payload and a range of up to 15 000 km. Suggested commercial business cases include: flights from the Chinese hinterland to assembly works at the coast, flights from eastern-European manufacturers to their western-European clients, Intra-continental package transport like DHL and others presently provided by Boeing 737-sized transport or smaller aircraft such as the ATR42. Van Groningen (2017) analysed the cost efficiency of a long-haul drone transporting a 5000 kg payload weekly between Stuttgart, Germany and Shenzhen, China and compared it to other possible modes of transport. It concluded that for this specific scenario and when shipping automotive goods a cargo drone would be more cost effective than a Boeing 777 by 17%, or 35% more efficient than by sea. However, the study also showed that the achieved efficiency depends largely on the amount of freight demand and its timing, with a minimum of a 1250 kg of high value payload transported between Stuttgart and Shenzhen when competing with a Boeing 777 or 500 kg when competing with rail.

Thus, SESAR JU (2016) expects that initially drone deliveries will be available in areas with very low accessibility and generate new growth rather than displacement of surface deliveries.

They also forecast a very low displacement rate for current standard urban freight delivery, but expect a growth market for premium services and high value goods. Urban premium delivery with goods might be cost efficient for suppliers if a single operator can control at least 15 freight drones built for payloads of up to 2.5 kg. This small scale, (sub)urban business cases have attracted the most media attention due to high profile experiments by Amazon and other e-commerce companies.

At the same time – or even before drone freight delivery becomes feasible - ground freight transport will also fundamentally change with the (phased) introduction of automated trucks, which might alter the currently projected business cases for freight drones significantly, particularly in areas with established surface networks.

Freight drones today

Currently no regular large-scale drone fleet is operating for freight delivery. But, when compared to passenger drones more freight drone services are already operating for specific use cases. Small freight delivery drones, for payloads of up to 5 kg are being trialled in various countries in everyday conditions, e.g. by FedEx, UPS, DHL, Amazon and Alphabet and the potential of large unmanned cargo planes is being explored by the military in several countries and its transfer to civil transport studied by global aircraft manufacturers.

Humanitarian services are currently the most prominent use-cases for freight drones in a small to mid-sized payload category. (see "Drones for humanitarian aid and development projects").

The following paragraphs highlight a few examples of the current state of the art for different deployment scenarios:

Food delivery service to end-consumer over difficult terrain in low-density city

AHA, one of Iceland's largest e-commerce companies, started to use drones for regular goods delivery in Reykjavik in mid-2017. When launched it operated about 20 flights a day, if weather permitted, along one route between two parts of the city that are separated by a river, cutting down delivery times by about 20 minutes and transport cost by about 60% compared to regular ground delivery operations.

The drone itself was provided by Flytrex, an Israeli start-up, it has a multi-rotor design, a payload of up to 3 kg, a flight time up to 35 minutes and operates about 50 metres above ground.

The operation was launched following intense public information and community engagement sessions and received regulatory approval from the Icelandic Transport Authority (Icetra). AHA and Flytrex continue to work with Iceland's regulatory authorities to increase the number of routes as well as experiment with different air/ground interfaces for delivery (Banker, 2017).

High value goods delivery with a combined drone/van system in dense city context

A combined drone-ground vehicle delivery concept is currently being tested in Zurich by US drone systems developer Matternet in conjunction with Daimler and the Swiss e-commerce platform siroop aG. Its goal is to speed up delivery times and create safe air-ground interfaces for drones by using the roof of a van as the designated a landing zone.

The employed drone can carry packages of up to 2 kg for approximately 20 kilometres, and it lands on the roof of Mercedes-Benz Vans at four pre-defined drop off points in Zurich, dropping off the parcel at a height of about two metres, thus ensuring the safety of passers-by. The goods are then delivered to the end-customer by the van driver. The drone is integrated into the Swiss airspace system using sense and avoid technologies similar to helicopters (Daimler, 2017).

The trial has been authorised by the Swiss Federal Office of Civil Aviation (FOCA) based on the Specific Operations Risk Assessment (SORA) methodology developed by JARUS (Joint Authorities for Rulemaking on Unmanned Systems) and was approved by all relevant Swiss air and ground authorities (Daimler, 2017).

Examples for higher payloads and for longer distances are detailed in the section "Drones for Humanitarian and Development Projects".

Other freight drones at advanced concept stage

Apart from the examples mentioned above there are many other global companies experimenting with drone delivery tailored to special use cases, including the development of drones for large payloads, e.g. the projected deployment of a FlyOx drone by Astral in Kenya with an estimated payload of up to 1200 kg and a range of 1 800 kilometres.

Two examples supporting other transport modes

Crew support and spare parts delivery to ships: Maersk, a Danish shipping and logistics company, which operates a fleet about 100 tankers currently employs barges to deliver medicine, mail and spare parts to its ships. Per trip the barge costs between USD 1 000 and USD 3 000. To evaluate the potential of drones to substitute barge transport Maersk in early 2016 trialled a drone developed by French Xamen Technologies. The drone had a payload of up to 2 kg, and was approved for use in potentially explosive environments. Maersk estimates that with the current technology (payload capacity, weather sensitivity and travel distance) drone delivery would be able to substitute three barge transports per year per vessel served. Thus generating savings of USD 3 000-9 000 per ship or nearly USD 1 million for its whole fleet even for such a limited use case. As Maersk pointed out drones could potentially serve more shipping related use cases, e.g. vessel maintenance or port monitoring and the business case for using drones to support maritime industries could grow substantially (Paris and Wall, 2016).

Ship and oil rig resupply or supply of semi-dense logistic cluster distribution centres: Boeing has recently unveiled a cargo drone prototype able to carry substantial loads for mid to long-range supply missions. Measuring 4.5 m in length, 5.49 m in width and 1.22 m in height, the electric VTOL multi-copter vehicle weighs 339 kg and will be able to support up to 227 kg of payload (Boeing, 2018a). It is predicted it will be able to fly at a speed of 97 to 113 km/h at a height below 120 metres (Davies, 2018). The first prototype was able to support 68 kg of cargo for about 15 minutes (Davies, 2018). Boeing's goal is to mature the already existing building blocks of autonomous technology for future applications. Although there is no concrete plan or timeline for commercialisation of the drone, Boeing expects a cargo drone with this payload and range capacity could be used to replace the use of expensive manned helicopter operations to deliver time-sensitive and high-value goods and conduct autonomous missions in remote and dangerous environments. Its possible commercial applications include oilrig and ship resupply, port operations, mining, construction, and logistics (Boeing, 2018b). The drone's range of operation is ideal for last mile supply or short-distance deliveries between clustered distribution centres (King, 2018).

Major policy concerns concerning freight drones

The main policy concerns regarding freight drones, beyond the safety and security of vehicles and airspace management systems are energy consumption per ton of freight delivered, related emissions and the impact on the workforce. Depending on the location and scale of operation other environmental impacts, including noise, visual amenity and the effects on land use values close to droneports also need to be taken into consideration.

Drones for support missions

Imagine a camera equipped drone mapping a port or highway planning site in 3D thus speeding up the timeline and quality of the design process. Imagine a sensor equipped drone spotting a critical fault in a railway line and alerting the maintenance crew before an accident can happen. Imagine drones inspecting the hulls of ships, airplanes and difficult to reach sites thus reducing the risk to human workers. Imagine drones monitoring people flows during large events, helping transport operators to direct capacities where most needed or deploying emergency services quickly.

Why drones for support missions?

Some of the first commercial use cases for drones were support missions. Already in the early 1980s, unmanned helicopters were deployed alongside piloted helicopters to guide them where to spray pesticides over fields in Japan. By 2018 drones are replacing manned helicopters for agriculture purposes across Japan (Thornhill, 2016).

Today, drones designed for support missions for planning, monitoring, maintenance and emergencies are of special interest to companies and governments that have to manage assets dispersed over large areas or assets that are inherently hard to inspect. In the transport sector, drones present an opportunity to improve the quality and efficiency of a large variety of use cases, e.g. railway companies monitoring the state of their infrastructure, port operators monitoring and guiding incoming vessel movements and inspecting hull stability, logistic providers managing their intermodal hubs or construction companies constantly surveilling complex construction sites.

There are three key drivers for the use of support drones within the transportation sector:

1. Improving safety: Drones can perform hazardous work and thus save human lives, e.g. during the inspection of construction sites, aircraft, ports, railway tracks or auxiliary infrastructure. According to a recent study (PwC, 2017), the number of life-threatening accidents on an average construction site monitored by drones could be decreased by up to 91%. Airlines such as Lufthansa and EasyJet (Perry, 2017) are trialling drones to inspect the fin and topside of their aircrafts, thus supporting the safe operation of manned aviation.

   Drones can not only be used to improve the safety of work crews during planning, construction and maintenance of transport infrastructures, but also quickly assess disaster impacts, guide emergency support to the locations where it is needed or even deliver life-saving tools.

2. Reducing cost: using drones to inspect infrastructure can significantly reduce cost. In a test by the New York Power Authority in 2017, a drone was used to inspect an ice boom near Lake Erie that was installed to reduce the amount of ice entering the Niagara River and impeding hydropower stations located there. Inspections by boat or helicopter cost between USD 3 000 and USD 3 500. Using drones could halve the costs (NY Power Authority, 2017). Similar savings can be achieved when inspecting bridges, tunnels and other transport infrastructure where the costs of in-person inspections are even higher. The labour cost per drone flight in 2017 was already less than USD 300. A few hundred fixed-wing drones could monitor approximately 200 000 kilometres of railways, according to an estimate by SESAR JU (2016).

3. Improving information: drones can be equipped with a wide array of sensors, thus enabling the collection of data that has so far have proven to be impossible, or too expensive, to collect. Drone-mounted high-resolution image sensors can detect structural faults, enable 3D-modelling of planned and existing infrastructure. Therefore, globally operating planning companies for the construction industry have been investing in drone companies over the past few years. Drone imagery can also improve the quality of real-time information for crowd control during large and small-scale events, providing a real-time view from above and enabling authorities to address problems before they escalate.

Drones for support missions today

Drones to map and monitor construction sites

Service providers within the construction industry, including globally operating planning software providers such as Autodesk have already been investing in drone companies over the past few years. Autodesk employs drones designed by 3D Robotics in partnership with Sony which carry 35 different sensors and 20 microprocessors on board, can operate in a radius of 1 km from the controller's standpoint and have a per trip flight time of 16 minutes. Drones equipped with high-resolution image sensors will continue to improve the mapping, 3D-modelling and monitoring of planning and construction sites.

The use of drones within the construction sector has also accelerated when in 2016 the FAA released Part 107 of its rules for commercial drone operators (Danielak, 2018). Under the regulatory framework, a traditional pilot's licence is no longer required to operate a small unmanned aircraft. Instead, passing a knowledge test is sufficient to obtain a drone piloting certificate. Thus in early 2017, Caterpillar, one of the world's largest construction equipment manufacturers acquired the drone company Airwave and already offers drone services through its regular dealer network in the US (Kolodny, 2017).

The importance of drones in this area is underlined by the 2018 launch of a Grant Call by the Land Transport Authority of Singapore seeking industry proposals to estimate bulk excavation volumes via drones equipped with 3D photogrammetry technology.

Drones for transport infrastructure maintenance

Drones equipped with high resolution cameras and scanners allow for precise inspections of infrastructure assets. The use of drones improves the infrastructure maintenance process and is a cheaper and often safer alternative to current monitoring techniques. At the same time, data collected by drones can be comparable over time, allowing for measurements and forecasts of wear. PwC (2017) puts the total global addressable value of the use of drone technology in road and railway segments at an estimated USD 4 billion for infrastructure maintenance. Alongside maintenance, drones can also be used for otherwise time and labour-consuming stocktaking. PwC (2017) notes a large scope for further application of novel deep learning techniques to enable fully automated drone services, which would further increase the efficiency of maintenance operations at significantly reduced costs.

Transport authorities around the world have been testing drones for use in infrastructure inspections. In Singapore, the Land Transport Authority aims to deploy drones for maintenance inspection in MRT (Mass Rapid Transit) and to enhance underground tunnel inspections in order to gradually replace manual effort within the next few years. As of spring 2018 more than 20 proposals are under evaluation (LTA, 2017). In India, Zonal Railways are set to procure drones for project monitoring and maintenance of rail infrastructure (The Economic Times, 2018). With the 2016 FAA commercial drone regulation, the use of drones for maintenance is likely to accelerate in the US as well, and projects such as Minnesota Department of Transport's use of drones for routine bridge inspections – where it was found that drones significantly improve the quality and safety of maintenance activities (Zink and Lovelace, 2015) – are expected to proliferate.

Drones monitoring traffic flows, crowds and providing emergency support

A drone's bird's eye view, autonomy from road traffic and ability to access otherwise unreachable or dangerous areas gives them an edge in traffic surveillance, crowd monitoring and the monitoring of emergency situations.

For traffic surveillance, drones can provide useful information about vehicle trajectories, and help estimate roadway usage and O-D (origin-destination) flows (Puri, 2005). However, their autonomy is still limited due to short battery life and tethered drones – such as the one used by Elistair to monitor a busy suburban roundabout in Lyon, which is connected to an on-ground electricity supply by a long cable – can be a solution for smaller areas that need to be continuously monitored (Elistair, 2016).

Drones can also be used for crowd monitoring during mass events: the Italian Air Force has teamed up with the country's police to use MQ-9 Reaper drones for surveillance during football matches and demonstrations (Kington, 2014). Similarly, in the United Kingdom the West Midlands Police has used drones during football games (Todd, 2016). Alongside safety, drones have also be used to ensure security at big events: as part of the security package for the 2018 Winter Olympic Games, South Korea deployed drones with CCTV and facial recognition technology (Perry, 2018).

In emergency situations, drones are used to assist the response by enhancing situational awareness. EENA (European Emergency Number Association) has collaborated with DJI, a large Chinese drone manufacturer, to explore the use of drones by emergency services in a variety of situations ranging from search missions to putting out chemical fires. They concluded that the emergency response system can be further enhanced by pre- and post-incident drone use – in providing up-to-date maps and assisting in forensic evidence gathering (EENA and DJI, 2016).

Drones to enforce compliance with transport policy goals

In order to be able to monitor the compliance of surface transport with emission policy goals, Trident Alliance, a coalition of ship-owners and operators working together to ensure a robust enforcement of maritime sulphur regulations in ECAs (Emission Control Areas), has endorsed using "sniffer drones" to monitor air pollution. The drones can be deployed above ships operating in the ECAs and will register any breaches of international sulphur emission regulations. There are two main advantages to the drone solution: using drone technology is a much cheaper option than traditional drone surveillance methods, while at the same time drones can easily link sensor results to a specific ship (Marine Electronics & Communications, 2015).

Drones for support missions service models

The focus of the emerging support drone industry has increasingly been on delivering end-to-end products, which combine hardware, software and services.

Some of the biggest drone manufacturers do so by taking over relevant companies – as was the case of Parrot acquiring software manufacturer Pix4D and sensor manufacturer MicaSense, while sensor-chip companies such as Intel Corporation acquired autopilot system manufacturer Ascending Technologies and mobile vision processor manufacturer Movidius.

DJI, China's largest drone manufacturer, on the other hand, has focused more on building strategic partnerships – for example with camera manufacturer Hasselblad (creating the first 100-megapixel integrated photography platform (Cade, 2017), infrared camera manufacturer FLIR, surveying system software developer Leica Geosystems and micro ADS-B (automatic dependent surveillance-broadcast) transponder manufacturer uAvionix (Perlman, 2017). DJI has also formed a number of partnerships with service providers – such as Shapeways (a digital design and printing company), Lufthansa Group, EENA, Facebook and Apple (DBX Drones, 2016).

Alternatively established service providers for different transport related tasks, such as construction, maintenance or monitoring have also either acquired drone companies, such as Autodesk and Caterpillar as described above, or are acquiring off the shelf drones and equipping them with sensors themselves.

For regulators this poses important questions around accountability of such service provision that a not so distant future could see, e.g. French railway tracks being assessed for maintenance by a Chinese drone equipped with a German sensor offered by a US-based drone service provider and remotely controlled by an operator located in the Philippines.

Major policy concerns with regards to support drones

Privacy is one of the major concerns for the public when it comes to sensor-equipped drones, as is (cyber) security. Questions about the impact on the workforce are also more immediate than for freight and passenger drones due to the advanced technology readiness level of drones for support missions.

Drones for humanitarian aid and development projects

Imagine a drone capturing images of a disaster-struck area to assess the scale of the event and to help identify the best response from humanitarian aid agencies. Imagine drones delivering blood or medical supplies to areas cut off by seasonal floods. Imagine regular laboratory runs by drones to and from remote areas.

Why drones for humanitarian aid and development projects?

The use of drones in humanitarian action is a rapidly emerging field, with the scope of activities ranging from mapping, monitoring and damage assessments to delivering essential items to remote or otherwise inaccessible locations (FSD, 2016).

The phased introduction and explorative testing of drones by the humanitarian aid community might serve as an example on a) how to open up space for innovation, b) create partnerships between clients, service providers and public authorities and c) develop missions for drones that gain support from all parties involved.

The 2016 Agenda for Humanity of the United Nations Secretary General states that to deliver collective outcomes, the humanitarian sector must promote a strong focus on innovation (UN, 2016). Novel technologies, such as drones, can be part of such innovation if they are tailored to support the delivery of the core value: provide efficient and well-targeted support.

Based on findings from various trial projects a recent study analysing "Drones in Humanitarian Action" (FSD, 2016), found that the use of drones in humanitarian work is generally viewed as positive by humanitarian and aid workers. The ease and speed of using drones for area assessments and monitoring has been stressed alongside their capacity to access and deliver to hard-to-reach locations. However, some worry about the drones arriving too late onsite to provide useful information and that replacing actors from field operations might deteriorate the quality of aid. Moreover humanitarian workers have also stressed that local populations may feel threatened by the use of drones, especially in countries and contexts with conflict environments (FSD, 2016). In some cultures, without supplying appropriate information to the public, drones may be associated with abnormal activity or witchcraft (Fraser, 2017a). Common concerns include the fear of drones crashing, the fear of hijacking the drones for negative purposes, and fears of drones carrying contagious diseases. However, community engagement sessions, such as provided by UNICEF to introduce positive use cases for drones and thus support their social acceptance have generally been welcome and have improved the understanding of the use of drones for humanitarian purposes (Fraser, 2017b).

Two examples of a partnership between aid agencies, public authorities, the drone industry and inclusion of local citizens can be studied in Africa. In this context it is important ensure that true partnerships that focus on serving local needs are established in order to avoid abusing humanitarian projects in emerging economies as "unregulated test grounds" for vehicles and yet unratified legal texts and conventions.

In Rwanda the world's first regular drone medical delivery system at a national scale started operating in 2016 as a partnership between Silicon Valley-based robotics company Zipline and the Rwandan government.

The drones deliver blood to 12 regional hospitals from a base in eastern Rwanda. Health workers at clinics and hospitals send their orders online or via text message and within minutes, the order is launched in a fixed wing drone. Powered by two electric engines and moving at a speed of over 100 km/h it then drops the cargo with a parachute at a predefined 5 metre radius drop zone, before returning to base where cushions help soften the landing and shortening the necessary landing strip (Zipline, 2018). For the selected clinics the average delivery time of routine medical supplies in Rwanda has thus been reduced from four hours to 45 minutes and emergency deliveries are now also performed (McVeigh, 2018).

The introduction of drone deliveries has helped introduce a cheaper and more demand-responsive system, preventing stockouts at local facilities while at the same time minimising waste (which is particularly relevant in case of blood which has a short shelf life and must be kept refrigerated) (Rosen, 2017). The Rwandan authorities established supportive drone regulations.

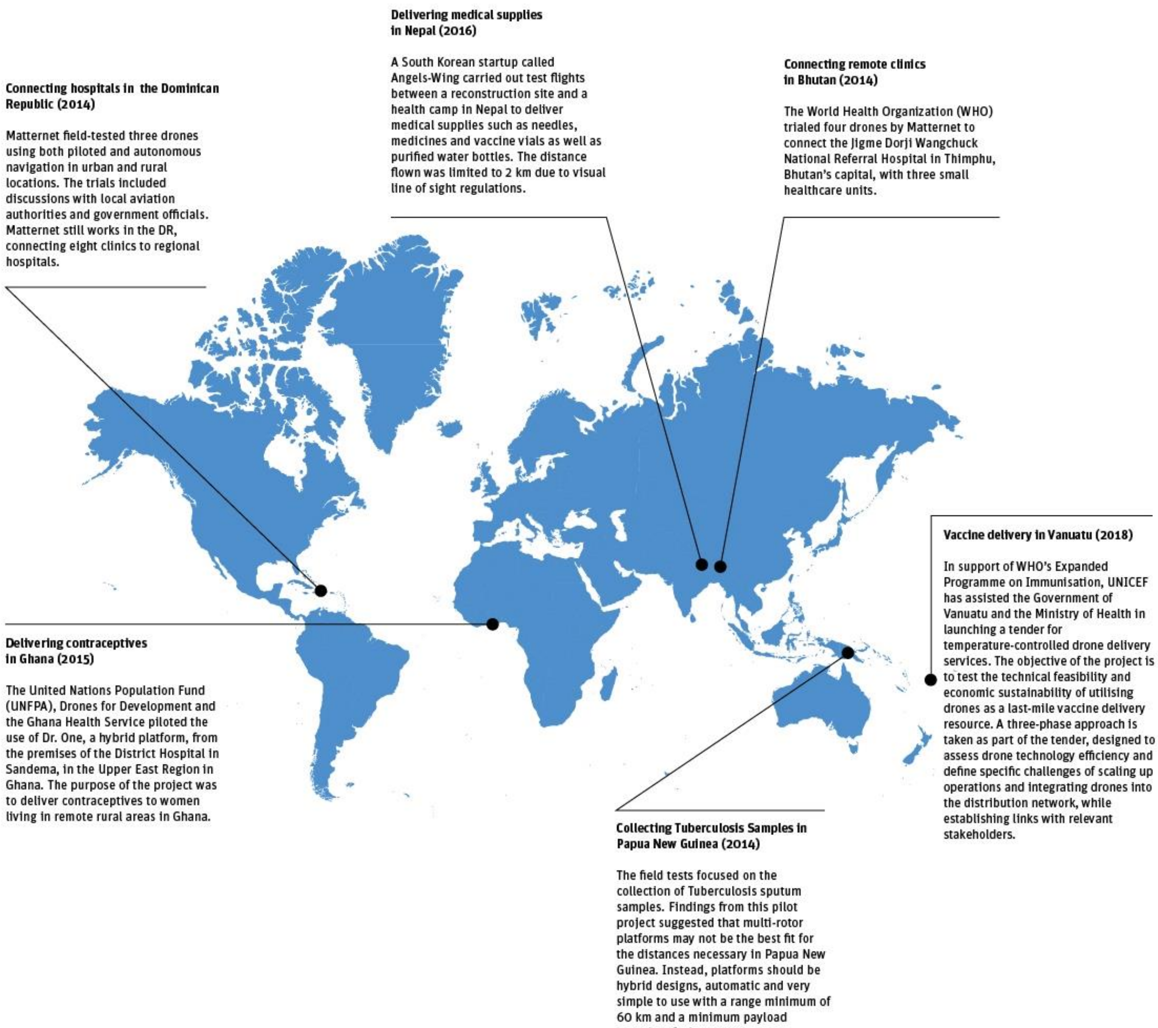
In 2017, the Government of Malawi and UNICEF launched Africa's first humanitarian drone corridor. With a radius of 40 km, an allowed operational ceiling up to 400 m altitude, a total area of 5 024 km^2, the corridor is designed to provide a controlled high altitude, long endurance flight testing platform for private sector, institutions, NGOs and other partners to explore how drones can be used in humanitarian and developmental causes. The corridor was opened with the goal of facilitating testing in mapping, alongside connectivity and transport, to address various needs for the population of about 500 000 people living within the corridor area. Within this project, UNICEF Malawi has had over a dozen international and local drone companies, NGOs and academic institutions performing tests, and facilitating training workshops to strengthen community engagement and include citizens in the development of use cases and missions for drones (Schroeder, 2018).

Overall, the need for clear guidance and rules for the use of drones was identified by the humanitarian community as the main factor needed to increase the usefulness of drones (FSD, 2016).

Drones for humanitarian and development projects today

Figure 1. **Examples of humanitarian mapping projects (based on input by UNICEF, GlobalMedic and WeRobtotics)**

Figure 2. **Examples of humanitarian cargo drone pilot projects (based on input by UNICEF, GlobalMedic and WeRobotics)**



Lessons for the introduction of drones for other use cases

Lessons learned from the use of drones for Humanitarian aid and development projects can inform the large-scale deployment of drones for commercial use cases. They demonstrate how the technology can be tailored to solve specific problems and how areas lacking connectivity can leapfrog by implementing latest technologies when regulatory authorities, commercial drone service providers work together and engage with the civic society. Moreover local transportation technology and service companies are emerging, thus strengthening the local economy.

Furthermore, the adoption of a "Code of Conduct" for drone services similar to the "Humanitarian UAV Code of Conduct" can contribute to building public confidence in the use of drones. (UAVcode.org, 2018)

Challenges for transport policy makers

National and international aviation authorities have already started developing regulatory frameworks to ensure that drones will be safe and support a wide variety of use cases.

The pace of adoption for the commercial use of drones in the transport sector will be influenced by policies and regulations within the next few years. The private sector is ready to explore market opportunities for drones, but it requires transparent rules on allowable uses and what the industry must do to guarantee the efficiency, safety, sustainability and social equity of their drone services.

As noted earlier, there are many ongoing initiatives amongst international and national civil aviation authorities to develop and implement new regulations. While safety regulations will build the foundation for creating trust in the new technologies, there is a wide variety of other factors that need to be considered by transport policy makers. Many countries have yet to develop regulations to create a legal environment for passenger, freight and support drone missions that balance benefits, such as the creation of new markets and jobs, increased accessibility of remote regions and improved services for special transport purposes, such as emergency deliveries, with potentially negative impacts.

National and sub-national lawmakers should exercise caution in enacting laws affecting drones so as not to stifle innovation by passing restrictive, burdensome and highly volatile legislation that will prevent new markets and jobs from being created. Instead, regulatory authorities should strike a balance that allows commercial use of drones while addressing citizen and policy concerns. Those concerns can be addressed by creating a phased approach for different use cases in order to grow regulators' and the public's familiarity with drones and ultimately gauge where the social licence for drone use lies amongst different transport tasks.

Based on the previous chapters, the following framework may usefully serve to guide and assess policy priorities for drone regulation as part of a future transport system.

Safety and security first

If drone use is to scale up, it must be objectively safe from the perspective of regulators and felt to be safe from the perspective of the general public.

As technology in aviation has been constantly evolving, so have the safety issues that the industry has confronted and the ever-changing safety requirements deployed to address them. In this respect, unmanned aviation is no different. However, innovation in unmanned aviation has been happening at a brisk pace, which is not typical in the world of aviation. The aviation industry has had a tendency to prefer slow and proven evolution over quick revolution. The conservative nature of aviation and its purposeful abundance of safety measures explain the excellent safety record of today's commercial aviation.

In manned aviation, there is always the expectation that when all systems fail, a pilot can still take over and safely land the aircraft. Pilots constantly train for such events and manufacturers have put in place comprehensive procedures for the air crew to manage a system failure. Moreover, regulators rely upon the cooperation of human and machine capabilities to ensure the safety of aviation.

> "Today manned aviation develops and improves upon ways to aid a pilot with the responsibility of flying safely. Regulations (e.g., airworthiness certification) and procedures (e.g., periodic maintenance) assure the integrity of the pilot's aircraft. Initial and recurrent training prepare the pilot for anticipated and unanticipated flight events. The pilot and perhaps others in the operator's organization assist in the preparation and planning for a safe flight. Civil Aviation Authorities (CAA) and air navigation service providers (ANSP) provide and oversee a highly

> organized infrastructure comprised of procedures, routes, and services to assure safe flight. All aspects of the air navigation system combine to manage the safe, efficient flow of air traffic. The introduction of RPAS challenges the extant aviation system infrastructure and raises multiple questions." *(ICAO, 2016:2)*

Safety functions currently performed by humans on board will need to be transferred to remote operators or fully substituted by technological systems that perform at least as well (and hopefully better) than pilots, e.g. lacking the eyesight of the human pilot, unmanned aircraft must rely on artificial sense-and-avoid systems to perform collision avoidance and "remain well clear" of other traffic and dangerous situations. Multiple other safety-relevant procedures must be reliably transferred from the current human-machine interaction system to a machine-machine interaction system with little to no need for human intervention.

The main international and national regulatory bodies agree that the safety standards of drone systems should be equivalent to comparable manned aviation system. This principle is known as the "equivalent level of safety (ELOS)". Its goal is to achieve an approximately equal level of safety that may be determined by qualitative or quantitative means. However as it is difficult to quantify what exactly the ELOS requirements would entail another method is to directly specify the "target level of safety" (TLS) for drones, which defines the acceptable mean number of collisions per flight hour which could result in fatalities by modelling the end-to-end system performance. Given the fundamental change of managing drones compared to current aviation, other metrics targeting overall system performance, e.g. "rate of loss of communication" could be introduced in addition to the traditional reactive metrics.

With no on-board pilot, complex operating systems, ever-changing avionics and continuous software updates, safety concerns appear to be one of the major hurdles for integrating drones into the conventional airspace – a topic that is currently addressed by aviation regulators worldwide through guidelines and regulations underpinned by ICAO's Standards and Recommended Practices (SARPs) (ICAO, 2011).

The lethal crash of a manned aircraft is an unfortunate reality that societies have accepted to a certain extent in order to enjoy the benefits air travel and cargo transport bring to individuals and economies as a whole. In contrast, the social reaction to a lethal crash involving a drone is yet unknown, but will probably cause a greater sense of unease since there is no direct human control involved. To build up a satisfying safety track record a high number of drone missions must be carried out – which amounts to a chicken and egg problem, if drones are not allowed to fly. Drones may have to aspire to a higher safety standard than current manned aviation, which is already quite high. Depending on standardisation guidelines, certification of such drones is however likely to be expensive and time-consuming, especially as an entirely new set of standards will have to be developed.

Protecting drones from cybersecurity risks is another important challenge since they can be targets for a cyber-attack themselves just as they risk being used as potential attack vectors.

Hacking is a real issue for drones. In its 2017 Threat Prediction Report, McAfee Labs identified "Dronejacking" as a quickly growing security threat (McAfee Labs, 2016). Already in 2015, a proof of concept hack of a drone was demonstrated at DefCon (Culpan, 2015), the world's largest "underground" hacking conference, where hackers, corporations and government agencies meet every year to demonstrate cutting edge hacking research and latest countermeasures.

Every drone is equipped with its own firmware that includes built-in security features linked to the specific drone design, e.g. maximum altitudes or range allowance from take-off, complemented by location specific security features such as no-fly zone coordinates. Both sets of information must be protected from tampering and modification.

McAfee expected drone exploit toolkits to be available on the darknet within a year, but also stated that most of the identified vulnerabilities discovered on commercial drones could easily be fixed with a software update. However quick, reliable software patches are usually only available for high-end products by large globally active product manufacturers.

Not only can an unauthorised party control the flight path of a hacked drone - including setting it intentionally on a collision course - but the drone itself could be surreptitiously outfitted with hacking software. It could then be used to collect data in drone "spying" attacks, e.g. by landing on the roof of a private home, business, or critical infrastructure facility and or by attempting to break into the local wireless network and transmit sensitive data back to the hacker.

What makes drones potentially easier to hack than other Internet of things (IoT) devices is that they are designed to have a quick and easy setup, often using unencrypted communication and many open ports.

Moreover, other security risks need to be taken into account, e.g. the illicit use (terrorism or criminal) of drones or the use of sensor-equipped drones for espionage.

Privacy a close second

Hand in hand with espionage and counterintelligence, the everyday privacy of citizens must be protected.

The privacy issues surrounding drone uses are distinctive because of the unique vantage point from which they can survey their surroundings. There are significant concerns that camera-equipped drones could be used to watch people without their consent or even knowledge.

There is also sensitive data on the drone itself that must be protected: it can range from information about the authorised user of the drone, its mission profile, client data and all potentially privacy or business-sensitive data sets it collects during its mission. For support drones it is part of their mission to collect vast amounts of data, which will sometimes include confidential or sensitive information about private property or passers-by.

Privacy is already a significant regulatory concern due to the unique capabilities of sensor-equipped drones, but also a relatively new one for civil aviation authorities and the transport sector as a whole. These issues are usually managed through the lens of privacy laws rather than through aeronautical or transportation regulation. Nevertheless, they have attracted the attention of privacy advocates in a number of places, including North America, Europe, Japan and New Zealand. Even if those concerned are currently mostly related to the use of leisure drones, clear regulations and accountability procedures will be paramount to gain social acceptance to operate drones in greater numbers. In this ongoing debate, the case of Sweden is of particular interest as it reveals the scope of regulatory challenges and how complex it is for authorities to simultaneously reconcile business interests and privacy. In October 2016, a Swedish court ruled that unmanned aircraft equipped with cameras were surveillance equipment, which would require an expensive permit to operate. That ruling grounded virtually the entire unmanned aircraft fleet of the country and UAS Sweden, a trade advocacy group, argued that the ruling could put 5 000 local jobs at risk (BBC, 2016).

On June 20, 2017, the Swedish Parliament passed legislation allowing private individuals to operate unmanned aircraft equipped with cameras without a prior licence or approval from state authorities (Hofverberg, 2017). The legislation created debate on the protection of privacy rights in a changing technology landscape. The government expects the integrity of the public will continue to be sufficiently protected through the Swedish Privacy Act.

Under this legislation, the unmanned aircraft operator has the responsibility to properly evaluate whether or not a flight can be performed without infringing on people's privacy rights. A guide has been developed to help operators ascertain whether or not they are using their unmanned aircraft in a way consistent with Swedish privacy laws and suggest weighing the interest of using an unmanned aircraft against the privacy rights of the individual. Individuals who feel that their rights have been violated can file a claim for compensation against the drone operator.

As in the other 27 EU jurisdictions, in May 2018, Sweden privacy legislation will be replaced with the new EU Directive 2016/680, the General Data Protection Regulation (GDPR), which will create a new framework for data and privacy protection across the EU (European Commission, 2018). It will have the merit to harmonise how privacy concerns and unmanned aircraft are treated across the EU. Consequently, the newly adopted Swedish rules will need to be changed to reflect changes in European privacy regulation.

A different approach to data privacy is pursued by China, especially within its planned "Social Credit System", that is currently under development, with first pilot tests underway since 2015 (State Council of China, 2014). and full implementation planned for 2020 with mandatory enrolment for all Chinese citizens. The "Social Credit System" is a ranking system that will monitor the behaviour of Chinese citizens and rank individuals based on their "social credit", which will include whether people pay bills on time – similar to existing financial credit systems – but also monitor other behavioural and moral dimensions. Monitoring of behaviour in public spaces already relies on about 170 million CCTV cameras across China. Sensor-equipped drones will allow for new vantage points and faster analysis.

The increased monitoring and surveillance capabilities provided by drones will continue to highlight the different global perspectives on privacy and the role of government vis-à-vis their citizens. When it comes to cybersecurity and privacy standards for passenger drones, existing laws may have to be adapted and new sets of security and privacy protocols will likely need to be negotiated and implemented.

Challenges for the overall transport system and their impact on drone policies

Safe and secure operation, in combination with clear privacy and accountability regulation, will build trust in drone transport. But as with other areas of transport, many other challenges will have to be addressed in order for societies to accept drone use. For example, a survey by the US Postal Service in 2016 revealed that only 32% of US consumers believe that drone delivery will be safe (Office of Inspector General, 2016). Perhaps even more telling is that the potential adoption of drone delivery led to a drop in public trust of companies with a high level of esteem among US consumers – including Amazon, Alphabet, FedEx and UPS. Challenges related to public acceptance will have to be assessed when considering the deployment of large fleets of drones as part of the future transport system. Assessment guidelines must carefully balance potentially positive and negative factors.

These areas for policy guidance include environmental concerns:

- Noise, vibrations and light pollution and their impact both on humans and wildlife;
- Energy consumption, emissions and overall sustainability of drone transport

They also extend to several economic and societal concerns:

- Accountability and liability
- Workforce impacts
- Social equity
- Visual amenity (both during flight and for air/ground interfaces) and integrity of the environment
- Impact on real estate values and infrastructure financing cost

Noise, vibrations and light pollution

Current noise emission regulation in aviation

Aviation noise is one of the most significant causes of adverse community reaction to development and operation of airports (ICAO, 2018). There are well-established links between aviation noise and psychophysical wellbeing. Negative impacts of noise include annoyance, sleep disturbance, cardiovascular diseases, cognitive impairment and mental health problems (European Commission, 2017).

ICAO's action to reduce noise pollution is based on the Balanced Approach to Aircraft Noise Management (ICAO, 2004). The Balanced Approach consists of identifying the noise problem at an airport and then reducing it through the exploration of four principal elements, with the goal of addressing the noise problem in the most cost-effective manner. The elements of the approach are: 1) reduction at source of plane noise, 2) land use planning and management measures, 3) noise abatement operational procedures, 4) local operational restrictions. The Balanced Approach seeks to harmonise methods used across the world to address aircraft noise, while allowing a relatively high degree of flexibility across countries to identify noise problems.

Through the Environment Action Programme to 2020 (EU, 2013), the EU has committed to decrease noise pollution by 2020 towards the levels recommended by the WHO. The Environmental Noise Directive sets a general framework for the assessment and management of noise in the EU; it defines indicators and population exposure assessment methods, and it specifies the requirements for mapping of noise. In addition to the Environmental Noise Directive, aviation-specific regulation includes: Regulation No 216/2008 and Regulation No 748/2012 with respect to limitation of aircraft noise, and Regulation No 598/2014 on operating restrictions at Community airports (although land-use management and airport operational procedures generally fall within the competence of Member States, airport authorities also have the power to set local operating restrictions).

In the United States, all aviation-related aircraft noise rules are specified in Title 14 of the Code of Federal Regulations. Part 36 refers to noise standards by aircraft type and in aircraft certification; Part 150 addresses airport noise compatibility planning, and Part 161 relates to access restrictions. FAA has exclusive authority over all matters related to operation of aircraft and aircraft certification. Airport authorities have certain competences in planning and implementing operational restrictions, while local governments have some authority over zoning and land use controls.

Potential issues with drones

One of the most important issues associated with a more widespread use of commercial drones is the impact on noise levels, especially in urban and peri-urban settings. One potential outcome of scaled-up drone operations is an increase in urban noise volume exceedances above legal or desired limits. The impact of these will depend not just on their volume, but on the duration of the exceedances and their frequency. There will likely be pressure for drone operations to fall in line with a trend in reduced urban noise levels that may accompany the uptake of electric vehicles, active travel and shared vehicle use and reduced overall vehicle kilometres travelled.

Another issue is the possible impact of large-scale drone operation on property rights, and whether compensatory or protective measures should be introduced. This is particularly relevant for residential zoning districts with lower average noise levels. As the number of air/ground interfaces is potentially without limits, zoning regulations will have to address these questions. This point raises the issue of which authority will have the right to regulate those "droneports" and what regulatory procedures must be followed to be able to build and operate these.

Status of current discussion

The marginal change in noise volume resulting from increased drone operations in a city seems logarithmic (Lohn, 2017): the more units already in use, the smaller the increase in overall drone noise volume. While ground-level drone sound levels are comparable to background noise levels in current urban environments (Lohn, 2017), there is evidence that their higher-pitched noise signature can produce higher annoyance levels (Christian and Cabell, 2015). Whether this noise can be interpreted as a violation of property right laws in certain contexts (e.g. as a "taking" in the context of the US Constitution's 5th Amendment "…nor shall private property be taken for public use without just compensation") is not yet decided as there is little basis in case law for this specific case. In determining whether there has been a taking in the US, consideration has been given to the altitude, type of aircraft, frequency and timing of flights over a property in a number of aircraft noise lawsuits (Widener, 2016). The question remains, how the problem of incomplete aircraft noise regulation will be approached when the costs of a widespread drone operation are more dispersed than they are in case of airplanes.

Similarly, the potential impacts of large-scale drone operations on vibration and night-time light pollution on both humans and wildlife requires better understanding than at present before making a case for drone-specific regulation. Currently there are very few studies assessing these impacts and this indicates that research funds may need to be oriented to support building knowledge here. More research as well as broad public consultation will be necessary to gain better certainty around the balance of the benefits and disbenefits of large-scale drone deployment for both day and night-time operations over both dense urban areas and remote or even protected landscapes.

Energy consumption, emissions and sustainability of drone transport

Current energy consumption, emissions and sustainability of aviation

Aviation is a significant contributor to global CO_2 emissions, accounting for over 2% of global man-made emissions; that contribution is expected to increase to 3% by 2050. ICAO (2016a) estimates that aviation fuel use and carbon dioxide emissions will increase in the coming decades as aviation demand increases, even as emissions per RPK (revenue passenger kilometre) decrease due to technological and operational improvements. This is further reinforced by a fact that there are few commercially viable alternatives to traditional jet fuel.

National policies affect mainly domestic aviation, which accounts only for 30–35% of total air transport (IPCC, 2014), and CO_2 emissions of international aviation have not been included in the Paris climate agreement. In order to address this issue, ICAO has proposed a Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), a market-based measure to offset CO_2 emissions generated by international aviation (ICAO, 2016b). CORSIA will be implemented from 2021 on (until 2023 in a pilot phase, from 2023 until 2026 in a voluntary phase, finally from 2027 onwards on a compulsory basis for all states, with some exceptions). So far, 73 countries (including the United States and China) accounting for over 88% of international aviation emissions have signed up to participate in the scheme from 2021 (IATA, 2017). The scheme is designed to complement existing initiatives related to technical performance of airplanes (such as ICAO's first global CO_2 certification standard for new aircraft (ICAO, 2017) and sustainable alternative fuels (e.g. ICAO's 2050 Vision for Sustainable Aviation Fuels).

Potential issues with drones

One of the main questions concerning drone transport is whether drones could offer a comparable or even more energy-efficient alternative to existing modes of transport. A gradual shift of freight delivered by truck to drone-based systems raises questions about the effects on the total energy consumption required for package delivery. Some of the issues that need to be assessed on a case-by-case basis are the weight of packages and the drone itself, length of trips and route optimisation. Gulden (2017) raises doubts that drone delivery can efficiently substitute truck delivery – especially in light of the increasing energy-efficiency of trucks.

There is also a question of whether the increased demand for drones – and hence for electricity – will exceed the potential energy savings from switching to autonomous air cargo. Similar questions arise for passenger drone travel.

Status of current discussion

The use of drones as a complement to a traditional road-based delivery system has been generally assessed as energy saving through their contribution to truck delivery route optimisation. However, current studies suggest that the energy-efficiency of VTOL drone delivery is largely limited to transporting light items across short distances (Gulden, 2017) – per-kilogram efficiency increases initially and flattens out quickly as more drone weight and battery are needed to support the load and traverse longer distances (Lohn, 2017).

Much of the current discussion focuses on lifecycle emissions (Uber Elevate, 2016). A higher number of drone distribution centres (additional warehouses with battery charging facilities) brings significant efficiency improvements through reducing distances – but at the cost of higher lifecycle impacts through additional energy needed for the centres (Stolaroff et al., 2018). With the goal of improving energy-efficiency and reducing the environment footprint of electric vehicles (drones included), there is also a significant effort aimed at promoting alternative fuels for electricity generation (Tessum et al., 2014). There is also a push for promoting strategies for the efficient use of drone platforms – aimed particularly at overcoming inefficient use of drone batteries in targeting longer and more autonomous flights (Corral et al., 2016).

Overall, a bulk of research concentrates on finding the most efficient setup for drones to help reduce the negative environmental consequences of emissions and energy use in the freight sector (Stolaroff et al., 2018).

Given the ramp up time of large-scale drone services, it still remains unclear how drone services will affect Paris COP 21 agreements.

Accountability and liability

Current accountability and liability in aviation

Liability refers to the state of being legally responsible for damage. In aviation, that typically includes the damage caused to people and property (third parties) either on the ground or in mid-air collisions.

There is no common international regime for third-party liability in aviation (whether manned or unmanned). While a global legal instrument exists (the Rome Convention), very few countries have ratified it (Masutti, 2016). It follows that rules governing liability for third-party damage are based on domestic law. Liability can be limited through a cap on the potential level of compensation or unlimited, with no cap on the amount of damages for which defendants are potentially liable. In practice, compensation will be limited by the value of the insurance policy purchased. Hence regulations exist to establish minimum insurance requirements, such as in the EU (see Current State of Play).

Liability can also be strict or fault-based. In a strict liability regime, the party is liable without any proof of negligence or fault, whereas in a fault-based regime an entity may only be liable if some form of negligence is established, or it may be able to avoid liability if it can prove that it was not at fault. In Europe, most countries adopt a strict liability regime but some countries have fault-based regimes (e.g. the Netherlands) and others combine the two (e.g. the United Kingdom with respect to mid-air collisions). Outside Europe, the case of Australia shows that a framework can equally foresee strict and unlimited liability for the aircraft owner and the operator (Steer Davies Gleave, 2014).

Potential issues with drones

Liability issues are linked to the nature of unmanned aviation. The nature of drone operations makes it difficult to allocate liability amongst manufacturers, operators, the (remote) pilot, software providers or any other entity involved in drone operations. In case of mid-air collisions, drones may be involved either in crashes with other drones or with manned aircraft.

The definition of damage may also prove contentious. In the aviation industry, incident reporting practices help understand the risks and potential impacts caused by aircraft. Databases with occurrences are also useful to the industry at large in order to develop better safety standards and ancillary products, including insurance packages. If incidents and accidents are not clearly defined with a specific focus on drones, it follows that reporting occurrences in a consistent manner may be difficult and hence the potential for lessons learnt may be lower.

When it comes to operators, the lack of a harmonised liability regime internationally can result in more complex (and hence more costly) legal proceedings for operators active in more than one country. In this case, specific insurance policies capable of covering requests for damages both in strict and fault-based liability regimes may be available for international operations.

In the case of potential victims, issues may arise with respect to identifying the source of damage and reporting this to the competent authorities. Victims, who may be individuals or businesses on the ground, would not find it easy to directly identify the owner and/or the operator, let alone establish responsibility. Similarly, it is unclear whether victims should report occurrences to local police and/or competent aviation authorities, and whether such information would be shared.

Status of current discussion

There is no push for harmonising liability regimes in the aviation sector at the international level. While harmonisation would reduce uncertainty, it does not appear to be a condition *sine qua non* for clarifying roles and responsibilities in the case of drone accidents and incidents.

Solutions are likely to come both from the industry itself and from regulators. The insurance industry will most likely build on the emerging body of evidence on drone crash incidents to come up with products tailored to the needs of commercial drones. Manufacturers and regulators could agree on production standards to include small identification plates as well as geofencing software in order to better identify each aircraft in case of accidents and incidents. Discussions on the creation of national and international registers of commercial drones would benefit from all of the above.

As described by Masutti (2016), it is reasonable to believe that the future set of regulations for drones should aim at creating a fair balance between the protection of victims and the financial interests of the players in the marketplace by, for example, setting limits on compensation.

Workforce

Current workforce in aviation

The aviation industry employs approximately 9.9 million people (ATAG, 2016). Airport operators account for 447 500 of these jobs, airlines – 2 669 000, air navigation service providers – 224 000, the latter two are expected to be impacted quickly following the introduction of drone services.

In the US, there were 609 306 active pilots certificated by FAA (FAA, 2018), 23 130 air traffic controllers, 7 920 airfield operation specialists, 6 760 aircraft cargo handling supervisors and 108 510 flight attendants (DOT, 2015). In the EU, employment in air transport was estimated at 665 000 people, with 375 000 air and cabin crew employees, and 245 000 airport operation and handling staff (Steer Davies Gleave, 2015).

Potential impacts of drones on employment in aviation industry

The development of drones and their integration into the airspace is expected to have a significant impact on this workforce. In the US, the total impact is estimated at 103 776 new jobs by 2025, including 50 529 manufacturing jobs (AUVSI, 2013). FAA (2018) expects the demand for drone pilots over the next five years to exceed 300 000 new jobs. SESAR JU (2016) estimates that approximately 105 000 jobs will be created by 2035 (135 000 by 2050) as a direct impact of drone integration, with the services sector (piloting and operations, and value-added services) contributing most to the overall job increase. With an assumption of a single pilot managing multiple specific drones from 2025, approximately 250 000 pilots are expected to support the operation of a fleet of 400 000 drones in 2035; 20% of these jobs will represent incremental job creation (SESAR JU, 2016). A creation of additional 250 000-400 000 jobs in non-aerospace industries is also expected.

Control over training and licensing

Through the Manual on RPAS – a result of long-term on-going consultation with aerospace industry stakeholders – ICAO has developed high-level guidance for safe and harmonised integration of drones (ICAO, 2015). Rules for licensing aircraft for cross-border operations are subject to international standards under the Chicago Convention. Apart from this, the specific design and enforcement of training and licensing guidelines falls under the jurisdiction of nationally-defined competent authorities, typically civil aviation authorities.

In case of the European Union, new regulation harmonising training and licensing legislation is currently being drafted (EASA, 2018).

Status of current discussion: licensing of pilots for drones

Recent changes to licensing requirements have generally contributed to lowering barriers to entry. In the United States, Part 107 replaced the pilot licence requirement with a knowledge test and a drone certificate (FAA, 2016). In the EU, through EASA's new proposed regulatory framework, licensing requirements will be harmonised and proportionate to the level of operational risk – for example, in the "open" category, the requirement for prior authorisation will be removed (EASA, 2018).

Some obstacles are harder to overcome: BVLOS operations and flights over urban areas continue to be subject to more stringent rules, although waivers and special certifications can be obtained.

Positive aspects on workforce diversity and work-life balance (e.g. opening up the piloting profession to more women and people with disabilities due to different job requirements for remote operators) will also need to be assessed.

Social equity

The nexus of digitalisation, new business models and lack of infrastructure funds is already having an impact on many aspects of modern life, including the way in which people and goods (can) move. Within the right regulatory framework new technologies and business models can help to ensure that more people can fulfil their mobility needs in a sustainable and cost efficient way. For example, drones may offer remote, often indigenous communities unique opportunities create more social equity. Usually accessible only by air, these remote communities, e.g. in Canada, have extremely high costs of living. Drones may offer a substantially reduced cost structure and might provide remote communities with new economic opportunities to retain youth. (Harris, 2017)

There is a risk, however, that without regulation that takes the overall outcomes from transport into account, drones may only provide services for those who can pay for premium services. While policy makers can allow these markets to establish themselves, two questions remain: how much attention should policy makers expend to develop regulations that serve exclusive markets, and what might be the societal impacts of drone fleets, especially for those who cannot afford these services, but may be disproportionately exposed to negative impacts (e.g. the location of drone ports and increased noise/night time disturbances in areas with cheaper land prices).

Visual amenity

The impact of drones on the perception of cities and landscapes might prove to be another obstacle to wider institutional and public acceptance. Visual considerations are especially hard to assess for policy makers.

A parallel could be drawn between the effect of wind turbines, and drones, on visual amenity. Public opposition to wind farm development is well established in Europe and North America. There is frequently a gap between public attitudes towards cleaner energy and individual support for wind farm construction in one's proximity – the so-called NIMBY (Not In My Back-Yard) problem. In line with this, Jones and Eiser (2010) have discovered how in the United Kingdom the support for specific offshore projects is often significantly higher than for undefined plans for onshore projects – potentially in the vicinity of settlements. One reason for this could be the so-called "visual pollution", and its impact on house prices. Gibbons (2015) used house price reductions as a proxy for visual impacts of wind turbines, and found an average reduction of 5-6% for housing with a visible wind farm within 2 km. There is also a parallel to be drawn to the disamenity of close proximity to very crowded roads and urban motorways.

Drones can similarly be a source of visual disamenity, and positive views about their energy saving and convenience increasing qualities could suffer from a NIMBY problem too. However, droneports are unique in their non-localised nature, which limits the options for organised community engagement and compensation considerations – policy solutions widely discussed in the context of wind farms.

Drones within more traditional urban contexts might also raise questions of visual integrity, which is an important concern for historic towns and cultural heritage sites across the globe. UNESCO guidelines define integrity (one of the criteria for selection of World Heritage Sites) as "a measure of the wholeness and intactness of the natural and/or cultural heritage and its attributes. Examining the conditions of integrity therefore requires assessing the extent to which the property … suffers from adverse effects of development and/or neglect" (UNESCO, 2017: Art. 88). UNESCO's Vienna Memorandum (UNESCO, 2005) additionally states that "urban planning infrastructure … must include all measures to respect the historic fabric, building stock and context, and to mitigate the negative effects of traffic circulation … Townscapes, roofscapes, main visual axes … are integral parts of the identity of the historic urban landscape". This has traditionally involved the establishment of buffer zones around the property, to protect "important views" from and toward the property. In disputes – in historic parts of Vienna, Prague, Vilnius, to name just a few – the recommendation has normally been to extend zoning regulations and high-rise limitations (UNESCO, 2013).

Drones represent a challenge different to the building of modern skyscrapers, but might nevertheless be easily considered an intrusion to historic sites' visual integrity. On the other hand, some cultures might welcome the sight of drone transport as a signifier of modernity and increased attractivity of the surroundings.

Impact on real estate values and infrastructure financing costs

Both issues are raised as concerns by many policy makers. The impact on real estate values is particularly worrisome to local and urban governments while the issue of infrastructure costs related to drone use, particularly drone-compatible ATM management, has been raised by national civic authorities. Limited research input on these questions is currently available.

Drones in urban settings

Using airborne vehicles to move effortlessly around cities has captured the minds of the public ever since Fritz Lang's 1927 movie Metropolis.

As yesterday's science fiction is on the verge of becoming today's reality, urban populations and city authorities face a new set of questions. Drones can present a number of opportunities for cities, from potentially alleviating pressure on ground transportation networks to enhancing the speed and availability of emergency services and becoming crucial tools for different city departments to perform their duties in safer, more cost efficient manners.

Drones also present new challenges to cities, ranging from questions regarding the safety and security of drone operations and most importantly the allocation, design and regulation of droneports within complex, constantly changing urban environments. In 2016, there existed 3 883 airports with scheduled commercial flights globally and 41 788 airfields in total, including military and general aviation. There are potentially no limits to the number of droneports in any city – let alone globally.

There is the issue of integration, or competition, with existing urban ground transport services and those regarding privacy, visual amenity and noise. Local communities and urban planners are already exploring what infrastructure requirements could be necessary in urban areas to accommodate the operations of drones and some cities are beginning to consider these in their city planning processes.

With large-scale drone operations in cities becoming a more distinct possibility, local governments are demanding a voice in the decision-making process.

Urban land use and zoning regulations are typically decided on the local level and mayors could use these plans to designate where drones may take-off and land as well as other operational criteria, very similar to the authority to regulate the access and operation of other transport modes, e.g. parking, access, routing and operations of private cars and public bus services.

The design and location of new air-ground interfaces are of particular interest in cities. Three different approaches have been suggested:

- Use of existing infrastructure (e.g. passenger drones landing on flat roof buildings or close to existing urban highway junctions)
- Creation of new small scale logistics centres dispersed across the city
- Creation of new street furniture or new designs for buildings

The service models for urban areas include fixed-route transfers, e.g. to and from airports and other high capacity multimodal transfer terminals, or on-demand route generation, relying on many dispersed dronepads similar to helicopter landing facilities on top of buildings or making use of unused on ground space next to existing road infrastructure, e.g. empty parking sites or the "eyes" of clover leaf highway crossings.

Current regulatory status

Most national frameworks forbid the use of drones in urban areas, typically because the risks are greatest in congested areas where flight occurs over other people's property (Perritt Jr. et al, 2016). Nevertheless, the competitive advantage of commercial drones is greatest precisely in dense, urban and suburban areas (SESAR JU, 2016). In the case of delivery, routing density is a crucial factor of competitiveness when comparing drones to delivery vans (The KiM Netherlands Institute for Transport Policy Analysis, 2017).

Hence, the case of urban operations by commercial drones best exemplifies the trade-offs emanating from different regulatory approaches and deserves a specific discussion.

Regulatory conundrum

In banning drone operations in urban areas, national regulations depart from the basic premise that aviation regulatory frameworks are well suited for drones, subject to adequate modifications and updates. Whereas manned aircraft are normally allowed to fly over cities (with exceptions due to noise regulations at night), public safety concerns have prevailed in the case of drones.

Safety concerns are mitigated by the low altitude at which drones fly. Conventional aircraft are not allowed to fly at such low heights, making it easier for air traffic managers to develop 'drones only' urban airspace. Nonetheless, unless autonomous collision avoidance systems and drone-to-drone communication systems cannot be shown to work reliably, zero risk under an outright ban is the only acceptable level of risk that regulators are willing to accept even when the likelihood of airplane-to-drone crashes is very limited.

It also matters that the connectivity needed for drones to stay electronically connected to their pilots in congested, built-up areas over significant distances is expensive and so the only economically viable way for drones to retain their competitive advantage is to rely on fully autonomous aircraft in dedicated airspace (Forbes, 2017).

However, in a similar fashion to insurance markets, regulatory agencies will only be able to relax requirements as the body of evidence on drone crashes and their impacts grow. Paradoxically, restrictive regulations are putting a break on the possibility of observing and collecting the outcome of real-life occurrences and creating more evidence-based approaches to safety. Several drone operators have simply stopped developing their business cases for urban settings as a result of those very restrictive rules.

Overlapping responsibilities

The outright ban to fly over cities also raises a critical question of regulatory responsibilities: Which jurisdiction applies to urban drone operations – national regulations or local authority rules? This is likely to become one of the greatest challenges for regulators and policy makers over the coming years.

Recent legal research in the United States shed some light on the potential magnitude of this challenge. In the United States, there is a likely conflict of jurisdiction between federal laws and rules by the FAA and state law. In the aviation context, federal law generally pre-empts state law (Perritt, Jr. and Sprague, 2015). However, state and municipal authorities may find that they have the power to regulate certain aspects of drone operations as part of a complex matrix of responsibilities (Box 2).

Box 2. Federal versus state rules in the US

The Federal Aviation Administration (FAA) is the air safety's regulatory agency in the United States. The FAA initially took a restrictive approach to authorising drone applications across the United States. Its guidelines and policy documents were understood to effectively prohibit the use of drones of any size without explicit FAA approval (Clarke and Bennett Moses, 2014). The first approval for commercial flights was granted in September 2013 and the authorisation only applied in the Arctic. New rules for non-hobbyist small unmanned aircraft (UAS) operations – Part 107 of the Federal Aviation Regulations, passed in 2016 – cover a broad spectrum of commercial uses for drones weighing less than 55 pounds (approximately 30 kg) (FAA, 2016).

In the absence of a comprehensive federal framework to regulate all commercial drone operations, states and municipalities have contemplated putting forward their own regulations. In the United States, the Commerce Clause prohibits states from interfering with interstate commerce, while the Supremacy Clause nullifies state law that conflicts with federal law. In conjunction, these clauses allow the FAA's authority to preempt state and municipal drone regulation. But, in the case of conflicts, which jurisdiction is more likely to prevail over the other?

Case law provides some potential answers. States or municipal legislation or rules that target drones are more likely to be pre-empted than a statute or regulation of general effect, such as relating to noise, taxation, or environmental protection. Moreover, pre-emption is less likely if a state narrowly targets a particular highly localised area of drone operations, and relates it to matters of traditional state concern, such as personal privacy, or security of property occupancy. Limiting the purposes for which drones may be flown, for example, prohibiting flights for surveillance or to capture imagery of a particular individual, might be permissible.

States and municipalities may not, however, regulate the height at which drones can be flown. Because the FAA prescribes a maximum height above ground level, justified by reducing interference between drones and higher flying manned aircraft, these requirements would be pre-empted. On the other hand, a state or local rule establishing a minimum height is less likely to be pre-empted because there is no FAA-established minimum height, and because of traditional police power to regulate land use. The cases involving claims of trespass to land by aircraft might suggest otherwise, however.

Sources: Adapted from Perritt, Jr. and Sprague (2015) and Perritt, Jr. and Sprague (2017).

In Europe, some city governments have obtained derogations from civil aviation authorities to run public events dedicated to hobbyist drones, such as Paris opening up its parks to drone owners on Sundays during the summer, as part of the plan ‘Paris, capital of start-ups’. When it comes to commercial operations, the typical procedure involves the drone operator obtaining a national licence from the civil aviation authority; subsequently, the operator can apply to the local *prefecture* (Interior Ministry local office) for a case-by-case approval of operations in a given area of the city for a limited amount of time.

The third instance in which responsibilities may be unclear is for operations within a city, but not in an open/public space. For example, both civil aviation and local authority rules may not apply in the case of operations taking place within a closed urban space, such as a factory, a hangar, or a shopping centre.

Developing drone infrastructure

Regulatory issues and jurisdictional questions are inevitably linked to infrastructure development. To use drones for transport in urban areas, vertical take-off and landing are a must (The KiM Netherlands Institute for Transport Policy Analysis, 2017). Vertical take-off may be at odds with high-rise development and densification of urban areas, while landing sites will compete with other priorities for the allocation of scarce land resources. In this context, land-use planning and interactions may be more of a barrier to commercial drone development than airspace management and city planners and regulators will need to work together to address the challenges of urban infrastructure for drones.

The public and the private sector alike may come up with solutions. For instance, cities may start planning for dedicated aerodromes and build those similarly to car parks. If landing sites remain under public ownership, sub-national authorities will have more direct powers to regulate drone conduct and to specify where drones may take-off and land in a city. Once again looking at case law in the United States provides support for the proposition that states and municipalities have the authority to regulate airport siting vis-à-vis federal agencies (Perritt, Jr. and Sprague, 2015).

Privately developed, drone-friendly urban sites have not yet been built but new concepts are emerging. A droneport prototype designed by the Norman Foster Foundation in collaboration with universities worldwide and exhibited at the Venice Arsenale in 2016 consists of a traditional brick structure with vaulted shelters. The government of Rwanda has identified a site and contributed funding to the project (Norman Foster Foundation, 2016). The idea is to create a network of droneports to deliver medical supplies and other necessities to areas of Africa and other continents that are difficult to access due to a lack of transport infrastructure. Away from congested existing urban areas, a new wave of urbanisation could well be accompanied by innovations of this kind.

Infrastructure development in the form of landing sites or droneports will put to test existing planning and airport rules. Widespread growth in urban aerodromes would require some reallocation of responsibilities. A first option is that all regulatory functions related to aerodromes are absorbed within city council departments. Alternatively, national civil aviation authorities could remain in charge of safety and standards while devolving infrastructure planning only to sub-national authorities.

Efforts in industry self-regulation could also see operators and landing site managers come up with standards and guidelines to promote the emergence of dedicated infrastructure in cities. This would open up more opportunities for collaboration between planners, regulators and drone operators in areas such as crashes, noise and other related drone-hazards with the aim of developing the safest and most operationally sound drone infrastructure plans into the urban fabric.

Preparing for tomorrow

Competing visions for the future of mobility are being pursued at present. New technologies to better understand, monitor, provide and manage mobility emerge almost constantly and transform how people and freight move.

Among these constant changes, the disruptive potential of drones to the existing transportation system is still unclear. Specialised services might work well in a particular socio-cultural and economic context, e.g. mid-range freight services in countries with less extensive ground transport networks or high-value passenger shuttle services in cities with many flat roof skyscrapers downtown, but might fail in others. At the same time, civil aviation authorities are faced with the challenge to prepare for the safe integration of large fleets of drones and to balance the need for evolving rules/frequent review of regulations due to the quickly evolving technologies with predictability for business and expectations of the civic society. The future proofing of policies and regulations will be a challenge as they must be designed to accommodate both the rapid development of drone technologies and the novel emerging transportation services.

A few key elements need to be put in place in order for the overall transport system to benefit from the introduction of drones for passenger and freight transport and support missions.

These include:

- Establishing a public-private policy dialogue for drones as part of the overall transport system
- Building regulatory capacity in authorities
- Development of a well-rounded R&D strategy and establishment of experiment and testing areas/licences
- Collecting and sharing data on drones to understand their impact and tailor policies
- Developing visions to integrate drones with transport system

Establishing a public-private policy dialogue for drones as part of the overall transport system

In several countries, including France, Germany, Spain, the United Kingdom, the United States and Japan, joint public-private discussion forums have already been set up to serve as a national exchange platform bringing together the different parties interested in the development of a market for the use of civil drones. (see Box 3 French Civil Drone Council)

While the organisational structure, decision-making procedures and the composition of the parties may vary, these discussion forums generally are comprised of public authorities, universities and research centres, drone manufacturers – large industrial conglomerates as well as SME's, drone operators and training services, potential drone service customers and support services, e.g. legal, financial and insurance sectors.

Among the high-level goals that most of these drone platforms share, are:

- the study of possible solutions to scientific, technical, socio-economic and regulatory challenges
- the exchange and coordination between national players and
- international discussion and harmonisation where beneficial.

Sub-committees are often established in order to tackle specific questions in more depth, e.g. to establish training requirements for drone pilots and controllers or to tackle long-range operations. These sub-committees often focus on the issues that currently feature most prominently in the national regulatory authorities' concerns. International platforms have also emerged, among them the non-profit UVS International that includes 32 national drone associations and more than 4 100 companies from 35 countries. JARUS, the Joint Authorities for Rulemaking on Unmanned Systems is a group of experts from National Aviation Authorities and regional aviation safety organisations from 52 countries, plus EASA and EUROCONTROL, which work on recommendations to create a single set of technical, safety and operational requirements for the integration of drones into airspace management.

Working closely together all parties want to jointly shape the regulatory framework for drones, thus providing industry and society with a stable outlook on what to expect from drones.

Currently these platforms benefit from the expertise of civil aviation experts, but not many consider including know-how from other transport domains. Inviting specialists from other transport sectors might be beneficial in a few crucial areas, e.g. the design and regulation of air/ground interfaces as well as for insurance questions, where learnings from automated ground vehicles might be taken into account for the development of drone insurance regulations. Moreover, it might be worth including the viewpoints of sub-national transport authorities, particularly cities in the composition of the discussion platforms.

The establishment of national drone councils and their close coordination with international public-private discussion forums will be of great use to transport policy makers.

Box 3. The French Civil Drones Council

Since 2012 and the introduction by the French CAA (DGAC) of a regulatory framework for UAV (drones) operations, the French civil drone industry has undergone significant development. The Civil Drones Council (CDC) was created in 2015 to pursue and accelerate this development by helping to structure the sector through dialogue between the main players in the industry, and coordinating the efforts to remove the operational, technological, economic and regulatory barriers all players face in order to develop the market (DGAC, 2017).

The CDC, a public/private body with no legal status, consists of an executive committee and four technical committees which themselves comprise different working groups. The Executive Committee leads, coordinates and monitors the actions of the four technical committees. It is chaired by Patrick Gandil, the Director General of Civil Aviation, and meets every six months. The four technical committees are each focused on a given thematic: operations, regulations and uses, technologies and safety, support and promotion of the industry and training.

The CDC is open to all French actors whose activities affect the civil drone industry, on a voluntary basis. Today it brings together manufacturers, operators, professional syndicates, test centres, training centres, administrations, the French data protection agency, major customers, major aeronautical groups, research organisations, clusters, incubators, insurers and lawyers. The DGAC chairs the Civil Drones Council and DGAC staff assume the general secretariat, while industry members co-chair the technical committees and their working groups.

Since its creation, the CDC has launched a number of structuring actions, in particular to involve French manufacturers and operators in European regulatory and normative processes and has worked to facilitate the implementation of current regulations for professional operators. It has launched several major initiatives on innovative uses with very high added value, at the same time pushing for an evolution of the French regulations from operational restrictions, which have allowed the emergence of the sector, towards a more aeronautical logic (airworthiness, demonstration of safety) which is essential to authorise those new uses.

For example, a "long range operations" (LRO) approach is underway to make it possible to monitor linear networks (railways, electricity networks), sometimes for several hundred kilometres, by drones. The development of an adapted safety methodology should enable the first large-scale pre-industrial operations in 2018. The full LRO missions will not become reality for a few more years, but these "interim" LRO missions, allowed above low-populated areas only, present significant interest for the network operators, in that they allow them to set up their internal organisation for drone monitoring and realistically assess what benefit they will get from a "full drone monitoring" of their network.

Building regulatory capacity in authorities

The digital revolution has already had a significant impact on how governments serve their citizens. Some countries are leading in providing e-services, others see the growth of large national "digital" sectors driven by private companies. A recent OECD report found that this generated considerable mismatches between the supply of and demand for ICT skills in general and for ICT specialist skills in particular (Reimsbach-Kounatze, 2015), which suggest that government authorities might increasingly have to bid against private firms for people with the required skills and could be forced to pay a premium to attract them to public service.

Given the potential capacity constraints of public servants to even ask "the right questions" vis-à-vis highly specialised technology developers and providers, policy makers involved with creating new regulations need to consider how best to address this mismatch in skills.

In 2017, the Canadian government earmarked CAD 77 million over 5 years to reinforce Transport Canada's regulatory capacity with respect to autonomous technology, namely by developing regulations for the safe adoption of connected and autonomous vehicles and drones. By working with industry, provinces, territories and municipalities to establish pilot projects, Transport Canada aims to increase its ability to establish and provide the standards and certifications that industry will need to safely use these new technologies.

Establishing drone councils (as discussed above), cross-agency (international) coordination and a shift to more open policy development processes, including expert citizen participation models, could alleviate some of the capacity constraints.

Development of a well-rounded research and development strategy and establishment of experiment and testing areas/licences

When it comes to innovation, transport clearly has all the markings of a "legacy sector" where the traditional way of doing things is protected by large, powerful institutions and industry players. The aviation sector certainly prefers slow, incremental changes in order to protect its high safety standards - and with this, incumbent players. Nevertheless, the recent confluence of technologies that enable drone transport have clearly raised the awareness of policy makers and the industry alike and spurred more innovation friendly approaches.

Bonvillian and Weiss (2015) detail a few strategies on how policy makers can support innovation in the legacy sectors in order to overcome their particular issues. One strategy includes "front-end, supply-side" policy measures that include direct government support for R&D, technology prototyping, testing and demonstrations. Furthermore, they argue that network economies can be achieved by imposing or agreeing on performance and interoperability standards.

For the drone sector this means creating competitive funding sources for R&D, dedicating test sites for prototype trials and eventually large demonstrations sites. Already significant funds are dedicated to drone R&D across the globe.

In the United States this is mainly driven by military related application for which a budget of USD 1.7 billion for drone R&D was approved as part of the 2017 Presidential Budget. This is complemented by NASA and FAA spending about USD 20 million annually to focus on air traffic management R&D and further funding from venture capital in the excess of USD 500 million to date. At the EU level, the Horizon 2020 programme is addressing drone research for air traffic management with about EUR 10 million annually, complemented by about EUR 50 million from the European Defence Agency. There is significant R&D spending on national levels, particularly in France and Germany and the numbers are increasing, but SESAR JU (2016) puts the overall R&D budget needs at a total of EUR 400 million over the next 5-10 years. Asian countries, among them China, Japan and South Korea are also heavily investing in R&D for drones and dedicating test sites for prototype work and large scale experiments in order to facilitate R&D cooperation between academia, companies and regulating authorities. In South Korea, for instance, the Ministry of Land, Infrastructure and Transport (MOLIT) has designated seven dedicated airspace zones for the activation of the drones industry and selected 25 representative companies to promote pilot projects. MOLIT also plans to have clarified drone regulations in the country and established a national flight test site in Goheung by 2020. (Cho, 2017).

The significance of large scale test sites that offer opportunities to test drones in a wide variety of conditions has been recognised in many countries and include seven FAA managed test sites in the United States (FAA, 2017), and several test sites in the EU, among them a UK site that includes 7 100 km^2 with unlimited height restrictions over sea (ICATS, 2014). Of particular importance are test sites for trials that focus on two particular questions: how to safely integrate drones into all areas of airspace management and how to design and manage all forms of air/ground interfaces safely and efficiently.

While questions that are closely connected to vehicle design and flight management of drones are currently the focus of R&D efforts (see Floreano and Wood, 2015) transport policy makers will also need answers to broader questions about how drones will affect transportation systems and societies as a whole. As Rao et al. (2016) in their overview about "The societal impact of commercial drones" state: "Rather than the technology itself, it is our use of it that affects our perception, and thus our behaviour." Focusing on drones in isolation from the overall transport system will "probably get the technology right", but research programmes and funds will also need to develop a more pro-active approach towards questions regarding the environmental, economic and social impacts of drones overall. As Rao concludes: "The future success of civilian drones depends on the ability of varied stakeholders to reconsider how this emerging technology platform can be best harnessed to serve the broad interests of society" (p. 89).

Universities and applied research centres able to support priority research efforts across the whole spectrum – vehicles, operation systems, unified air management systems and the effects on the overall transport system from an economic, socio-cultural and political perspective – are currently emerging. Examples include MIT's well-known AeroAstro programme, the Delft University of Technology, who is partnering with Delft city for deploying and assessing a fully autonomous urban drone network or Singapore's Nanyang Technological University who partners with Singapore's CAA to further develop air traffic management for drones (2017).

Today's efforts to formulate a broad R&D perspective for drones will have benefits for the short and long-term efficiency, sustainability and social equity of transport.

Collecting and sharing data on drones to understand their impact and tailor policies

The availability of accurate, timely and meaningful data is key for governments, industry and civic society to understand the proper functioning of any kind of system.

Aviation has a long tradition of collecting and sharing extensive operational and performance data sets, which are then used to formulate policies and regulations, monitor the industry and predict future needs. The importance of statistics in aviation is captured in Article 67 of the Chicago Convention (ICAO, 1944) which requires states to collect data on traffic, costs and financial statements for international aviation. Most countries also do the same for domestic aviation.

However, with respect to unmanned aircraft, data is sorely lacking. Basic information such as the number of aircraft is practically non-existent, except in jurisdictions where registration is mandatory. Aside from possibly knowing the number and composition of the (leisure) drone fleet, very little data is currently available. As a starting point, data on individual aircraft characteristics, the number of flights during a given period, the number of flight hours during that period, the types of mission flown and eventually the number of passengers and the weight of freight carried should be collected in order to enable authorities to conduct meaningful safety, security and economic analysis.

Governments may also require access to location data, either directly from the operator or from a future UTM system to better identify heavily travelled corridors and to better understand future infrastructure needs of unmanned aircraft. Given the technical systems already needed to perform any drone flight this data could be easily generated at little or no cost.

Thus civil aviation authorities should work with industry and ICAO to develop data requirements and data reporting and sharing standards that would help close the existing information gap for drones.

Develop visions to integrate drones with transport system

Until most recently regular drone transport was the domain of science fiction or cartoon movies, such as the Jetsons. Visions centred around either utopian or dystopian distant futures.

Today leading academics, architects or global design practices, such as Carlo Ratti, Sir Norman Foster and IDEO are developing feasible visions for drone services that are integrated with the transport system (Yalcinkaya, 2018).

Carlo Ratti, director of MIT Senseable City Lab together with ANAS, an Italian highway company developed a concept that integrated new infrastructure for autonomous cars with drone infrastructure along highways in order to tackle different issues of safety, emergency support, emissions monitoring etc. with the most appropriate, efficient technology. Similar ideas about the fluid cooperation between ground and drone transport have been reflected in the Daimler/Matternet combined drone-van delivery system described in chapter "Freight Drones".

Air/ground interface designs/Drop-off points/droneports

Not only will the interplay between different modes of transport have a significant impact on the usefulness and acceptance of drones, but as the real value of passenger and freight drones is generated when they touch ground and their "payload" emerges, the impact of the potentially millions of droneports will need to be understood and then integrated with the transport system as a whole.

The design of these droneports has been given very fleeting consideration so far, with the exception of proposals for scalable droneports for rural droneports in Africa by architect Sir Norman Foster and suggestions for the design of landing infrastructure on top of skyscrapers or adjacent to existing ground transport infrastructure, such as repurposed parking lots or adjacent to highway "cloverleafs" as proposed by Uber. Many more differently sized and equipped droneports must first be envisioned before policy makers can have a meaningful discussion about their introduction and regulation. Particularly city level authorities will need to have a better understanding of the variety of possible droneports to assess their impact on existing land use and zoning laws.

There has been a lot of discussion about the feasibility and economic efficiency of a drone delivery system, but a question of how it should be designed to ensure convenience and safety remains, specifically, where drones should pick up and drop off packages (and, in time, passengers). The Norman Foster Foundation (2016) has designed what is thought to be the first droneport in the world – flexible spaces covered by a vaulted brick structure on the ground. However, Norman Foster's droneport was designed for rural areas with abundance of space.

Designs for droneports in cities have focused on multi-level structures. Saúl Ajuria Fernández's "Urban Droneport" (2016), for example, is a solar-powered spherical drone hub designed for the city of Madrid. It consists of several levels (which can be modified), and consists of two parts: a logistics centre in the lower levels (with an industrial storage systems), and a state institute of technology development on the upper floors. In 2017, Amazon patented a "Multi-level Fulfilment Centre": a high-rise urban droneport that can be located in densely-populated downtown districts and its height adjusted to local zoning regulations. The centre can be designed to accommodate all types of orders, and potentially a self-service location.

With relation to urban landing and drop-off points, Mark Dytham expects future buildings to "sprout branches" to land on (Fairs, 2017). Some, among them Uber Elevate (2016), have focused on utilising rooftops or areas close to high frequency car routes, e.g. urban highways and using the now empty centres of "clover leaf" structures for future dronepads. Humphreys & Partners Architects (2017) envisioned an "Apartment of the Future", with a full-scale landing pad on the rooftop, and with a secured drop-off pad that can be lowered by an elevator and delivered directly to the resident's apartment by another drone. In their vision of a "Drone Tower", Charles Bombardier and Ashish Thulkar (2016) also focused on channelling the convenience of future drone proliferation onto residents, but by designing large balconies to accommodate small electric aircraft or shipping drones. In Priestman Goode's "Dragonfly" concept, delivery drones work in conjunction with autonomous barges, which would act both as a distribution centre and a charging station. The drones would deliver packages on landing pads placed on the rooftops and sides of buildings (Ravenscroft, 2018). Given the many constraints – drone vehicle designs, building construction technologies and legal frameworks for buildings and cities – more in-depth studies that combine design thinking with rigorous technical analysis and projections are needed.

Globally renowned design ideation companies like IDEO and frog, as well as local product design companies, are starting to work with industry to develop feasible visions for different drone missions. Analysing and comparing those visions will allow policy makers to better understand the commonalities of drones, e.g. the safety requirements or airspace management systems necessary to operate them during flight. How air/ground interfaces for different purposes and within different urban and non-urban contexts should also be designed and which existing land use, building code and related regulations will be affected.

These analysis-based visualisations will enable authorities beyond the immediate aviation and transport sector specialists to identify significant challenges for drone transport that must be assessed and regulated by policy makers in order to leverage the full potential of social benefits.

Annex

European Union

In December 2015, the European Commission proposed to create an EU-wide framework for drones as part of its wider Aviation Strategy (European Commission, 2017). It tabled a legislative proposal that would allow the establishment of technical rules and standards for drones and drone operations. In parallel, the European Aviation Safety Agency (EASA) has been tasked with developing technical rules and safety standards. An intense consultation is ongoing since 2015 with Member States and industry. A 2017 Helsinki Declaration (EASA and Trafi, 2017) has been a major stepping stone to delivering a high-level drones strategy. With a commitment to ensure safe commercial drone operations by 2019, the Declaration identified three areas of cooperation:

- Legal requirements for drones and drone operations;
- R&D efforts to speed up integration;
- Effective standard-setting processes.

In accordance with Regulation (EC) No 216/2008, the regulation of civil drones weighing less than 150 kg fell within the competence of EU member states. In December 2017, a new Basic Regulation was proposed. It addresses the problem of regulatory fragmentation by extending EU competences to cover all drones, regardless of their size or mass. A new framework, proposed by EASA, categorises risk-mitigating measures into two main groups:

- Open category, which includes limitations, operational rules and competency requirements for the remote pilot and technical standards for the UAS, removing the need for prior authorisation;
- Specific category, which is based on a system that includes risks assessments conducted before starting an operation, operators complying with a standard scenario, or operators holding a certificate outlining specific privileges (EASA, 2018).

Following EASA's technical opinion, the Commission is expected to develop and adopt drones legislation during the course of 2018. Industry can then develop the corresponding standards.

In March 2018, SESAR JU published a roadmap for drone integration (SESAR JU, 2018). It identified the main R&D activities to be pursued in an attempt to secure complete and seamless integration of all types of drones into all environments and classes of airspace. The high-level strategy to enable this vision involves the establishment of a new framework for drone operations (U-space) and the evolution of air traffic management (ATM) towards the integration of large remotely piloted aircraft systems (RPAS). The document will feed directly into the 2018 European ATM Master Plan.

U-Space and RPAS (EASA, 2018). U-space will encompass services and procedures to ensure safe and efficient airspace access of large numbers of small drones. It covers altitudes up to 150 meters and will guarantee that drone use in low-level airspace is safe, secure and environmentally friendly. U-space providers would act just like air traffic service providers for aviation, but in a highly automated and digital way, effectively informing operators where and how drones can fly, and supplying them with services such as registration and identification of drones. U-space will develop in an incremental fashion over the course of the next decades; its full utilisation is estimated at after 2035.

RPAS integration forms the evolutionary thread of implementing EASA's vision. It will involve gradual accommodation and integration of large RPAS with manned aviation, with the goal of RPAS and manned aircraft interacting with ATM in the same way (with special provisions designed to compensate for the fact that the pilot operates the aircraft remotely).

EU network of drone demonstrators

Regulators would need to learn from real practice to make the rules future proof. That is why the Commission, together with the European Aviation Safety Agency, will manage a network of demonstrator projects. These projects can give guidance on where the regulatory bar for safe and secure operations would be set; industry then can demonstrate that their solutions would fall within the regulatory limits. Such reassurance would allow industry to further invest to test the feasibility of their technological solutions and standards.

United States

The Federation Aviation Administration (FAA) is responsible for developing policy and plans for the safe and efficient use of the US navigable airspace. Drones integration into the National Airspace System (NAS) involves co-ordination with existing national security, safety and privacy policies. FAA policies define the acceptable minimum standard levels of safety that must be met in three primary areas: equipment, personnel, operations and procedures. The FAA has published the Integration of Civil Unmanned UAS in the NAS Roadmap in 2013 (FAA, 2013).

With respect to operational rules, the FAA Modernisation and Reform Act of 2012 recognised the need for safe integration of drones into the NAS (FAA Modernisation and Reform Act, 2012). Section 333 grants "the Secretary of Transportation the authority to determine whether an airworthiness certificate is required for a UAS to operate safely". Under special certifications and authorisations, limited operations are allowed for new types of aircraft (since drones are, in the view of the FAA, aircraft) that are unable to meet current airworthiness standards.

Following the need to develop regulatory standards that would enable current drones technology to comply with the Title 14 of the Code of Federal Regulations, the FAA has outlined a series of guidelines related to non-hobbyist small drones (weighing less than 55 pounds, 25 kg) in 2016. Part 107 rule concludes the rulemaking process under the Operation and Certification of Small Unmanned Aircraft Systems (NPRM) and outlines the main rules governing the operation of small drones (FAA, 2016). Below are some of the main provisions of the rule:

Table 1**: Main provisions of Part 107 rule (FAA, 2016)**

Operational limitations (most restrictions are waivable if the applicant demonstrates this does not raise safety concerns)	Weight of less than 55 lbs. VLOS only Daylight only Must not fly over humans Must yield right of way to other aircraft Maximum groundspeed of 100 mph Maximum altitude of 400 ft. GL (or within 400 ft. of a structure) Minimum visibility of 3 miles from control station Operations in Class G airspace allowed without ATC permission Operations in Class B, C, D airspace allowed with ATC permission One person – one UAS at one time Foreign-registered small UAS are allowed to operate if they satisfy the requirements of part 375
Remote pilot in command certification and responsibilities	A remote pilot certificate with a UAS rating or direct supervision of a person with one Remote pilot certificate qualifications: test/part 61 pilot certificate, vetted by the Transportation Security Administration, at least 16 years old Foreign certifications not recognised

Aircraft requirements	FAA airworthiness certification not required
Model aircraft	Not applicable to models satisfying criteria of section 336

Source: FAA 2016

According to the Jones (2017, p. 5), "the creation of an effective ban, or permitting and licensing on an ad hoc basis while watching the trajectory of drone technology, may allow for regulatory flexibility without the need for additional legislation" in the United States.

With respect to airspace management, the UAS Comprehensive Plan, prepared by the FAA Joint Planning and Development Office (2013), outlines the strategy of acceleration of integration efforts and provides the foundation for interagency co-ordination and planning. The plan is a result of collaboration between Next Generation Air Transportation System (NextGen) partner agencies: the Departments of Transportation, Defence, Commerce and Homeland Security, the National Aeronautics and Space Administration (NASA) and the FAA, as well as industry representatives. The plan identifies incremental advances in R&D, rulemaking and development of drone-related technologies as the key drivers of drone integration. Six high-level goals were developed to address safe integration, with a target year of initial implementation of the goal:

- Routine public small VLOS operations conducted in the NAS (2015)
- Routine civil small VLOS operations conducted in the NAS (2015)
- Routine public operations in the NAS (2015)
- Routine civil operations in the NAS (2020)
- Define, determine, and establish acceptable levels of automation for drones in the NAD (to be determined)
- Foster US international leadership in drone capability and in standards development (ongoing).

Each of the partner agencies is tasked with working towards achieving these national goals and may develop specific plans and roadmaps.

China

The Civil Aviation Authority of China (CAAC) is in charge of regulating drone operations and integrating drones with the national airspace. As specified in the 2017 Management Regulations on the Registration of Civilian drones, all civil drones weighing 250 g or above must be registered online with the CAAC. Both manufacturers and owners of drones must submit relevant information online – manufacturers of produced models, while owners must submit personal information and list all of their devices (with technical details). A unique QR code is generated and must be placed on each drone (CAAC, 2017a).

All civilian drones are subject to VLOS, daytime and isolated area (with at least 10 km from other aircraft) flying rules, can operate at a maximum altitude of 120 m (400 ft.) and maximum speed of 120 km/h (CAAC, 2017b). CAAC uses a classification scheme according to weight: all drones weighing above 7 kg require a CAAC licence, and above 116 kg – a pilot's licence and a CAAC certification for operation. Commercial use of drones also requires obtaining a special licence from CAAC. Pilots must meet minimum qualification requirements.

Bibliography

Ajuria Fernández, S. (2016), "Saúl Ajuria Fernandez imagines an 'urban droneport' for the near future", https://www.designboom.com/architecture/saul-ajuria-fernandez-droneport-12-25-2016/.

Asian Development Bank (2017), *Meeting Asia's Infrastructure Needs*, Asian Development Bank, Manila.

ATAG (2016), *Aviation Benefits Beyond Borders*, Air Transport Action Group, Geneva.

Auchard, E. (2017), "German 'flying taxi' firm Lilium takes $90 million from Tencent, others", https://www.reuters.com/article/us-aviation-taxis-lillium/german-flying-taxi-firm-lilium-takes-90-million-from-tencent-others-idUSKCN1BG0PO.

AUVSI (2013), *The Economic Impact of Unmanned Aircraft Systems Integration in the United States*, Association for Unmanned Vehicle Systems International.

Banker, S. (2017), "Iceland Gets A Drone Delivery Service, A Light Version Of Jeff Bezos' Bold Vision", https://www.forbes.com/sites/stevebanker/2017/08/23/amazons-jeff-bezos-drone-prediction-was-far-too-optimistic/.

BBC (2016), "Sweden bans cameras on drones", www.bbc.com/news/technology-37761872.

Blyenburgh (2018), *Drone Operations: Today & Tomorrow*, Blyenburgh & Co, Paris.

Boeing (2018a), "Boeing Unveils New Unmanned Cargo Air Vehicle Prototype", http://boeing.mediaroom.com/2018-01-10-Boeing-Unveils-New-Unmanned-Cargo-Air-Vehicle-Prototype.

Boeing (2018b), "Unlocking the Future of Flying", http://www.boeing.com/features/2018/01/cargo-air-vehicle-01-18.page.

Boeing (2017), "Pilot Outlook: 2017-2036", www.boeing.com/commercial/market/pilot-technician-outlook/2017-pilot-outlook/

Bombardier, C. (2016), "It's Time for Fancy Apartments to Offer Balconies for Drone Landings", https://www.wired.com/2016/08/time-fancy-apartments-offer-balconies-drone-landings/.

Bonvillian, W.B. and C. Weiss (2015), *Technological Innovation in Legacy Sectors*, Oxford University Press, New York.

CAAC (2017a), "The Civil Aviation Administration formally issued the "Administrative Regulations on Registration of Real-name Systems for Civil Unmanned Aircraft"", http://www.caac.gov.cn/XWZX/MHYW/201705/t20170517_44079.html.

CAAC (2017b), *Civil Unmanned Aircraft Systems: Air Traffic Management Measures*, Civil Aviation Administration of China, Beijing.

Cade, D.L. (2017), "DJI and Hasselblad Unveil World's First 100MP 'Drone Photography Platform'", https://petapixel.com/2017/04/25/dji-hasselblad-unveil-worlds-first-100mp-drone-photography-platform/.

Cho, J. (2017), "Korean Government Concentrating on Growth of Drone Industry", www.businesskorea.co.kr/news/articleView.html?idxno=18705.

Christina, A. and R. Cabell (2017), *Initial Investigation into the Psychoacoustic Properties of Small Unmanned Aerial System Noise*, National Aeronautics and Space Administration (NASA), Hampton, VA.

Clarke, R. and L. Bennett Moses (2014), "The regulation of civilian drones' impacts on public safety", *Computer Law & Security Review*, Vol. 30/3, pp. 263-285.

Collins, T. (2018), "Airbus' one-seater Vahana 'flying taxi' takes to the skies for the first time and completes a minute-long flight ahead of its commercial launch in 2020", www.dailymail.co.uk/sciencetech/article-5343993/Airbus-Vahana-flying-taxi-completes-maiden-test-flight.html.

Corral, L. et al. (2016), "Towards Optimization of Energy Consumption of Drones with Software-Based Flight Analysis", Knowledge Systems Institute Graduate School, Skokie, IL.

Culpan, D. (2015), "Watch this drone being live hacked", http://www.wired.co.uk/article/drone-hack-defcon.

Daimler (2017), "Vans & Drones in Zurich: Mercedes-Benz Vans, Matternet and siroop start pilot project for on-demand delivery of e-commerce goods", http://media.daimler.com/marsMediaSite/en/instance/ko/Vans--Drones-in-Zurich-Mercedes-Benz-Vans-Matternet-and-siroop-start-pilot-project-for-on-demand-delivery-of-e-commerce-goods.xhtml?oid=29659139.

Danielak, M. (2018), "The benefits of employing drones in construction", https://www.constructiondive.com/news/the-benefits-of-employing-drones-in-construction/516713/.

Davies, A. (2018), "Boeing's Experimental Cargo Drone Is a Heavy Lifter", https://www.wired.com/story/boeing-delivery-drone/.

DBX Drones (2016), "Partnership in the Drone Industry", http://www.dbxdrones.com/partnership-in-the-drone-industry.

DGAC (2017), "The global need for smarter and more autonomous systems - Example of the French civil drone industry", *CSD&M*, 13 December 2017.

DOT (2015), Table 3-24: Employment in Transportation and Transportation-Related Occupations, Bureau of Transportation Statistics, https://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/html/table_03_24.html.

EASA (2018), "Introduction of a regulatory framework for the operation of unmanned aircraft systems in the 'open' and 'specific' categories", *Opinion*, No 01/2018, European Aviation Safety Agency, Cologne.

EASA and Trafi (2017), *Drones Helsinki Declaration*, European Aviation Safety Agency and Finnish Transport Safety Agency, Helsinki.

EENA and DJI (2016), *The use of Remotely Piloted Aircraft Systems (RPAS) by the emergency services: A Report from the joint EENA and DJI Pilot Project*, European Emergency Number Association, Brussels.

Elistair (2016), "Use Case: Road Traffic Monitoring: A busy roundabout in Lyon with Safe-T", http://elistair.com/wp-content/uploads/2017/01/Use-Case-Road-Traffic-Monitoring-at-roundabout-in-Lyon-with-Safe-T-tethered-drone-station.pdf.

European Commission (2018), *Communication from the Commission to the European Parliament and the Council: Stronger protection, new opportunities - Commission guidance on the direct application of the General Data Protection Regulation as of 25 May 2018*.

European Commission (2017), "Aviation Strategy: EU agrees to safer skies and EU-wide rules for drones", https://ec.europa.eu/transport/modes/air/news/2017-12-22-aviation-strategy-eu-agrees-safer-skies-and-eu-wide-rules-drones.

FAA (2018), *FAA Aerospace Forecast, Fiscal Years 2018-2038*, Federal Aviation Administration, Washington, D.C.

FAA (2017), "UAS Test Sites", https://www.faa.gov/uas/research/test_sites/.

FAA (2016), "Operation and Certification of Small Unmanned Aircraft Systems", *81 FR 42063*, pp. 42063-42214. // FAA (2016), *Operation and Certification of Small Unmanned Aircraft Systems*, Federal Aviation Administartion and Office of the Secretary of Transportation, Department of Transportation, Washington, D.C.

FAA (2013), *Integration of Civil Unmanned Aircraft Systems (UAS) in the National Airspace System (NAS) Roadmap*, Federal Aviation Administration, Washington, D.C.

FAA Joint Planning and Development Office (2013), *Unmanned Aircraft Systems (UAS) Comprehensive Plan: A Report on the Nation's UAS Path Forward*, Federal Aviation Administration, Washington, D.C.

FAA Modernisation and Reform Act (2012), Pub. L. 112-95.

Fairs, M. (2017), "Drones will bring "profound change" to architecture and cities, says Mark Dytham", https://www.dezeen.com/2017/05/04/mark-dytham-interview-drones-uavs-bring-profound-change-architecture-cities/.

Floreano, D. and R.J. Wood (2015), "Science, technology and the future of small autonomous drones", *Nature*, Vol. 521, pp. 460-466.

Forbes (2017), "How Will Delivery Drones Work In Big Cities Where Space Is Limited?", https://www.forbes.com/sites/quora/2017/12/12/how-will-delivery-drones-work-in-big-cities-where-space-is-limited/#6d5f3e47bd0a.

Fraser, A. (2017a), "'The Whites have brought planes': Perceptions of drones in Malawi", http://impakter.com/whites-brought-planes-perceptions-drones-malawi/.

Fraser, A. (2017b), "Witchcraft and Explosions: perceptions of drones in Africa", https://werobotics.org/blog/2017/08/10/witchcraft-and-explosions-perceptions-to-drones-in-africa/.

FSD (2016), *Drones in Humanitarian Action: A guide to the use of airborne systems in humanitarian crises*, Swiss Foundation for Mine Action (FSD), Geneva.

Gartner (2016), *Forecast: Personal and Commercial Drones, Worlwide, 2016*, Gartner.

Gibbons, S. (2015), "Gone with the wind: Valuing the visual impacts of wind turbines through house prices", *Journal of Environmental Economics and Management*, Vol. 72, pp. 177-196.

Global Drone Regulations Database, https://www.droneregulations.info/.

Goldman Sachs (2016), "Drones: Reporting for Work", www.goldmansachs.com/our-thinking/technology-driving-innovation/drones/.

Gulden, T.R. (2017), *The Energy Implications of Drones for Package Delivery: A Geographic Information System Comparison*, RAND Corporation, Santa Monica, CA.

Harris, T. (2017), "Drone to deliver food, goods to Moose Cree First Nation in northern Ontario", https://www.thestar.com/news/canada/2017/10/04/drone-to-deliver-food-in-effort-to-cut-prices-at-moose-cree-first-nation.html.

Hassanalian, M. and A. Abdelkefi (2017), "Classifications, applications, and design challenges of drones: A review", *Progress in Aerospace Sciences*, Vol. 91, pp. 99-131.

Hawkins, A.J. (2017), "Boeing is buying one of the companies working with Uber on 'flying taxis'", https://www.theverge.com/2017/10/5/16431640/boeing-aurora-acquisition-vtol-autonomous-uber.

Heerkens, H. (2017), "Unmanned cargo aircraft: From anywhere to everywhere", *Engineering & Technology Reference*.

Hoeben, J.S.F (2014), "A value analysis of unmanned aircraft operations for the transport of high time-value cargo", Delft University of Technology, Delft.

Hofverberg, E. (2017), "Sweden: Law to Allow Photo Drones Passed", Global Legal Monitor, www.loc.gov/law/foreign-news/article/sweden-law-to-allow-photo-drones-passed/.

Humphreys & Partners Architects (2017), "Next Generation: Apartment of the Future Concept Design", https://humphreys.com/next-generation-apartment-future-concept-design/.

ICAO (2016), *Remotely Piloted Aircraft System (RPAS) Concept of Operations (ConOps) for International IFR Operations*, International Civil Aviation Organisation, Montreal.

ICAO (2015), *Manual on Remotely Piloted Aircraft Systems (RPAS)*, International Civil Aviation Organisation, Montreal.

ICAO (2011), "Unmanned Aircraft Systems (UAS)", *ICAO Cir 328*, International Civil Aviation Organisation, Montréal.

ICAO (1944), *Convention on International Civil Aviation*, International Civil Aviation Organisation, Montreal.

ICATS (2014), "NAC – West Wales, UK", https://icatestsites.org/test-site-description/nac/.

INRIX (2014), *2013 Traffic Scorecard*, INRIX, Kirkland.

ITF (2017a), "Managing the Transition to Driverless Road Freight Transport", *International Transport Forum Case-Specific Policy Analysis Report*, OECD Publishing, Paris, DOI: http://dx.doi.org/10.1787/0f240722-en.

ITF (2017b), "Data-led Governance of Road Freight Transport", *International Transport Forum Corporate Partnership Board Report*, OECD Publishing, Paris, DOI: http://dx.doi.org/10.1787/e0dd1973-en.

Jones, C.R. and J.R. Eiser (2010), "Understanding 'local' opposition to wind development in the UK: How big is a backyard?", *Energy Policy*, Vol. 38: pp. 3106-3117.

Jones, T. (2017), *International Commercial Drone Regulation and Drone Delivery Services*, RAND Corporation, Santa Monica, CA.

Kendoul, F. (2012), "Survey of advances in guidance, navigation, and control of unmanned rotorcraft systems", *Journal of Field Robotics*, Vol. 29/2, pp. 315–378.

King, L. (2018), "Boeing's cargo UAV a shot in the arm for drone delivery market", https://aircargoworld.com/allposts/boeings-cargo-uav-a-shot-in-the-arm-for-drone-delivery-market-video/.

Kington, T. (2014), "Italian Reaper Drones To Be Used for Crowd Monitoring", https://www.defensenews.com/global/europe/2014/12/17/italian-reaper-drones-to-be-used-for-crowd-monitoring/.

Kitty Hawk (2018a), "Cora Fact Sheet", https://cora.aero/press/.

Kitty Hawk (2018b), "The Next Step", https://cora.aero/blog/findingourkittyhawk/.

Kolodny, L. (2017), "Caterpillar invests in Airware bringing drone tech to mining and construction enterprises", https://techcrunch.com/2017/02/02/caterpillar-invests-in-airware-bringing-drone-tech-to-mining-and-construction-enterprises/.

Lee, D. (2018), "CES 2018: Passenger drone thwarted by light drizzle", www.bbc.com/news/technology-42616034.

Lineberger et al. (2018), "Elevating the future of mobility: Passenger drones and flying cars", *Deloitte Insights*, Deloitte.

Lohn, A.J. (2017), *What's the Buzz? The City-Scale Impacts of Drone Delivery*, RAND Corporation, Santa Monica, CA.

LTA (2017), "LTA to tap on technology to enhance tunnel inspections", https://www.lta.gov.sg/apps/news/page.aspx?c=2&id=8c205baa-6ee5-4cfd-a152-66ba6943bc11.

Martini, T. et al. (2016), "Humanitarian Use of Drones as an Emerging Technology for Emerging Needs", in Custers, B. (ed.), "The Future of Drone Use", *Information Technology and Law Series*, No. 27.

Masutti, A. (2016), "Drones for Civil Use: European Perspective on Third-Party Liability and Insurance", *Internationale Handel en Transportrecht*, Vol. 2, p. 246.

McAfee Labs (2016), *2017 Threats Predictions*, McAfee, Santa Clara, CA.

McVeigh, K. (2018), "'Uber for blood': how Rwandan delivery robots are saving lives", https://www.theguardian.com/global-development/2018/jan/02/rwanda-scheme-saving-blood-drone.

Michel, A.H. (2017), "Drones At Home: Local and State Drone Laws", Center for the Study of the Drone at Bard College.

Nanyang Technological University (2017), "Managing Drone Traffic", www.ntu.edu.sg/do/areas-of-impact/charting-global-frontiers/Pages/air-traffic-management-system-for-drones.aspx.

Navigation Code (2006), As amended with Legislative Decree 151/2006.

Norman Foster Foundation (2016), "Droneport", www.normanfosterfoundation.org/project/droneport/.

NY Power Authority (2017), "First Ever Drone Inspection of Niagara Ice Boom", https://www.nypa.gov/news/press-releases/2017/20170127-drone-inspection.

Office of Inspector General (2016), "Public Perception of Drone Delivery in the United States", *RARC Report*, RARC-WP-17-001, United States Postal Service, Arlington, VA.

Ong, T. (2017), "Dubai starts testing crewless two-person 'flying taxis'", https://www.theverge.com/2017/9/26/16365614/dubai-testing-uncrewed-two-person-flying-taxis-volocopter.

Paris, C. and R. Wall (2016), "Maersk Sees Savings in Using Drones at Sea", https://www.wsj.com/articles/maersk-sees-savings-in-using-drones-at-sea-1458153612.

Perlman, A. (2017), "Drone Market Strategies—DJI, Intel, and Parrot's Partnerships and Acquisitions", https://uavcoach.com/drone-market-strategies-dji-intel-parrot/.

Perritt, Jr., H.H. and E.O. Sprague (2015), "Law Abiding Drones", *Columbia Science & Technology Law Review*, Vol. 16, pp. 385-451.

Perritt, Jr., H.H. and E.O. Sprague (2017), *Domesticating Drones: The technology, law, and economics of unmanned aircraft*, Routledge, Abingdon and New York, NY.

Perry, D. (2017), “EasyJet to roll out drone inspections from 2018”, https://www.flightglobal.com/news/articles/easyjet-to-roll-out-drone-inspections-from-2018-441652/.

Perry, P. (2018), “South Korea will use "drone-catching drones" to defend the Winter Olympics”, http://bigthink.com/philip-perry/the-tech-being-used-to-protect-the-2018-winter-olympics-is-unreal.

Puri, A. (2005), “A survey of unmanned aerial vehicles (UAV) for traffic surveillance”, University of South Florida, Tampa, FL.

PwC (2017), *Clarity from above: transport infrastructure – The commercial applications of drone technology in the road and rail sectors*, PricewaterhouseCoopers, Warsaw.

PwC (2016), *Clarity from above: PwC global report on the commercial applications of drone technology*, PricewaterhouseCoopers, Warsaw.

Ravenscroft, T. (2018), “PriestmanGoode unveils concept for city-wide drone delivery system”, https://www.dezeen.com/2018/03/22/priestmangoode-dragonfly-concept-drone-delivery-system/.

Reimsbach-Kounatze, C. (2015), "The Proliferation of “Big Data” and Implications for Official Statistics and Statistical Agencies: A Preliminary Analysis", *OECD Digital Economy Papers*, No. 245, OECD Publishing, Paris. http://dx.doi.org/10.1787/5js7t9wqzvg8-en.

Rosen, J.W. (2017), “Zipline’s Ambitious Medical Drone Delivery in Africa”, https://www.technologyreview.com/s/608034/blood-from-the-sky-ziplines-ambitious-medical-drone-delivery-in-africa/.

Schroeder, A. (2018), “Localizing Humanitarian Drones: Robotics & Disaster Response”, https://werobotics.org/blog/2018/02/01/localizing-humanitarian-drones/.

Schwab, K. (2016), *The Fourth Industrial Revolution*, World Economic Forum, Cologny.

SESAR JU (2018), *European ATM Master Plan: Roadmap for the safe integration of drones into all classes of airspace*, Single European Sky ATM Research Joint Undertaking.

SESAR JU (2016), *European Drones Outlook Study: Unlocking the value for Europe*, Single European Sky ATM Research Joint Undertaking.

Sorkin, A.R. (2018), “Larry Page’s Flying Taxis, Now Exiting Stealth Mode”, https://www.nytimes.com/2018/03/12/business/dealbook/flying-taxis-larry-page.html.

State Council of China (2014), *Planning Outline for the Construction of a Social Credit System*, State Council of the People's Republic of China, Beijing.

Steer Davies Gleave (2015), “Study on employment and working conditions in air transport and airports”, *Report commissioned by DG MOVE, European Commission*, Steer Davies Gleave, London.

Steer Davies Gleave (2014), “Study on the Third-Party Liability and Insurance Requirements of Remotely Piloted Aircraft Systems (RPAS)”, *Final report prepared for the European Commission*, Steer Davies Gleave, London.

Stöcker, C. et al. (2017), “Review of the Current State of UAV Regulations”, *Remote Sensing*, Vol. 9/5, pp. 459-484.

Stolaroff, J.K. et al. (2018), “Energy use and life cycle greenhouse gas emissions of drones for commercial package delivery”, *Nature Communications*, Volume 9/409.

Tessum, C.W., J.D. Hill and J. D. Marshall (2014), “Life cycle air quality impacts of conventional and alternative light-duty transportation in the United States”, *Proceedings of the National Academy of Sciences*, Vol. 111/52, pp. 18490-18495.

The Economic Times (2018), “Railways to deploy drones to monitor projects”, https://economictimes.indiatimes.com/industry/transportation/railways/railways-to-deploy-drones-to monitor-projects/articleshow/62414086.cms.

The KiM Netherlands Institute for Transport Policy Analysis (2017), *Drones in passenger and freight transport*, Ministry of Infrastructure and the Environment, The Hague.

Thornhill, J. (2016), “The question marks hovering over drones”, https://www.ft.com/content/1db24dc0-c5d8-11e6-9043-7e34c07b46ef.

Todd, C. (2016), "CASE STUDY: Monitoring Crowds at Sporting Events with Drones", https://www.airborneresponse.com/single-post/2016/10/31/CASE-STUDY-Monitoring-Crowds-at-Sporting-Events-with-Drones.

UAVcode.org (2018), https://uavcode.org

UAViators (2014), https://droneregulations.info/

Uber Elevate (2016), *Fast-Forwarding to a Future of On-Demand Urban Air Transportation*, Uber, San Francisco, CA.

UN (2016), *Agenda for Humanity: Annex to the Report of the Secretary-General for the World Humanitarian Summit*, United Nations.

UNESCO (2017), *Operational Guidelines for the Implementation of the World Heritage Convention*, United Nations Educational, Scientific and Cultural Organisation World Heritage Centre, Paris.

UNESCO (2013), Background document, *International World Heritage Expert Meeting on Visual Integrity*, 6-9 March 2013, Agra.

UNESCO (2005), *Vienna Memorandum on World Heritage and Contemporary Architecture – Managing the Historic Urban Landscape*, United Nations Educational, Scientific and Cultural Organisation World Heritage Centre.

Van Groningen, R. (2017), "Cost Benefit Analysis Unmanned Cargo Aircraft: Case Study Stuttgart – Urumqi/Shenzen", Erasmus University Rotterdam, Rotterdam.

Wei, J. et al. (2016), "China Launches First Operational Rules for Civil Unmanned Aircraft", https://www.hlmediacomms.com/2016/01/21/china-launches-first-operational-rules-for-civil-unmanned-aircraft/.

Widener, M.N. (2016), "Local Regulating of Drone Activity in Lower Airspace", *Arizona Summit Law School Paper Series*, No. 2016-A-02.

Yalcinkaya, G. (2018), "Carlo Ratti unveils smart road system complete with on-demand drone swarms", https://www.dezeen.com/2018/01/25/carlo-ratti-unveils-smart-road-system-with-flying-drones-italy-technology-transport/.

Zhang, L. (2016), "Regulation of Drones - Peoples Republic of China", The Law Library of Congress, Global Legal Research Center.

Zink, J. and B. Lovelace (2015), "Unmanned Aerial Vehicle Bridge Inspection Demonstration Project", *Final report for the Minnesota Department of Transportation*, Minnesota Department of Transportation Office of Bridges and Structures and Collins Engineers, Inc., St. Paul, MN.

Zipline (2018), "How Zipline Works", http://www.flyzipline.com/service/ (accessed 28 March 2018).

(Un)certain Skies? Drones in the World of Tomorrow

This report investigates the role of drones as part of the future transport mix. It specifically addresses the issues policy makers face in engaging with the emerging private drone sector. Drones have the potential to improve existing practices, for instance in the surveying of infrastructure. They also have innovative uses in areas such as freight delivery, passenger transport in both urban and rural areas, or in disaster relief. With the sector developing at a rapid pace, regulators will want to create frameworks for drone use that allow innovation while ensuring positive overall outcomes.

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